Artist Material BRDF Database for Computer Graphics Rendering

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Abstract

A research project is underway to create a physical library of artist material samples and corresponding BRDF measurements that characterize their optical properties. This collection will provide necessary data for the development of a gonio-imaging system for use in museums to more accurately document their collections. A sample set has been produced consisting of 26 panels containing over 600 unique samples. Selected materials are representative of those commonly used by artists both past and present. These take into account the variability in visual appearance resulting from the materials and application techniques used. Five attributes of variability were identified including medium, color, substrate, application technique and overcoat. Combinations of these attributes were selected based on those commonly observed in museum collections and suggested by surveying experts in the field.

For each sample material, RGB and spectral image data will be collected and used to measure an average bi-directional reflectance distribution function (BRDF) and a pixel-wise BRDF will be fit using parameterized models. These results will be made available online as a searchable database. Additionally, it will include specifications for each sample, and other information useful for computer graphics rendering such as the raw image data, normal map and height maps.

Introduction

Digital images are used by many museums to document their collections for archival purposes. These images, typically captured from a single, straight-ahead viewpoint, are inadequate in conveying the often-complex surface structure of the artwork resulting in limited visual accuracy when compared to the original. When viewing artwork, attributes such as gloss and surface texture require examination from multiple angles to fully visualize and these qualities are not accurately represented when the digital record is limited to a single image taken from only one angle.

A research effort is underway to develop a gonio-imaging system that is capable of capturing bi-directional reflectance distribution function (BRDF) data, which can be used to overcome some limitations associated with traditional imaging methods. A preliminary step in the development of the gonio-imaging system was the creation of a set of samples that would provide necessary data of artist materials. These samples do not aim to be a comprehensive set of all artist materials, but rather a representative set of the most common materials used by artists both past and present.

For each sample, the set of images obtained using the gonio-imaging system are used to estimate BRDF data for the various materials. The BRDF data provide a basis for model development that can be used to simplify the gonio-imaging workflow and make it practical for museum use.

The BRDF measurements obtained using the gonio-imaging system will also be used in the development of an online database. BRDF databases such as MERL [1] and CUReT [2] contain BRDF data for many common materials, but there is a lack of BRDF data available for artist materials. The completed artist material database will provide BRDF data for artist materials along with the raw images captured with the gonio-imaging system. Descriptions and images of how the samples were made will also be included as a reference for others attempting to recreate the samples for use in their research.

Artist Material Samples

Five Attributes of Variability

A primary goal when creating the artist materials database was to achieve a range of visual appearances by altering various attributes of the samples. Five attributes were identified that could be independently changed to alter the appearance of the samples and include: medium, substrate, color, application technique and overcoat. It was important in selecting the materials and the combinations of the five attributes that the resultant samples were representative of what is typically found in museums.

Medium, the first dimension, has the most significant impact on the appearance. While some mediums, such as oil and acrylic paints, can be very similar in appearance, others like oil and watercolor paint are very different visually.

The substrate on which the medium is applied also has a profound effect on the visual appearance. It can be seen in Figure 1 that when acrylic paint is brushed onto three different substrates: Masonite, fine canvas and coarse canvas, the appearance is quite different. While the brushstrokes are very defined on the Masonite panel, the texture of the coarse canvas shows little of the brushstrokes.

Nearly all the mediums, with the exception of charcoal, graphite and Conté crayon, are available in a range of colors. The color of the medium impacts the appearance in many ways including the degree of the spectral highlights seen in the artwork. For example, a painting done primarily with black oil paint will have much more distinct spectral highlights when compared to an identical work done with a neutral gray shade.

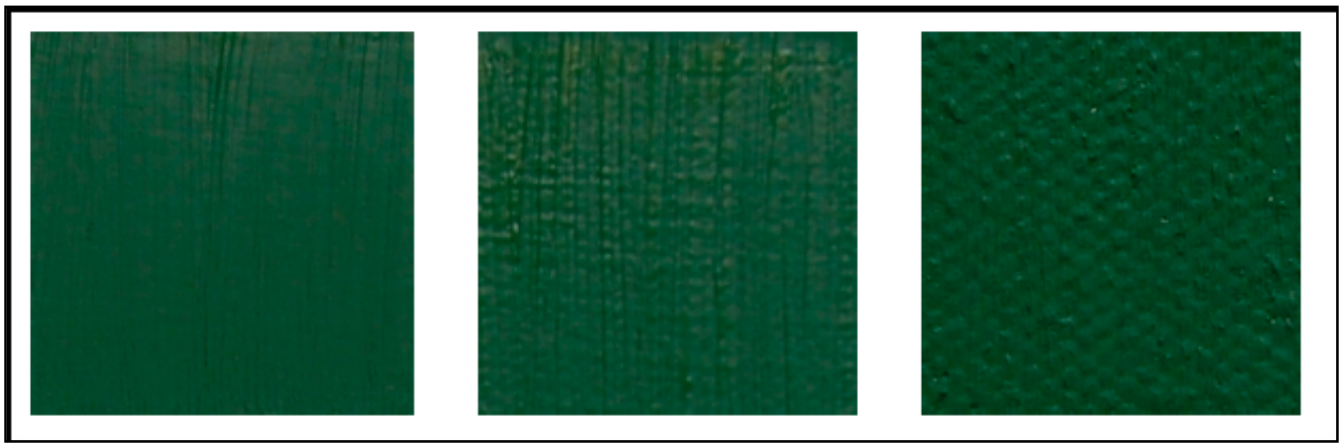

Figure 1. *Acrylic paint brushed onto three different substrates: Masonite, fine canvas, and coarse canvas.*

The technique refers to the various tools used to apply the medium, variations in application method and also alterations made to the medium itself. Oil paints applied with a brush compared to application with a palette knife produce a very different appearance. Also, using the palette knife, the paint can be applied in a smooth, even coat or with significant surface texture. An example of altering the medium would be the water to paint ratio when painting with watercolors.

Lastly, the application of an overcoat refers to varnishes, typically used on oil and acrylic paintings as both an aesthetic choice by the artist and to protect the painting from environmental factors, and fixatives, used as a protective coating on works done with pastels and charcoal. Varnishes and fixatives come in a range of appearances from matte to glossy, dramatically changing the appearance of the artwork.

Material Selection

In examining the types of materials used by artists both past and present, the vast amount of variability quickly becomes evident. It was important to accurately sample the range of materials while at the same time not becoming overwhelmed with all the possibilities. An initial investigation was conducted by exploring the online catalogs of some major museums including the National Gallery of Art, Washington, D.C. and the Metropolitan Museum of Art, New York. Using the descriptions from the museum's websites, a sense was gained of what mediums were most common and also the typical substrates used with each of the mediums.

To further aid in the determination of material selection, a survey was distributed to several museum conservators and individuals in the artist material industry. The survey, compiled from the information gathered from the museum websites, listed combinations of medium/substrate/overcoat and asked participants to check either "common" or "uncommon" for each choice. The results of the survey were helpful in determining not only the mediums that should be focused on, but more importantly, the combinations of medium/substrate/overcoat.

The final selection of materials, for which nearly 600 unique samples were made by hand (see Figure 3) under the direction of an art materials expert, are summarized in Table I. Each sample measures approximately 39 mm square and is arranged in a five-by-five pattern on a 25 cm square panel. A finished panel consisting of acrylic paint on coarse canvas with different types of varnish applied to each row is shown in Figure 2.

In creating the panels, two different methods were used depending on the medium. When working with canvas and Masonite panels on which oil, acrylic and egg tempera were painted, the panel was sectioned off with tape to create the 25 individual squares. Mediums applied to paper were cut into squares and adhered to the sample panel. The initial set of samples is comprised of 26 panels, some of which are not filled to capacity.

Figure 2. *Acrylic paint on coarse canvas with a different type of varnish in each row. The paint was applied with a palette knife to create impasto.*

TABLE I: The materials and techniques used to create the 600 samples in the artist material database

Medium	Substrate	Color	Technique	Overcoat
Oil & Acrylic		Venetian Red		Unvarnished
	Coarse Linen Canvas	Chromium Green Oxide	Brushed	Gamvar
	Fine Cotton Canvas	Neutral Grey	Palette Knife (Smooth)	Golden MSA Matte
	Masonite	Bone Black	Palette Knife (Impasto)	Golden MSA Gloss
		Titanium White		
Watercolor		Terra Rosa Red	Brushed: mixed 15:1 with water	Unvarnished
	Hot-Pressed Watercolor Paper	Chromium Green Oxide	Brushed: mixed 30:1 with water	
	Cold-Pressed Watercolor Paper	Ivory Black	Brushed: mixed 60:1 with water	
Gouache		English Red		Unvarnished
	Hot-Pressed Watercolor Paper	Chromium Green Oxide	Brushed: no water added	
	Cold-Pressed Watercolor Paper	Ivory Black	Brushed: mixed 50:50 with water	
		Titanium White		
Ink		Red	Brushed	Unvarnished
	Cold-Pressed Watercolor Paper	Green		
	Hot-Pressed Watercolor Paper	Black		
Egg Tempera	Masonite	Venetian Red	Brushed	Unvarnished
		Chromium Green Oxide		
		Bone Black		
		Titanium White		
Colored Pencil		Burnt Sienna		Unvarnished
	Sketch Paper	Moss Green	Applied in one direction	
	Cold-Pressed Watercolor Paper	Black	Applied in all directions	
		Slate Grey		
		White		
Marker		Crimson Red		Unvarnished
	Sketch Paper	Dark Green	Applied in one direction	
	Cold-Pressed Watercolor Paper	Black	Applied in all directions	
		Neutral Grey		
Pastel	Sketch Paper	Red	Applied in all directions and	
		Green	blended with tissue paper	Matte Fixative
		Black		Gloss Fixative
		White		
Charcoal	Sketch Paper	None	Applied in one direction	Matte Fixative
	Cold-Pressed Watercolor Paper		Applied in all directions	Gloss Fixative
Graphite	Sketch Paper	None	Applied in one direction	Unvarnished
	Cold-Pressed Watercolor Paper		Applied in all directions	
Conté Crayon	Sketch Paper	None	Applied in one direction	Unvarnished
	Cold-Pressed Watercolor Paper		Applied in all directions	

Medium

A total of twelve mediums are represented in the database. The selected mediums cover a range of history, from egg tempera, which has been used for hundreds of years as a painting medium, to materials that are more recent additions to the artist's cache such as marker. The mediums can be broken down in two subsets: those mediums that are used to paint with and those that used to draw with.

The painting mediums include: egg tempera, oils, acrylics, watercolor, gouache and inks. Egg tempera, which predates the other paint mediums, uses egg yolk to bind pigments and is typically painted on a wood panel. Most early murals and paintings prior to the 16th century were done with egg tempera [3].

Oil paint, the dominant painting medium from approximately the 16th century onward [3], is characterized by its luminous quality, thick consistency and slow drying time. Acrylics have similar working properties to oils, but dry in a matter of hours as opposed to weeks with oils.

Watercolors are typically diluted with water, resulting in a transparent quality, and can be applied in thin layers or washes when covering large areas or less diluted when adding detail to the painting. Watercolor paintings are distinctive, as the colors are very understated with the color of the substrate contributing quite a bit to the appearance.

Gouache is best described as an opaque version of watercolor paint and can be mixed with large amounts of water for use as a wash or applied thickly for a more saturated and opaque look.

Lastly, inks, when used as a painting medium, are applied in thin layers comparable to watercolors, but have a more vivid, saturated appearance. It should be noted that inks are also often

Figure 3. *Acrylic paint being applied with a palette knife to create surface texture.*

used to draw with, as in a pen and ink drawing, but that application of the medium was not included in the initial set of samples.

The drawing mediums include pastel, marker, colored pencil, Conté crayon, charcoal and graphite. Pastels consist of pure powdered pigment held in a binder and usually come in stick form. Pastels range from soft to hard. Soft pastels have a higher proportion of pigment, therefore they produce brighter colors and can be easily blended.

Markers are a newer addition to the artist's palette, but more modern works of art are created with this medium. Markers produce opaque, saturated color that usually masks the substrate onto which it is applied. Colored pencil, on the other hand, produces colors that are subtle and therefore the substrate on which they are applied is usually visible and can significantly affect the appearance.

Conté crayons are usually black in color and have a waxy feel typical of a crayon. They can be applied thickly to the substrate so that it is completely concealed. Charcoal is often used for making rough sketches in painting, but also is used to produce drawings. Charcoal is easy to blend and is also very dusty so that fixative is often used to prevent smudging.

Graphite has a flaky and greasy consistency and is used for line drawings and sketches. It can range in hardness from soft to hard and can vary from light gray to black. A 4B graphite pencil was used to create the samples and is of medium hardness.

Substrate

There are a large variety of materials an artist can use to paint or draw on. When considering paints, particularly oil and acrylic, canvas is a common choice. Canvas comes in a range of textures and two were used in creating the samples: a tightly woven 'fine' canvas typically used for portrait painting, and a 'coarse' textured canvas that might be used to paint a landscape. Masonite, used as a painting surface for oils, acrylics and egg tempera, was used as a substrate for its characteristic smooth texture.

The remaining nine mediums were applied to paper of varying texture. The remaining paint mediums including watercolor, gouache and colored ink were applied to watercolor paper of varying texture. Cold-pressed watercolor paper is rough textured while hot pressed is very smooth.

The remaining mediums: pastel, marker, colored pencil, Conté crayon, charcoal, and graphite were used on a sketch paper that has a slightly rough texture. These mediums were also applied to cold-pressed watercolor paper that has considerably more surface texture than the sketch paper.

Color

It was important to sample a range of colors for each medium while at the same time keeping the selection to a reasonable number. Colors were first selected from oil and acrylic pigments and included: Venetian red, chromium green oxide, neutral gray, bone black and titanium white. These pigments were chosen based on their dominant scattering ability so they would be opaque when applied to the substrate.

For the remaining mediums, the colors were generally not specified by the same pigment name given for the oils and acrylics. Colors for these mediums were selected by choosing the closest visual match to the oil and acrylic colorants.

Technique

The technique used to apply the medium was varied in different ways to achieve various appearances. In some cases, such as oil and acrylic paint, assorted tools were used to apply the paint to the substrate. When applied with a brush, the strokes maintained a distinctive appearance compared to when the paint was smoothed on with a palette knife. Also, using a given tool, such as the palette knife, different appearances were achieved. The paint could be smoothed on using the palette knife or used to create impasto where the surface has a distinctively rough texture.

Different ratios of water to paint were used when working with the watercolor and gouache. A mixture with a lot of water resulted in a "wash" that is quite transparent when applied to the paper and would typically be used as the beginning layer of a watercolor or gouache painting.

When working with drawing mediums the direction of application was varied to achieve different levels of paper coverage.

Overcoat

An overcoat layer, which includes varnishes and fixatives, is common with particular mediums for both aesthetic and protective reasons. The artist, to give a certain visual quality to their piece, often varnishes oil and acrylic paintings. A varnish layer also acts as a protective barrier against environmental pollutants such as dirt and smoke. Several different varnishes were used on the acrylic and oil samples. Gamvar, a low molecular weight synthetic resin, was used and applied using two different methods. Also, an acrylic solution varnish was used in both a matte and gloss finish. The charcoal and pastel samples were treated with a fixative spray to prevent smudging. Both a matte and gloss version of the fixative were used.

Artist Material Database

The BRDF measurements derived from the artist materials will be made available online as a searchable database, available at http://www.art-si.org. Once completed, the database will have several components in addition to the BRDF measurements of the samples.

The raw image data captured from the artist material samples will be provided so that other researchers can use these images to fit different BRDF models if desired. Also included will be normal maps and height maps of each of the samples that will be generated using image-based measurement techniques and direct laser scanning [4-6].

A search feature will allow individuals looking for data on a particular medium or substrate to filter the data and retrieve information on that particular item of interest.

Lastly, a comprehensive list of the materials used to make the samples, along with images and videos of the samples being made, will be provided so that researchers can duplicate the samples if needed.

Gonio-Imaging Data Collection

The gonio-imaging system, shown in Figure 4, is used to capture the image data necessary in determining BRDF for the artist materials. In developing such a system, it was of primary importance to keep the equipment for image capture, along with the software needed for post-processing of the images, practical enough so it is possible to implement the system in a low cost research setting. To accomplish this objective, it is necessary to use a combination of hardware including a sample positioner that allows the target to be positioned at any angle, relative to the camera, and BRDF-based models used to simplify the image-processing workflow.

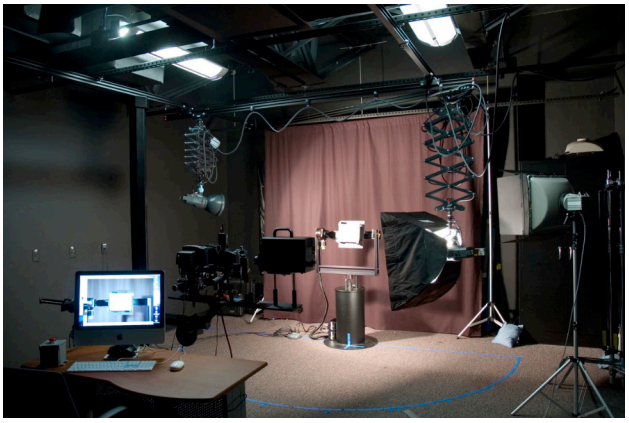

Figure 4. *The gonio-imaging room. In the foreground is the computer used to control the entire imaging process along with the detectors. The lights are positionable from a grid on the ceiling. The three-axis sample positioner is visible in the center of the image.*

Hardware configuration

The gonio-imaging system is able to capture images from multiple angles through the use of a sample positioner that allows movement of the samples about three axes relative to the center of the target. Three detectors, shown in Figure 5, are used to capture image data and include a Canon 5D camera, the MCSL-Sinar multispectral camera [7] and a Konica Minolta CS-2000 spectroradiometer.

The Canon 5D, fitted with a 135 mm lens and set to an aperture of F22, can be used to produce HDR images by capturing multiple exposures of the target. The small aperture size allows for the entire sample to remain in focus when the panel is tilted at steep angles relative to the camera. The spectroradiometer is coupled with a pan-tilt mirror so that measurements can be made at various locations on the target without having to move the detector.

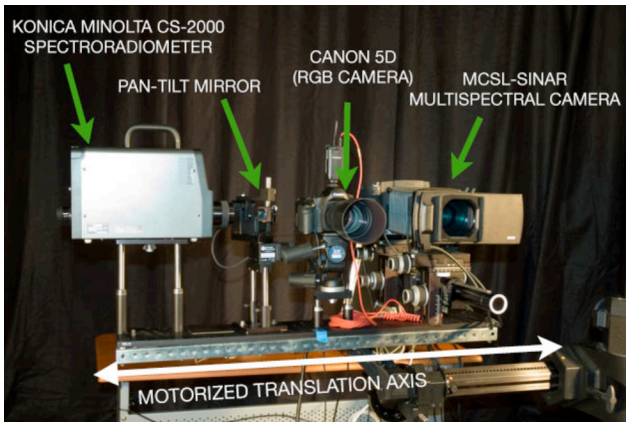

Figure 5. *The various detectors used in the gonio-imaging set-up which are mounted on a motorized translation axis allowing them to be repositioned to capture image data with either of the two cameras or the spectroradiometer.*

The detectors are positioned approximately 8 feet from the target. For the preliminary tests of the system, images were illuminated with an Oriel tungsten source with a constant current power supply, positioned 6 feet from the target and with an aperture size of 10mm x 7mm. The small aperture size aids in simplifying the BRDF modeling of the samples. After using the small-area light source to characterize the artist database materials, a technique for using large-area light sources will be developed that is capable of imaging large-canvas artwork in a museum setting.

BRDF model fitting

The set of images captured using the gonio-imaging system will be used in performing image-based BRDF estimation with parameterized models and then used in a computer graphics rendering workflow to accurately visualize what the artwork would look like under any lighting environment and from different viewing angles [8].

It was important when designing the imaging targets that they be as uniform as possible. Using typical artwork to supply the necessary data for model development would have had several inherit limitations. Because measurement area changes with viewing angle, spatial non-uniformity would introduce measurement uncertainty. The samples created for the artist

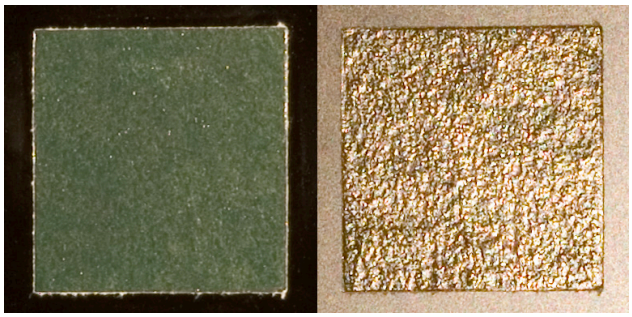

Figure 6. *Two digital images from the Canon 5D of green pastel on paper with four coats of gloss fixative. Diffuse view (left) taken with light source and detector on the same side of surface normal ($\theta_i,\phi_i,\theta_r,\phi_r$)=(13.4°, -12.0°, 26.9°, -2.4°). Near specular view (right) is shown here at a reduced exposure ($\theta_i,\phi_i,\theta_r,\phi_r$)=(6.1°, -152.6°, 8.5°, -8.1°).*

database overcome some of these limitations by maintaining consistent material and surface properties over each sample's area.

Early results were obtained using a sample consisting of green pastel on sketch paper with four coats of gloss fixative. The results of two images captured from both diffuse and near-specular angles are shown in Figure 6. The green color of the pastel is evident in the image captured at a diffuse angle while the image taken from the near-specular view shows little of the chromatic content of the sample. The lack of color in the image captured from the near-specular view demonstrates the spectral non-selectivity of the material's specular reflection.

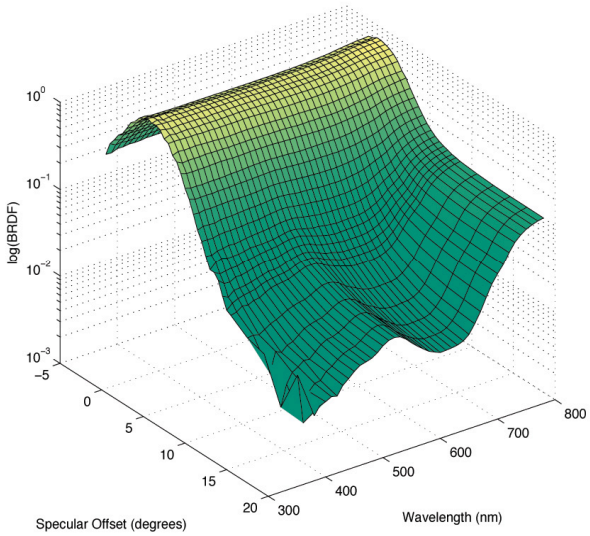

Figure 7. *Spectral BRDF of glossy green pastel sample measured with Konica-Minolta CS-2000 with in-plane illumination. The detector and illumination were fixed with an angle of 13.8° between them while the sample was rotated through multiple angles.*

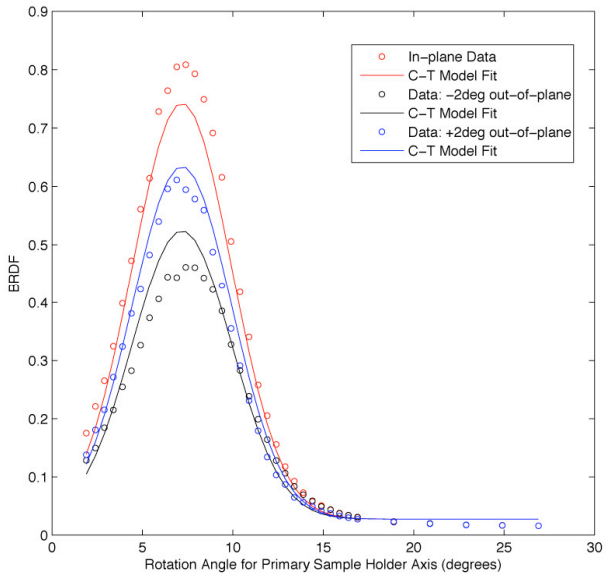

Figure 8. *Cook-Torrance BRDF model fits for spectroradiometer data at 550nm for both an in-plane and two out-of-plane measurements.*

The Konica Minolta CS-2000 spectroradiometer was used to measure the spectral BRDF of the green pastel sample, the results of which are shown in Figure 7. Spectroradiometer measurements were made for a range of BRDF angles by rotating the sample holder around two of its axes while the light and detector were held at fixed positions, 13.8° apart.

At the specular angle (0°), the sample exhibits non-selectivity across the spectrum, accounting for the achromatic appearance of the near-specular view shown in Figure 6. As the view moves away from specular angles, the BRDF measurements reveal the spectral selectivity (green) of the diffuse reflectance. As seen in Figure 7, the peak centered around the middle portion of the spectrum becomes more pronounced as the specular offset increases.

The parameters for a Cook-Torrance BRDF model [9] were fit to the spectroradiometer data at 550nm using non-linear optimization. Data and fitted results are shown in Figure 8 over a range of sample holder angles for both in-plane and out-of-plane (+/- 2°) measurements. For the fixed lighting and detector positions, the specular peak occurs when the primary axis of the sample holder is rotated to 6.9°. The model curve fits have similar peak locations and specular lobe widths as the measured data, but have some deviation in the absolute peak height.

Conclusions

A physical library of artist materials was created containing nearly 600 unique samples that represent the common materials and application techniques used by artists both past and present. The BRDF measurements obtained from the samples will be used to develop models that, when incorporated into the imaging workflow, makes possible a practical gonio-imaging system for use in a museum setting. The gonio-imaging system provides a means to more accurately document artwork by capturing images from multiple angles that can be used to simulate different lighting and viewing environments.

The artist material BRDF data will also be made available online as a searchable database for use in applications such as computer rendering of real-world surfaces. The database will have several features in addition to the BRDF data. Raw image data will be provided so that other researchers can fit new BRDF models if desired. Also, descriptions of the materials and application techniques used to make the samples will be provided to aid others in recreating the samples.

An early test of the gonio-imaging set-up was conducted and preliminary results were obtained for a single glossy green pastel sample. A spectroradiometer was used to measure spectral BRDF data for the sample and Cook-Torrance BRDF model parameters were fit for the measurements at 550nm. Once additional samples are measured, model performance can be more accurately evaluated and other BRDF models tested.

The materials and techniques that comprise the initial set of samples are by no means an exhaustive collection of all the materials and application techniques seen in museum collections. As results are obtained for the initial set of samples, it may prove valuable to add supplementary samples to the database. Additional samples can be added to further investigate a specific medium or substrate, or to introduce new materials not previously represented in the database.

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References

[1] Wojciech Matusik, Hanspeter Pfister, Matt Brand, Leonard McMillan, "A Data-Driven Reflectance Model," ACM Transactions on Graphics (TOG), 22,3, (2003).

[2] Kristin J. Dana, Bram van Ginneken, Shree K. Nayar, Jan J. Koenderink, "Reflectance and Texture of Real-World Surfaces," ACM Transactions on Graphics (TOG), 18,1, (1999).

[3] Ralph Mayer, The Artist's Handbook of Materials and Techniques (Viking, New York, NY, 1970) pg. 20-23.

[4] Reinhard Klette, Ryszard Kozera, Karsten Schluns.: Shape from Shading and Photometric Stereo Methods. Communication and Information Technology Research Technical Report, 20, (1998).

[5] Srinivasa G. Narasimhan, Sanjeev J. Koppal, and Shuntaro Yamazaki: Temporal Dithering of Illumination for Fast Active Vision. Proc. European Conference on Computer Vision, 830-844, (2008).

[6] J. Taylor, J.A. Beraldin, G. Godin, L. Cournoyer, R. Baribeau, F. Blais, M. Rioux, and J. Domey, "NRC3D Technology for Museum and Heritage Applications," The Journal of Visualization and Computer Animation, 14:(3), 2003.

[7] R.S. Berns and L.A. Taplin, Practical Spectral imaging Using a Color-Filter Array Digital Camera, MCSL Technical Report, July 2006. (http://www.art-si.org)

[8] Y. Chen, Model Evaluation and Measurement Optimization for the Reproduction of Artist Paint Surfaces through Computer Graphics Renderings, M.S. Thesis, R.I.T., Rochester, NY, 2008.

[9] Robert L. Cook and Kenneth E. Torrance. "A Reflectance Model for Computer Graphics," Computer Graphics. 14(3), 1981.

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