Multi-texturing approach for paint appearance simulation on virtual vehicles

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Abstract

This paper proposes a new approach for paint appearance simulation. Coatings color and appearance change significantly according to lighting and observation conditions. The aim of this study is to propose both real time and accurate solutions for painted surface simulation. To solve real time constraints, we have chosen to simulate the paint appearance thanks to textures. Each texture represents an appearance criterion of the coating directly linked with the paint composition (layers and micro-components). A final multi-pass algorithm is applied to combine these different textures. Especially, we describe the building and the combination of the different textures used to simulate respectively color, metallic appearance, environment reflection and tension effects. In any case, a validation step will be performed through subjective and quantitative comparisons between simulation results and reality. Finally optimization for real time paint simulation, applied to driving simulation to increase traffic vehicle realism, is carried out.

Résumé

Cet article propose une nouvelle approche pour la simulation de l'aspect des peintures. La couleur et l'apparence de revêtements peinture varient de façon significative en fonction des conditions d'éclairage et d'observation. Aussi, le but de cette étude est de proposer une simulation, la plus fidèle possible et en temps réel, de surfaces peintes. Pour répondre à la contrainte du temps réel, nous avons choisi de simuler l'apparence des revêtements peinture grâce à des textures. Chaque texture représente un critère d'aspect du revêtement directement lié à la composition de la peinture (couches et micro-éléments). Un algorithme à plusieurs passes est utilisé pour combiner ces différentes textures. Nous décrivons plus précisément la construction et la combinaison des différentes textures utilisées pour simuler la teinte, l'aspect métallisé, les réflexions de l'environnement sur la surface et la tension du revêtement. Dans tous les cas une étape de validation comprenant des comparaisons subjectives et quantitatives entre simulation et réalité sera effectuée. Enfin des optimisations pour la simulation temps réel des peintures, appliquées à la simulation de conduite pour améliorer le réalisme des véhicules du trafic, sont développées.

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Introduction

Automotive coating not only has a protective function against outside aggressions but it also has a contribution in the appearance of the car exterior. All the coating include a varnish layer and new pigments allow hue and intensity variations according to lighting and observation conditions. Virtual reality application of paint appearance rendering is a cost effective design tool to be used in the vehicle development process. Real time paint simulation is also useful in driving simulation to increase vehicles realism in the traffic or cockpit inside elements when a helmet is employed.

1.1. Paint coatings and characterization

1.1.1. Paint description

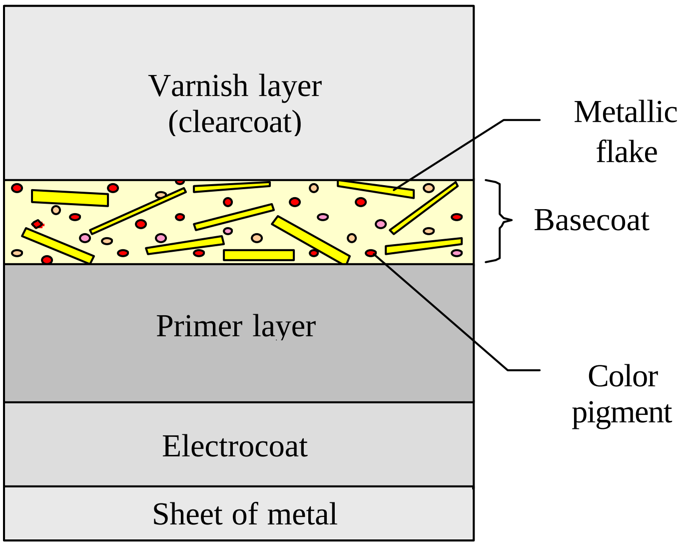

*Figure 1 : Structure of a paint layer*r

Paint is applied on the body after three surface treatments. The first one acts against corrosion, then a gray layer called electrocoat is applied on the sheet of metal to suppress surface large amplitude deformations. Another gray layer called primer layer continues to level the surface and protects it from loose chippings. Electrocoat and the primer layer are separately baked. The paint coating is composed of a 15-18 μm layer of colored paint called basecoat, and a 35-45 μm layer of transparent varnish also called clearcoat.

The clearcoat is a protective layer against weathering. It also carries on the surface leveling and gives gloss property to the surface. Basecoat and clearcoat are baked together without an intermediate firing.
The basecoat is a blending of pigments, binders, solvents and additives. Pigments are thin colored and insoluble powders. Binders are generally resins, more or less transparent bodies. They bind the paint components together. Solvents thin binders to allow the application, then they vanish. The role of the additives is to give special properties to the coating (resistance, hiding power, pigments dispersal…)
There are different types of basecoat: plain basecoat and basecoat with effects like metallic or pearlescent paints. Plain basecoat only contains color pigments. Metallic paint contains color pigments and aluminum particles spread in the film that produce special lighting effects. Aluminum flakes act like small mirrors that reflect the incident light in the specular direction. Paint appearance changes with the observation and lighting conditions. At different visual angles, the observer can see either the metal flakes or the colored film. Metallic flakes are fifty times bigger than colored pigments. Their size changes from 5 to 45 μm and their thickness from 0,1 to 1 μm.

For pearlescent paint, a colored aspect is added to the reflection aspect there is with metallic paint. So, the coating's color evolves according to the observation position. The particles used are mica pigments covered with a thin layer (from tens to hundreds of nanometers) of metallic oxide (generally titanium dioxide: TiO_2). Their size is noticeably the same as aluminum pigments. When the incident light reaches the pigments there is the combination of absorption, reflection and interference phenomenon. The reflected color is controlled by the nature of the metallic oxide, the thickness of the oxide layer and the size of the mica pigment.

1.1.2. Paint characterization

Paint color and appearance change significantly with lighting and observation conditions, so many measurement geometries are needed to precisely characterize coating behavior. A goniometric device has been used to determine L*, a*, b* values [9] of a coating. The goniometric system is composed with a MAS 30 spectrometer, a tungsten halogen light source and its stabilized power supply, a motorized GON 360 goniometer and two fiber bundles with their adapter. It is controlled by a computer. Measurements (L*, a*, b* values) have been done in the visible spectral range, for a 10° observation field and with a D65 illuminant. They have been made every 10° from 0° to 70° for the incident angle, and every 10°, from -70° to 70°, for the reception angle except in the specular area where measurements have been done every degrees.

Coating can also be characterized by appearance criteria that conveys the visual sensation produced by their observation. Such a characterization is not easy because it is difficult to apply a criterion on a sensation and even more to quantify and measure it. Three criteria have already been defined and used at Renault. The first one is the gloss. It conveys the surface ability to reflect more or less light. It is evaluated as a ratio between the reflective light and the incident light. The tension, also called "orange peel", corresponds to high amplitude surface undulations that cause the deformations of the environment reflections on the surface. DOI (Distinctness Of Image) corresponds to small amplitude surface undulations. The environment reflection image appears more or less sharp. Other parameters can be used to describe a coating like the glitter linked to the size of the specular splash, the size and density of metallic flakes, the paint homogeneousness, the paint density…

Seen closely, metallic coatings produce sparkling and depth effects. Human binocular vision plays an important role in the perception of these effects [19]. In particular the luminance disparity between the two eyes implies sieve and rivaldepth effects [22].

1.2. Lighting models for complex surfaces simulation

Many illumination models have been proposed to simulate surfaces properties. The specification of the surface color appearance must include spectral and spatial distribution of the reflected light. The BRDF (Bidirectional Reflection Distribution Function) is the most general way to represent these distributions.

Many parametric models have been proposed to simplify and lighten the use of a full BRDF dataset. Phong [23] and Blinn [3] have developed such models that are implemented in most current graphics hardware. More complex models have also been proposed such as Cook and Torrance [7] that uses a gaussian microfacets distribution function to represent the surface and a Fresnel reflection term. He et al. [14] proposed the HTSG model derived from the Kirchoff theory and optic wave to calculate the directional diffuse reflection. Icart and Arquès [15] also used this approach. Anisotropic models have also been developed by Poulin and Fournier [24] and Ward [28]. In 1999, Stam [26] has proposed a model taking into account light diffraction

effects. Nevertheless, with nowadays hardware it becomes realistic to use a full BRDF directly, either measured or computed.
Some techniques have been proposed to synthesize a BRDF, such as the approximation of the surface by a succession of layers that have absorption and diffusion properties. The linear transport theory is used to compute the radiation exchanges between the layers and a global surface reflectance is deduced. Kubelka-Munk [17] has first introduced such a model in 1948. Billmeyer and Carter [2] have extended it with metallic particles. Haase and Meyer [12] have brought it in the computer graphics field in 1992. Hanrahan and Krueger [13] have also used a similar approach. This technique has also been used by Dorsey and Hanrahan [8] to simulate metallic patinas.
The most general approach to synthesize a BRDF is to create a virtual goniospectrophotometer. An explicit surface modeling is created taking into account the microstructures beneath the surface. Then light rays with a specific direction are cast on the surface. Geometric optics is used to determine the ray behavior into the material. Reflected rays are captured in a data structure, which represents the BRDF at the end of the process. Cabral et al. [5], Westin et al [29] have used such an approach. Gondek et al. [11], Schramm et al. [25] have extended this approach to take into account the wavelength and interference effects. This method has also been used by Nagata et al. [21] to build pearl images.
The BRDF computation is time consuming and is generally conducted separately from the scene rendering. Concerning the rendering, multipass algorithms can help to achieve interactive simulation. They allow the implementation of complex reflection model on hardware. Using blending operations, some equations can be decomposed into simple functions that are then combined. These functions can be stored as texture maps. Heidrich and Seidel [16] did use two texture maps (dual paraboloid maps) to create environment reflections. Cabral et al. [6] used a set of pre-computed Radiance sphere maps to integrate complex BRDF that were interpolated during the rendering stage to achieve interactive display rates.
We propose here a new approach for interactive paint appearance rendering using textures with single and multi-pass rendering techniques. Our aim is to provide a tool that allows the accurate rendering of colored coating on a virtual vehicle to appreciate appearance changes according to user specified observation and lighting conditions.

2. A new multi-texturing approach for paint appearance simulation

To respect the constraint of interactive simulation, the technique of texture mapping is used to simulate paint appearance.

2.1. Paint representation principle

To take into account the real paint structure and composition, our solution proposes to generate paint appearance thanks to textures which match with a coating layer or a paint characteristic.
From the basecoat, we extract two components, the color and the presence of particles, and we represent each of them by a specific texture. A correction texture is applied to correct the darkening brought by the particles texture.

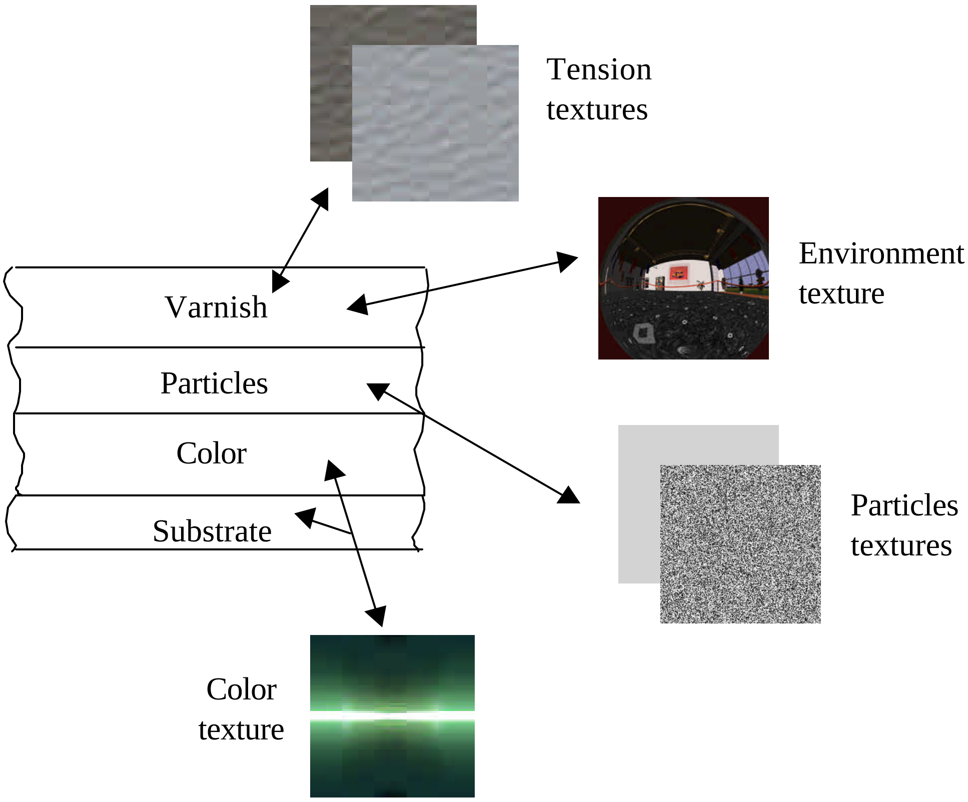

Figure 2: Coating modeling with textures

From the clearcoat, two other components can also be underlined, the gloss and surface undulations. The gloss is simulated using an environment map representing the environment reflections onto the object. Large surface undulations are rendered with a bump mapping technique that implies the generation of two texture maps. To simulate small surface undulations, that are perceptible only through the distinctness of the reflected image of the environment on the surface, we did chose to blur the environment texture map according to the undulation amplitude. The composition of up to six textures is used, directly linked to the paint composition to simulate coating appearance.

2.2. Textures construction

2.2.1. The color texture map

The color texture map is indexed on incident and observation angles. It is built up from goniometric measurements described in the introduction section. L*a*b* values are converted in digital display values RGB, taking into account display system characteristics. Then, these digital display values are expressed as a function of the angle θ between surface normal and the observer and the angle α between the specular reflection direction and the observation direction (see Figure 3). They are interpolated between incident angles. For each measured paint, it leads to an approximation of RGB values according to incident and reception angles. Now texture coordinates directly depend on the θ and α angles, therefore the corresponding texture map can be built. The texture size is 512×512 pixels for a variation of θ and α angles from –90° to 90°.

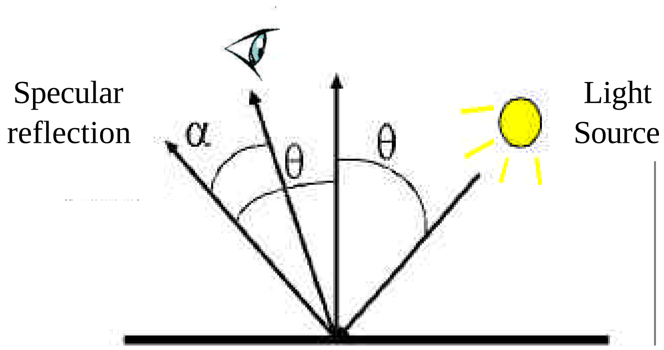

Figure 3 : Illumination and observation angles

From the scene, we retrieve the observer and light source positions, as well as the position of the object's polygons' vertices and the normal at each vertex. With these values, we compute the incident and observation angles for each polygon vertex and we obtain the corresponding color value from the texture map. The color texture is an approximation from measurements of the coating color, therefore it takes into account the size and the intensity of the specular spot and color changes with incident and observation angles (as shown in figure 2).
Making the assumption of directional light sources, we can encode the lights contributions in a sphere map (same technique as the building of an environment sphere map). The sphere map follows the light source direction. This solution decreases the rendering time as the texture coordinates can be generated using the hardware. Moreover, when we use multiple light sources, their contribution is integrated only once during the sphere map texture update instead each frame for each light source at each vertex.
Another benefit of this method is that we change the texture coordinate space from (θ,α) to the reflection space. This makes texture interpolation taking into account the normal to the surface, producing high quality highlights even on poorly tessellated models.

2.2.2. The particles texture map

Because of the random distribution and orientation of the metallic particles in the paint layer, these particles can be represented by a noise texture. The particles texture is only perceived by the observer when he is near the object. The texture level of details depends on the observation distance. When the observer is far from the painted surface, he or she can't see the particle in the layer but he sees the average color of the object. We have chosen a texture size of 256×256 pixels. To balance the darkening due to the combination with the noise texture (multiplication by a real number between zero and one), a "correction" texture is used. This texture allows to keep the surface average color value.
For each polygon vertex, the texture coordinates are computed as a function of the vertex position and a scale factor. They also depend on the observer and lights positions because the distribution of the "lighted" particles is directly linked to the observation and lighting conditions. The scale factor allows to tune the average particles size that is different from one paint to another.

2.2.3. The environment texture map

The environment texture map is a sphere map that represents the environment surrounding the vehicle, such as a showroom in our sample pics. We use environment mapping technique that consists in projecting a texture image, which represents the object-surrounding environment, on an object. The sphere map is a single texture image of the reflections on a perfectly reflecting sphere. A reflection vector from the eye to each polygon vertex of the object is computed and indexes this texture images. The texture size is 256×256 pixels.

2.2.4. The "orange peel" (or tension) texture map

We have used the diffuse bump mapping method, which is based on the embossing technique. Two textures are successively mapped with a small shift to produce a relief illusion. The shift is compute in the light source direction. The light source must be directional. The bump maps are height variations maps. The map is applied to the object polygon, then the same texture map is applied with a shifting and in a subtractive mode. The textures (128×128 pixels) used to simulate tension have been described in [1]. Instead of using only one texture and the subtractive mode, we have chosen to use two different textures and the additive mode. In this case, the second texture is the negative image of the first one.

2.3. Textures composition

OpenGL does not allow to use six textures at the same time (two textures at the same time with a GeForce 2 Graphic card, four with a GeForce 3). Therefore, a multi-passes algorithm has been created to apply one or more textures at each pass. Additions and multiplication on texture R, G, B, A components have been used to combine the different textures.
We have first represented the tension parameter because its simulation needs the contribution of two textures. Two passes are needed to generate the "orange peel". The result is then combined with the color texture. Then we have applied the noise texture and the correction texture. The last texture to be blended is the environment texture. R, G, B, A components of this texture are mixed with the R, G, B, A components of the previous textures blending, taking into account the alpha value (A) of the environment texture.

3. Results

Our paint simulation method allows interactive and realistic display of acquired paint materials. It is currently being implemented in an in house digital mock-up tool. We present our results within this framework, and then discuss some of its benefits for driving simulation.

3.1. Integration in P2V tool

P2V (Presentation of Virtual vehicle) has been internally developed at Renault. It is a tool that allows 3D interactive visualization of the interior and the exterior of a virtual vehicle. The observer can move around and inside the vehicle to examine its characteristics. A position sensor detects the observer movements and allows to calculate and update in real time the image of the scene from this new point of view. The tool is based on OpenGL Performer graphics libraries. The 3D virtual vehicle is extracted directly from CAD data. A material (a color and a texture) is assigned to each part of the vehicle. The tool also allows a stereoscopic vision thanks to stereoscopic glasses or an immersive helmet. An image is generated for each eye taking into account their position. Therefore the observer can see the scene in depth.

Paint color and appearance significantly depend on lighting and observation conditions. The challenge of our application is to accurately simulate and evaluate such coatings in real time on a virtual vehicle. This application can be a design, a sale or a validation tool. It allows to visualize a vehicle that is not existing yet, to choose the more suitable color, to assess the vehicle final appearance… It avoids the costly fabrication of a real vehicle and gives a more representative evaluation of the final car appearance than an evaluation on real small paint samples. Its interactivity is an asset to visualize metallic and pearlescent coatings that present significant color changes with the observation point of view.

To cope with the model complexity while maintaining interactivity, P2V largely exploits multiprocessing and view dependent rendering, such as view frustum culling and level of details adaptation. It also uses a "quality mode" to produce a high quality and time consuming rendering when the user stops interacting.

3.2. Images

Images are snapshots of interactive sessions. The first image shows a painted vehicle. We can see environment reflections on the coating. The car is too far from the observer to perceive the presence of metallic particles. In the next two images the observer explores more closely the surface properties. He can discern the presence of metallic flakes.

Figure 4 : Paint color rendering on virtual vehicle

Figure 5 : Zoom on the paint coating

3.3. Computation workload

These results have been obtained with a Pentium III, 800 MHz computer with a accelerating graphic cards GeForce 2 Gts. Tables show calculation times needed to display a scene with a vehicle body illuminated by one or four directional light sources. The vehicle body is composed ~ 52000 triangles. The image resolution is 500 × 500 pixels.

Number of texture	Textures	Explicit calculation		Sphere map	
		1 source	4 sources	1 source	4 sources
1	Color	10,6	3,9	28,3	28,3
2	Color + Particles	9,4	3,7	21,2	21,2
3	Color + Particles + correction	7,7	3,4	6,1	6,1
4	Color + Particles + correction + Environment	7,7	3,4	6,1	6,1
4	Color + Orange peel + Environment	7,7		6,1	
6	Color + Particles + correction + Orange peel + Environment	6,1		5,0	

Table 1 : Image generation frequency (Hz)

3.4. Simplifications for driving simulation

As stated above, when the observer is not close enough to the vehicle, the metallic particles are not perceptible. We can use this to reduce the rendering complexity of our method: we make the assumption that in the context of a driving simulator, all the neighbouring vehicles are sufficiently far from the observer so that we can neglect the metallic particles rendering. Going farther in that way, we also neglect the orange peel effect, thus reducing the rendering complexity to only the paint and environment textures. These two lasting textures can even get merged into one single texture that leads to a single texture / single pass rendering with high quality highlights at the cost of a classical GL rendering.

4. Conclusion and future works

We have proposed a new model that accurately and interactively simulate paint appearance. Our model consists in assigning a texture to each paint parameter or appearance criterion we want to render. Texture combination allows to use efficiently computer graphics hardware and graphics cards capabilities to achieve real time image generation. Efficient single pass multi-texturing optimization allows application to driving simulation enhancing the perception of traffic vehicles.

A validation step is scheduled to evaluate the accuracy of the presented simulations. Subjective and quantitative comparisons between real coatings and simulated coatings are about to be performed to validate our model representativeness, taking into account color and luminance limitations implied by the display system. The validation will include a global color appearance validation (observer far from the surface) and a detailed evaluation (painted surface seen more closely) of each appearance criterion.

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