Reflectance Modeling of an Anisotropic Surface: The Ham

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Abstract

This article describes our method to measure and model the reflectance of an anisotropic and colorimetricaly in-homogeneous material : the ham. The main difficulty is to find a model which is suitable to all hams. Moreover, we have to face difficulties inherent to the measurement system itself. It doesn't enable to make measurements for all the positions of lighting and observation. Phong and Torrance-Sparrow models are compared. We explain how the ham reflectance modeling can be useful to achieve tracibility control of meat products.

Introduction

Spectral reflectance of an object is an inherent physical property of its surface. It describes its visual appearance according to lighting and viewing geometries and depends on the roughness of its surface as well as on its composition. Thus, modeling the reflectance of an object enables to know its visual appearence owing to the observation and lighting angles. More than an essantial tool in image synthesis, reflectance is an interesting cue in image analysis. Indeed, the modeling function gives us information about highlights, and provides useful cues, for example to remove them from the image.[16,15,1]

Our work deals with traceability of meat products. Indeed, we have to detect on fresh ham the position of the carcass identifier and move the camera in front of it in order to ensure its correct reading. Some segmentation results have been obtained behind diffuse lighting conditions.[5] In this context, the study of reflectance is justified by several points. First, specularities can harm the segmentation task and the tracking process. Knowing the reflectance of the material makes possible to remove specularities in the image. During the segmentation works, some problems appeared on the edges of the ham, because of its curvatures. We will propose some issues to solve this problem by the knowing of the reflectivity function.

This article is presented as follows. First, the reflectance is defined. Then we explain our technique to measure and model the ham reflectance. To finish, we present some applications of this model.

The Reflectance

Definition

Bidirectional reflectance or *Bidirectionnal Reflectance Distribution Function* (BRDF) is useful to describe the diffusion and specular reflections of an opaque surface according to the lighting direction **L** and observation direction **V**. We will refer to the figure 1 to explain the scene geometry and the notations used. The reflectance of a material is defined as the ratio of the radiance L_r emitted by the surface dA in the direction θ_v on the irradiance Ir received by the surface from the direction θ_l, with a solid angle $d\omega$ and the wavelength λ.

$$\mathcal{R} = \frac{L_r}{Ir}$$

The BRDF is given by:

$$f_r(\theta_l,\phi_i,\theta_v,\phi_r,\lambda) = \frac{dLr(\theta_v,\phi_r,\lambda)}{dIr(\theta_l,\phi_I,\lambda)} \quad (1)$$

The reflectance is bidirectional since the Helmotz reciprocity propriety stipulates that the inversion of the luminous way doesn't modify the reflectance:

$$f_r(\theta l,\phi_i,\theta_v,\phi_r,\lambda) = f_r(\theta_v,\phi_i,\theta_l,\phi_r,\lambda)$$

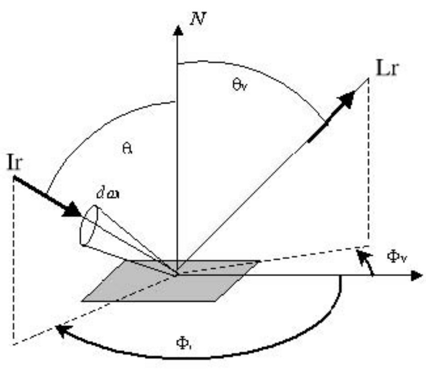


Figure 1. Spherical system used to describe the reflection process.

The Reflection Models

Many empirical and theoretical models of light reflection on a surface were introduced into the thirty last years.

The Dichromatic Model

The dichromatic model proposed by Shafer[16] is based on the fact that a dielectric, convex, uniformly coloured and shining object reflects the light either by surface reflection, preserving more or less the spectral characteristics of the incidental light, or in body reflectance, resulting from the penetration of the rays in the object and from its diffusion by the particles (pigments) of material. The dichromatic model separates these two phenomena, so that the reflectance $R(g, \lambda)$ of an object is the sum of interface reflectance $R_s(g, \lambda)$ and body reflectance $R_b(g, \lambda)$:

$$R(g, \lambda) = R_s(g, \lambda) + R_b(g, \lambda)$$

where g is a function of the photometric angles defining the geometry of the scene. Each reflectance R_i , $i = s, b$ makes up of two terms. $C_i(\lambda)$ is associated with the spectral distribution of the material, i.e. with purely physical characteristics of material, $M_i(g)$ is a scale factor depending only on the scene geometry:

$$R(g, \lambda) = C_s(\lambda)M_s(g) + C_b(\lambda)M_b(g)$$

According to this model, the whole of the material colors forms a plane defined by the vectors C_s and C_b in the color space. The Shafer model is qualitative, insofar as it doesn't specify the values of the functions $C_s(\lambda)$, $C_b(\lambda)$, $M_b(g)$ and $M_s(g)$.[2] $C_s(\lambda)$ and $C_b(\lambda)$ correspond respectively to the reflectance of Fresnel and the surface albedo.[4] The dichromatic model, generalized by Healey[6] is valid for a great number of materials.[17] It is largely used in color constancy tasks,[18,3] in color segmentation.[10,12]

The Phong Empirical Model

An empirical model is an expression whose parameters are adjusted in order to describe some reflectance functions. It attempts to approximate the materials photometric behaviour without taking into account the optical geometry, which describes the interaction between light and matter. Phong[14] proposes to model the radiance of a specularity lobe by a cosine lobe:

$$L_r(\theta_l, \theta_v) = k_s \cdot \cos^n(\theta_v, \theta_s)$$

where θ_s is the zenithal angle of the ideal specularity direction. Even if n has no physical signification, the higher it is the higher the specularity lobe is and comes close to the ideal reflection. This model requires the adjustment of a few parameters. The Phong model is widely used in computer vision, because of its mathematical simplicity. For exemple, Tominaga[19] has used it to determine the reflection parameters of objects in a scene simply thanks to one image of the scene.

A Model Based on Optical Geometry: The Torrance-Sparrow Model

Unlike the empirical model, the theorical one attempts to approach the real reflectance function thanks to parameters from the physical theory. The reflectance approximation by a theorical model is interesting since it enables an easy determination of the material physical parameters without carrying out a rather complicated measure.[21] Some numerous theorical models, generally very complex, have been found. For example, the Beckmann-Spizzichino one is based on the electromagnetic waves, which is physically irreprochable but whose complexity reduces its utilization.

The Torrance-Sparrow model[20] is based on optical geometry, i.e. it neglects the electromagnetic characteristics of the light, which makes it less complicated. We consider that the light wavelength of the incident light is far smaller than the micro asperity size of the ham, what allows us to use the Torrance-Sparrow model. It is widely used for a large number of dielectric and inhomogeneous materials, for example by Ikeuchi.[9]

The radiance is expressed as follows:

$$\begin{cases} Ir = K_l \cos\theta_l + \dfrac{K_s}{\cos(\theta_r)} e^{-\frac{\beta^2}{2\sigma^2}} & \theta_l \in \left[0, \dfrac{\pi}{2}\right] \\ Ir = 0 & \text{else} \end{cases} \quad (2)$$

where σ depends on the matter rugosity. Let's refer to figure 2. If L_0 is the specularity direction, B the bissecting line between the viewing (**V**) and lighting (**L**) directions, n_o the bissecting line between V and L_0, then β is the angle between n_0 and B, or the angle between **L** and L_0. So we replace β by $\alpha - \in_i$ and by $2\sigma^2$ by γ, α being the angle between **L** and **V**, and $\in_i$ and γ are constants.

Reflectance Measuring

Existing Methods

The most common method to obtain the reflectance function of a material is to carry out a measure for each lighting position among the zenithal angles and each positions of the camera among zenithal and azimuthal angles. Nevertheless, this technique is time consuming. It is worth using a few approximations by exploiting the inherent properties of the material studied in order to reduce the number of measures. One acquisition can be sufficient when the material is lambertian.[22] Nevertheless Tominaga and Tanaka[9] had recently estimated the reflection parameters of a specular material with one image. In most cases, several acquisitions are required. For example, in Ref. [11], the object is rotated and the camera and the light are fixed. An other technique consists in moving the light, or both light and camera, the object being fixed.[21] Some authors[8] have further reduce the acquisitions number by choosing appropriate lighting geometries. A 3D scanner can be useful to compute the elevation in each point of the image, so that only few images are required to model the reflectance.[9]

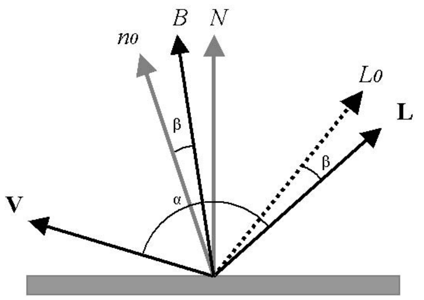


Figure 2.The angle β in the Torrance-Sparrow model.

Figure 3. Example of image to be segmented. The identifier to detect is a numerical code, composed of eight characters printed with a blue ink.

Our Method

We have used the gonio-reflectometer system presented on the figure 4. The radiance L_r is measured with a spectroradiometer and an image of the measured surface is acquired. The main drawback of this system is that the surface studied is not exactly situated at the center of the semicircle, what causes imprecisions on angles measure and a complex variation of lighting solid angle according to the incidence angle. The second disadvantage is due to the object itself, because it is hard to obtain a perfectly horizontal surface with the ham. Furthermore, the pigmentation of the pork rind is very heterogeneous, and we must measure the reflectance on a representative surface, a circular area of 3 cm diameter approximately. Measurements on different hams, with different colors and wetnesses have been compared.

The radiance L_r is measured for each position θ_l of the light along zenithal angles, only a few viewing θ_v directions being considered; the irradiance I_r is measured with a white patch whose surface is supposed to be perfectly matt. Because the measured surface isn't situated at the center of the system (see figure 4), the distance between the surface and the light, and thus the illumination E, varies according to the angle θ_l. Let's call $d(\theta_l)$ the distance between light and surface. If the illuminated area is the same, whatever the lighting position is. Illumination E is inversely proportional to the square distance $d^2(\theta_l)$:

$$E = \frac{I}{d(\theta_l)^2} \cos\theta_l$$

where I is the intensity of the source. If R is the radius of the semicircle and a the thickness of the ham, then:

$$E(\theta_l) = \frac{I}{(R - a\sin\theta_l)^2}\cos\theta_l$$

The maximum illumination is given for $\theta = \theta_0 = 0°$. We can correct the reflectance by dividing it by the following ratio:

$$\frac{E(\theta_l)}{E(\theta_0)} = \frac{(R-a)^2}{(R - a\sin\theta_l)^2}\cos\theta_l \qquad (3)$$

Then, we consider the matter anisotropism. If a matter is isotropic, its bidirectional reflectance doesn't depend on the azimuth ϕ_l. The anisotropy of a material is generally related to its surface quality, for example if the surface is striated or composed of aligned fibres. The anisotropism measure is achieved by a rotation of the ham through an angle ϕ round the normal N.

Reflectance Modeling

The difficulty of the modeling task lies in two main points. First, the color and matter of the pork rind is very inhomogeneous, on a same ham but also from a ham to another. Moreover, occurrence of specularities depends also partially on humidity of the rind, which is extremely variable, and therefore difficult to control.

First, the diffuse component of the reflectance is extracted. Owing to the form of the reflectance measurements (figure 5), we can determine approximately the lighting angles corresponding to absence or presence of highlights.

Nevertheless, it is more accurate to refer to the dichromatic model. The form of the color cluster in the RGB space gives us information about specularities. A "T" or "P" shaped cluster means occurrence of specularities in the image. So the zenithal positions for which there is no specular component are searched and the diffuse component is modeled thanks to the corresponding measures.

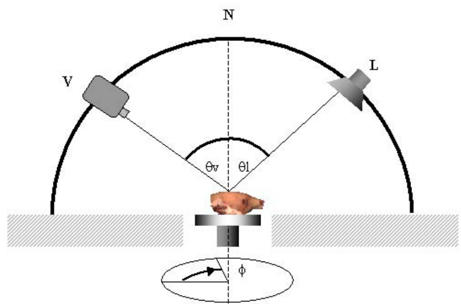


Figure 4. Gonio-reflectometer used. V denotes the viewer direction, L the light direction and N is the normal to the surface studied.

Thus, because of the configuration of the gonio-reflectometer, the lighted area is different for each position of the light source. The diffuse component of the radiance L_r^d (θ_l, θ_v) is not modeled by a Lambertian model but by a Phong cosine function:

$$L_r^d(\theta_l) = A_0 . \cos^n(\theta_l) \qquad (4)$$

Moreover, the measured surface isn't exactly horizontal, so we have to add a parameter ρ_0:

$$L_r^d(\theta_l) = A_0.\cos^n(\theta_l - \rho_0) \quad (5)$$

where ρ_0, A_0 and n are constants that we determine by interpolation. The irradiance I_r, which is obtained by the reflectance of the white patch, is modeled by the same way, so that diffuse reflectance $R(\theta_l, \theta_v)$ is expressed as follows

$$R^d(\theta_l) = \frac{L_r^d(\theta_l)}{I_r^d(\theta_l)} = K \quad (6)$$

where K is the ratio of the ham albedo on the white patch albedo. Once the diffuse component modeled, the two specular lobes, whose main directions are approximately at $\theta_v + 45°$ and $\theta_v + 90°$, are first modeled with an empirical model of Phong, then with a physical model of Torrance Sparrow. Each specular component consists of two terms whose values are closely related to surface roughness.[13] Let's call $\alpha = |\theta_v - \theta_l|$ the angle between the viewing direction and the lighting direction. For one lobe, the Phong model is given by the equation (7), whereas Torrance model is described by the equation (8):

$$L_r^s(\alpha) = \sum_{i=1}^{2} A_i.cos^{n_i}(\alpha - \rho_i) \quad (7)$$

$$L_r^s(\theta_v, \alpha) = \sum_{i=1}^{2} \frac{B_i}{cos(\theta_v)}.\exp\left(-\frac{(\alpha - \in_i)}{\gamma_i}\right) \quad (8)$$

where the values A_i, B_i n_i, ρ_i, $\in_i$ and γ_i are constants computed with the least squares method.

Reflectance is then modeled according to the azimuth angle ϕ, successively by the models of Phong and Torrance. The computation of the square error of the two models enables to choose the Phong model to approximate the reflectance according to the azimuth angle. If θ_l and θ_v are fixed:

$$L_r(\phi) = b_0 + b_1\cos^{n_3}(\phi - \rho_3)$$

where b_0, b_1, n_3 and ρ_3 are some constants that have to be determined. Because the reflectance measurement is reiterated on different hams, we may obtain different parameters of the model. Nevertheless we can determine some parameters that are almost similar from one ham to another.

Results

The table 1 contains the modeling parameters for the diffuse component, obtained by least squares method. The values ρ_0 are quite different from a piece of pork to another. Indeed, a positioning error can induce an angle between normal of the surface and the reference N (see figure 4). The value associated to the belly is rather little since this piece is less curved than the hams. Then, the two lobes are fitted by Phong and Torrance-Sparrow models. The results for the lobe at 0° with θ_v =45° are shown in table 2 and 3. The measure has been carried out for a few viewing directions in order to validate the model. The errors obtained prove that Phong model is suitable to model the ham reflectance function. This remark is also right for the lobe at 45° and for other viewing directions θ_v.

Table 1. Parameters obtained by Phong model with the least squares method, for 3 hams and a belly.

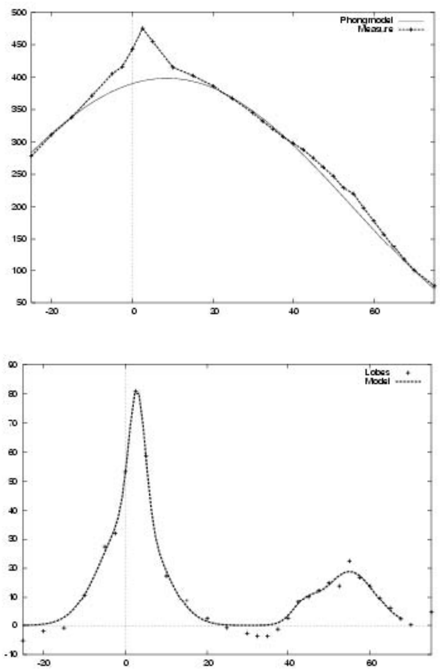
Parameters	Ham A	Ham B	Ham C	Belly D
K_0	0.398	0.349	0.425	0.480
ρ_0	8.5	16	23	-1.09
n	1.87	1.63	1.51	1.75

Table 2. Parameters of Phong model for specular lobe at θ_l = 0° with θ_v = -45°. Two hams (A and B) are considered.

	Parameters						Error
	K_{11}	K_{12}	ρ_1	ρ_2	n_1	n_2	($\times e^{-5}$)
A	0.038	0.044	46.4	47.9	63	841	7.25
B	0.051	0.012	46.5	60.7	98.6	396	8.51

Table 3. Parameters of Torrance model for specular lobe at θ_l = 0°, with θ_v = 45°. Hams A and B are considered.

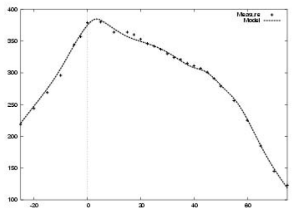
	Parameters						Error
	K_{11}	K_{12}	$\in_1$	$\in_2$	γ_1	γ_2	($\times e^{-5}$)
A	0.041	0.043	46.5	47.9	105	7.6	10.3
B	0.047	0.004	46.6	47.9	105	12	30.2



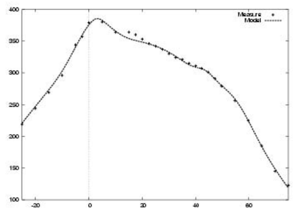
(a)

(b)

Figure 5. Phong Modelling with qv = 45. (a): Diffuse component. (b): Specular component.



(a)



(b)

Figure 6. Generalized modeling of the reflectance for Ham B. The dotted lines correspond to the measure, and the lines correspond to the model. (a) : Torrance-Sparrow. (b) : Phong.

However, by comparing the results of 2 and 3, we notice that parameters of the Torrance-Sparrow model are quite similar from a ham to another, and we can obtain a suitable generalized model, with $\rho_1 = 46.5°$, $\rho_2 = 47.9°$, $\gamma_1 = 105$ and $\gamma_2 = 10$. As shown by figure 6 (a), the modeling is still satisfactory. Even if the parameters of Phong model are more different, let's see what happens if we assume that roughness of the matter and highlight directions are similar from a ham to another. By computing the mean of the parameters for different hams, we obtain a model that is still suitable, as it is shown on figure 6 (b).

$$L_r(\theta_l,\alpha) = \begin{cases} a_0.\cos^{1,75}(\theta_l-\rho)+a_1.\cos^{100}(\alpha-45) & \text{if } \alpha\in[30;75] \\ a_0.\cos^{1,75}(\theta_l-\rho)+a_3.\cos^{70}(\alpha-90) & \text{if } \alpha\in[75;115] \\ a_0.\cos^{1,75}(\theta_l-\rho) & \text{else} \end{cases} \quad (9)$$

Let's now consider the rotation of the pork ring along the normal axis. We notice two peaks, at 50° and 275° respect to our reference. If θ_v and θ_l are fixed:

$$L_r(\phi) = \begin{cases} b_0+b_1.\cos^{6,5}(\phi-50) & \text{if } \phi\in[0°;120°] \\ b_0+b_2.\cos^{1,5}(\phi-275) & \text{if } \phi\in[175°;360°] \\ b_0 & \text{else} \end{cases} \quad (10)$$

The global model is obtained by replacing the coefficients a_i for $i = 0...4$ in the equation (9) by the reflectance variation according to ϕ given by the relationship (10).

Applications

This modeling has been useful as a learning stage. We can easily admit weak constraints on b_0, b_1 and b_2 : 0, 3 < b_0 < 0, 5 and b_1, b_2 < 0, 1. So, the reflectance model can be useful to extract the reflectance parameters with a restricted number of image acquisitions.

Moreover, by knowing the reflectance function of the ham, we can implement an acquisition system by choosing the angle between the camera and the light in order to minimize specularities in the image, and reduce segmentation errors. It could be interesting to use a system similar as the one described in the figure 4, the ham being placed on the conveyor belt. According to the equation (9), we must have an angle inferior to 30° between camera and lighting to obtain the minimum of specularities. Moreover, the ϕ angle will have to be included in [120° 175°].

The ham has a smooth curvature. The knowing of the reflectance model could make easier the reading of the identifier on the edge of the ham. After having removed the highlights, a Shape from Shading technique[7] we could correct the deformations of the identifier in order to ensure its correct reading.

Conclusion

Thus, the reflectance model gives some useful information about the matter used in our application. We have fitted the reflectance measures by a Phong model, which is easy to implement and offers the most accurate approximation. Both variation of reflectance according to zenith and azimuth angles were taken into account. In spite of the difficulties in modeling the reflectance of an inhomogeneous surface, it is possible to obtain a suitable approximation of the ham reflectivity by measuring it on a surface of significant size and by using some representative samples. Our future work will consist in exploiting the information given by the reflectance model to facilitate both the detection and the tracking of the identifier.

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References

1. R. Bajcsy and S.W. Lee and A. Leonardis, Detection of and specular interface reflections and inter reflections by color image segmentation, Int. Jour. of Comp. Vis. 1996, Vol. 17, No 3, pp 241–272.
2. L. Brun, Traitements d'images couleurs et pyramides combinatoires, Mémoire d'Habilitation à Diriger des Recherches. Université de Reims, Décembre 2002.
3. G.D. Finlayson and G. Schaefer, Solving for Colour Cons tancy using a Constrained Dichromatic Re flection Model, Int. J. of Computer Vision, 2001, Vol. 42, No 3, pp 127144.
4. T. Gevers and H.M.G. Stokman, Robust Photometric Invariant Region Detection in Multispectral Images, Int. Jour. of Comp. Vis., 2003, Vol. 53, No 2, pp 135–151.
5. M. Gouiffès and P. Marty Mahé and C. Fernandez Maloigne and A. Trémeau and P. Loisel and D. Brossard, Comparaison de deux méthodes de segmentation couleur appliquées à la traçabilité de produits carnés, RFIA'04, janvier 2004, Toulouse, France
6. G.E. Healey, Using color for geometry insensitive segmentation, J. Opt. Soc. Am. A., 1989, Vol.6, pp 920–937
7. B.K.P. Horn and M.J. Brooks, Shape from Shading, The M.I.T press, 1989
8. L. Hussenet, De l'analyse d'images à la reconstruction 3D : Application au contrôle d'objets métalliques. Thèse de doctorat Université de Reims, ChampagneArdennes, Décembre 2002.

9. K. Ikeuchi and K. Sato, Determining Reflectance properties of an object using range and brightness images, IEEE Trans. On PAMI, 1991, Vol.13, No.11, pp 1139–1153.
10. G.J. Klinker and S.A. Shafer and T. Kanade, A physical approach to image understanding. Int. Jour. of Comp. Vis., 1990, Vol. 4, pp 7–38.
11. J. Lu and J. Little, Reflectance and shape from shading using a collinear light source, Int. Jour. of Comp. Vis. 1999, Vol. 32, No 3, pp 213–240.
12. B.A. Maxwell and S.A. Shafer, Physicsbased segmentation : moving beyond color, IEEE Conf. on Comp. Vis. and Pat. Recognition. 1996, pp 742– 749.
13. S.K. Nayar and K. Ikeuchi and T. Kanade, Surface reflection : Physical and geometrical perspectives, IEEE Trans. on PAMI July 1991, Vol. 13, No 7, pp 611–634.
14. BT Phong, Illumination for Computer Generated Images Communications of the ACM. June 1975, Vol. 18, No 6, pp 311–317.
15. H. Rhagheb and E.R. Hancock, Separating Lambertian and Specular Reflectance Components using Iterated Conditional Modes, British Machine Vision Conference, 1999, pp 541–552.
16. S.A. Shafer. Using color to separate reflection components, Color Res. and Appli. 1985, Vol. 10, No 4, pp 210–218.
17 S.Tominaga. Surface identification using the dichromatic reflection model, IEEE Trans. on PAMI, July 1991, Vol. 13, No 7, 658–670.
18. S.Tominaga and B.A. Wandell, Standard Surface Reflectance model and Illumination Estimation, J. Opt. Soc. Am. A, 1996, Vol. 6, No 4, pp 576–584.
19. S. Tominaga and N. Tanaka, Estimation of reflection parameters from a single color image, IEEE Comp. Graph. and Appli. 2000, Vol. 22, No 5, pp 58–66.
20. K.E. Torrance and E.M. Sparrow, Theory for OffSpecular Reflection from Roughened Surfaces, J. Optical Society of America 1967. Vol. 57. No 9.
21. G.J. Ward, Measuring and modeling anisotropic reflection Computer Graphics, 1992, Vol. 26, No 2, pp 265–272.
22. Q. Zheng and R. Chellapa, Estimation of illuminant direction, albedo and shape from shading, IEEE Trans. PAMI 1991. Vol. 13, No 7, pp 680–702.

Biography

Michèle Gouiffès is PhD student in computer vision from the University of Poitiers. She carries out her research at the Cemagref in Rennes, where her research interests include color segmentation applied to traceability control.