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표면반사율 모델링을 위한 새로운 N차원 기저함수

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New N-dimensional Basis Functions for Modeling Surface Reflectance

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요 약

일반적으로 표면반사율과 분광반사율을 N차원의 칼라 코드로부터 정확히 복원하기 위해서는 N개의 기저함수가 필요하다. 전형적인 렌더링 응용에서 벡터의 덧셈, 스칼라 곱셈 및 성분별 곱셈에 대한 벡터 연산이 이질동형이라고 가정하고 광원의 중첩, 광원-표면간 상호간섭 및 상호반사와 같은 물리적인 연산을 모델링하지만 벡터 연산이 물리적인 현상을 그대로 반영하는 것은 아니다. 그러나 만약 기저함수가 특성함수로써 제한된다면 표면반사율과 분광반사율의 사상 결과 및 벡터들은 렌더링에서 물리적인 연산인 이질이형을 유지하게 된다. 본 논문은 새로운 N차원의 특성함수를 제안하고 N차원의 기저함수로 근사화된 먼셀 칼라 칩에 대하여 제안한 알고리즘의 정확성을 평가할 것이다.

Abstract

The N basis functions are typically chosen so that Surface reflectance functions(SRFs) and spectral power distributions (SPDs) can be accurately reconstructed from their N-dimensional vector codes. Typical rendering applications assume that the resulting mapping is an isomorphism where vector operations of addition, scalar multiplication, component-wise multiplication on the N-vectors can be used to model physical operations such as superposition of lights, light-surface interactions and inter-reflection. The vector operations do not mirror the physical. However, if the choice of basis functions is restricted to characteristic functions then the resulting map between SPDs/SRFs and N-vectors is anisomorphism that preserves the physical operations needed in rendering. This paper will show how to select optimal characteristic function bases of any dimension N (number of basis functions) and also evaluate how accurately a large set of Munsell color chips can approximated as basis functions of dimension N.

Keyword : Surface reflectance, illuminant, and color constancy

Ⅰ. Introduction

In a typical application we specify surface and light sources in a scene and then model light-surface interactions. The resulting image is only as accurate as the information about the spectral properties of light and surface used to describe the contents of the scene. Most rendering applications use simple RGB 3-channel codes to represent the spectral power distribution(SPDs) of lights and surface reflectance. Most conventional algorithms model interaction by addition and component-wise multiplication of these 3-vectors. These mathematical operations do not correspond to actual light surface interactions. It is not clear

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exactly what such an RGB code represents about a surface or light and there are likely advantages of using higher-dimensional representations.

Typical approaches to modeling spectral information includes developing subspace models for lighting [1], [2], surface reflectance [3], [4], and using these models to model human perception [5]. A typical "color constancy" algorithm is a method that models lights and surfaces by subspace models and attempts to recover the basis coordinates of the surfaces independent of those of the illumination.

Most conventional methods of modeling used in this literature involve criteria for selection of basis functions and assigning weights to surfaces and lights [2], [5]. These models can reproduce spectral information to any desired accuracy by increasing the number of basis functions used (the dimension N of the model) and there is no need to stop at N=3. A central focus of this research concerns how accurately such linear models capture surface reflectance or illumination as a function of the number of basis elements. Previous results show that we can approximate surface reflectance very accurately using a computation method with eight or more basis functions [6].

Even though a particular illuminant and a particular surface are accurately represented by a common linear model, the secondary illumination that results when the first illuminant is absorbed and reflected by the surface need not have any close representation in the model. Figure 1 shows an example of secondary illuminant. Even if a basis of a particular illuminant and α is the same fortunately, light reflected on γ cannot model as multiplication of each coefficient when a basis function of β or γ is different from that of α in a ray 3(dash lines).

The isomorphism between the N-dimensional function space and the N-dimensional real function space preserves addition, scalar multiplication and component-wise multiplication.

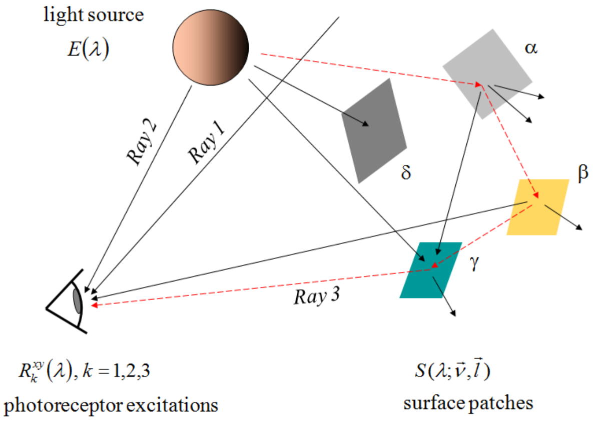

그림 1. 세 개의 표면반사율을 가진 2차 광원 효과의 예
Fig. 1. Example of the effect of a secondary illuminant with three surface reflectance factors

II. New N-dimensional Basis Functions for Surface Reflectance Models

It is typically used in mathematics to represent a subset of the domain of the function which in this article will always be the electromagnetic spectrum. We confine attention a constrained set of basis elements each of which is the characteristic function for an interval (λ_1, λ_2) in the visible spectrum. A characteristic function is a function that takes on only the values 0 or 1. The characteristic function is 1 for wavelengths $\lambda \in (\lambda_1, \lambda_2)$ and otherwise 0. The characteristic functions in a basis must be orthogonal precisely when their intervals are non-overlapping. We use the same basis to represent both lights and surfaces. It is easy to show that typical rendering operations of vector addition and multiplication then correspond to physical superposition of lights or surfaces and light-surface interactions. With characteristic function bases, it is easy to show that, if light$(\epsilon_1, \cdots, \epsilon_n)$ is absorbed and emitted by surface $(\sigma_1, \cdots, \sigma_n)$, the emitted light does have exactly the spectral power distribution corresponding to $(\epsilon_1\sigma_1, \cdots, \epsilon_n\sigma_n)$. Light-surface interaction is mimicked by component-wise multiplication of color codes. Scalar multiplication and addition are also preserved as they would be for any isomorphism between vector spaces.

Conventional basis functions can be biased by themselves because they are extracted the population. And also, it faces to the difficulty problem when implementing to surface-light interaction in virtual reality. So, we propose a novel basis function intended to reproduce surface-light interaction In general, the surface reflectance with a basis function is follow,

$$S = \sum_{i=1} a_i u_i (i = 1, 2, \cdots, n) \tag{3}$$

where μ_i is the principal component (or basis function) a function of wavelength. Examples of conventional basis functions and proposed characteristic functions are shown in Figure 2.

Conventional basis functions have a negative or positive intensity and cover full wavelength in each basis while characteristic model does cover not the entire wavelength and basis function has a variable wavelength I_i as follow,

$$u_i = \begin{cases} 1 & \lambda \in I_i \\ 0 & \lambda \notin I_i \end{cases} \tag{4}$$

Therefore, we can represent arbitrary function as,

$$f(x) = \alpha u_1 + \beta u_2 + \cdots + \gamma u_n \tag{5}$$

This is because the each coordinate is orthogonal and non-overlapping in wavelength. If there are two surface reflectances,

$$f_1(x) = \alpha_1 u_1 + \beta_1 u_2 + \cdots + \gamma_1 u_n \tag{6}$$

and.

$$f_2(x) = \alpha_2 u_1 + \beta_2 u_2 + \cdots + \gamma_2 u_n \tag{7}$$

We can add and multiply each as follow,

$$f_1(x) + f_2(x) = (\alpha_1 + \alpha_2) u_1 + (\beta_1 + \beta_2) u_2 + \cdots + (\gamma_1 + \gamma_2) u_n \tag{8}$$

and.

$$f_1(x) \times f_2(x) = (\alpha_1 \times \alpha_2) u_1 + (\beta_1 \times \beta_2) u_2 + \cdots + (\gamma_1 \times \gamma_2) u_n \tag{9}$$

From these factors, we can easily calculate the scalar value without spectra if we have basis functions with an orthogonal and non-overlapping in wavelength. To select the optimal basis functions, first of all, we have to determine which selection of intervals is optimal. From now, we will make the characteristic function using Munsell Color Chips even if real spectra and Munsell chips have differences in some ways using a proposed algorithm as shown in Figure 3. We first detected the two points through differential of the surface reflectance and color difference for characteristic function with N=3 dimension. To determine the next

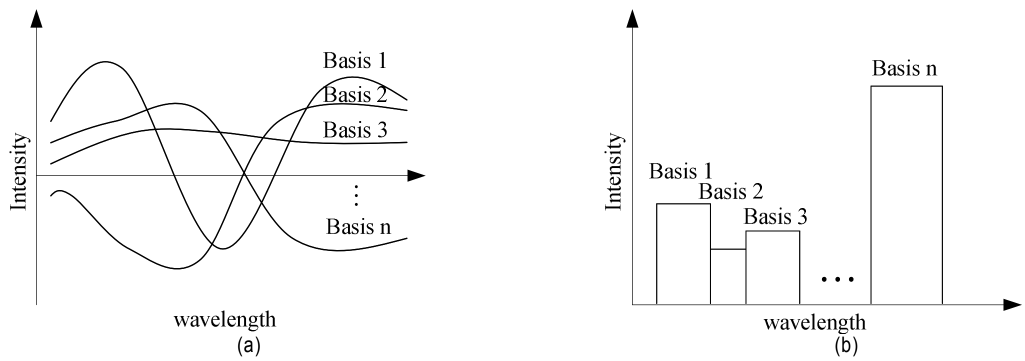

그림 2. n-파라미터를 가지는 기저 함수의 예 (a) 기존 기저함수 (b) 특성함수
Fig. 2. Examples of basis function with n-parameters; (a)conventional basis function and (b)characteristic function.

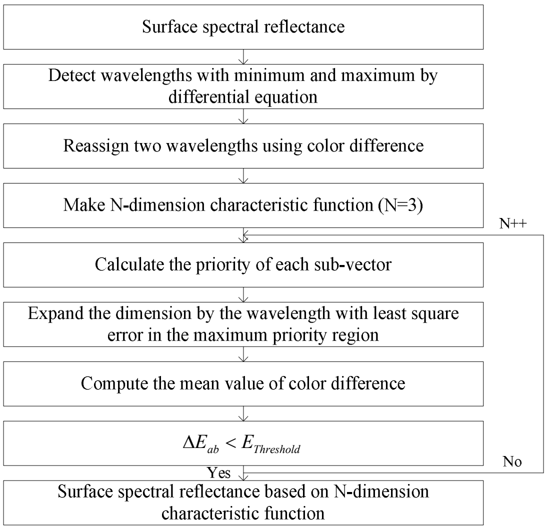

그림 3. 제안한 알고리즘의 흐름도
Fig. 3. Flowchart of the proposed algorithm

region, we considered the variation of a sub-vector. The priority, to quantize the variation, is calculated the properties in a sub-vector as follows; the singular value, slope of a principal component, amplitude, and standard deviation. If we are not satisfied with that result after calculating the color difference, the error can be reduced while increasing N. Finally, we will be able to obtain the characteristic function for each surface reflectance.

Our experiment consists of approximating Munselll color chips using N-dimension characteristic functions. Figure 4 show the histogram of color difference according to N-dimension characteristic functions. As N is increasing, the mean value of $\triangle Eab$ is smaller and its gravity shifts to the left side. The smaller errors than one were counted as one in histogram in Figure 4.

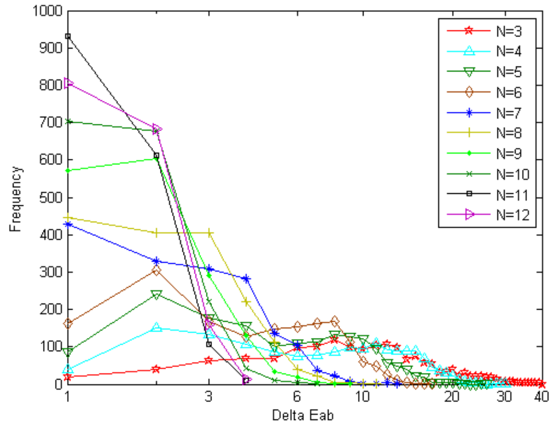

그림 4. N-차원 특성함수에 따른 색차의 히스토그램
Fig. 4. Histogram of color difference according to N-dimensional characteristic function

III. Conclusions

This paper proposed a novel set of basis functions for linear models of surface reflectance. The vector of weights in a linear model of surfaces or lights is effectively a representation of particular surfaces or light. If we constrain the choice of basis functions to be orthogonal characteristic functions then ordinary addition and multiplication of vectors mirrors the physical superposition of lights and surfaces and light-surface interaction. Normal rendering computations are then physically correct. We are able to reproduce color accurately in surface-light interaction by fixing optimal wavelengths to determine basis functions.

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