Spectral Color Appearance Modeling

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Abstract

In this paper, a spectral color appearance model is considered. This model is used for color image quality estimation when a color image is reproduced through a spectral image. The model is based on the statistical image model that sets a relationship between the parameters of the spectral images and color images, and the overall appearance of the image. This was used to create a set of test color images that were evaluated by twenty color normal test persons. The results of their evaluation were used for synthesis of a Fuzzy Logic System. Based on the test persons estimation two-dimensional colorfulness vividness quality evaluation surfaces were built for each image and for image groups. The study shows that a spectral-color relationship and Fuzzy Logic Inference are efficient in color image quality evaluation.

Introduction

In this paper, the spectral color appearance model for quality of color and spectral image estimation is considered. The model can be used in a number of different applications, from digital archiving to communications and industrial applications.

Most of the works on color appearance models are dedicated to the problem of reproduction of colors under different illuminants so that the overall appearance remains unchanged and independent of the viewing conditions, and the device used to represent the image.[2] The model, described in this paper, is used for color image quality estimation when a color image is reproduced through a spectral image. Two criteria are devised for this purpose: colorfulness and vividness. These, in turn, are based on a statistical spectral image model,[1] developed on the basis of the statistical characteristics study of natural images. According to the model, statistical characteristics of the image, like kurtosis and standard deviation, affect the appearance of the image. Kurtosis impacts image highlight reproduction, and standard deviation affects image contrast and color saturation. A set of test images was produced using the statistical model.

In order to prove the feasibility of the given spectral appearance model twenty color-normal persons graded the images and the results were input into a Mamdani Fuzzy Inference System, that models the behavior of the human expert and predicts the quality estimate depending on the level of colorfulness and vividness. For the latter, a set of tests was performed on the Fuzzy Logic System, where all images except one were used as a training data set and the image left was used as a testing image. The tests have proven that the prediction error is low in an average case and the Fuzzy Expert System is an efficient tool in predicting the human observer behavior in a quality estimation task. Similar work, dealing with discrimination of the performance of the human observer in a visual detection task in gray level images, is presented in Ref. [6].

For spectral images, a visual quality estimation method using a component gray level image for quality evaluation is proposed in Ref. [5].

Statistical Model

A generalized statistical spectral model, which copies the behavior of the statistical characteristics of natural images, is used in this work, as follows[1]:

$$f(x) = \mu + Dg(x) \tag{1}$$

where $\mathbf{f}(x)$ is a n-dimensional vector random field, and x is a vector with each element being a spatial dimension; μ is a mean vector, $\mathbf{g}(\mathbf{x})$ is a normalized vector image with zero mean and unit standard deviation for each component, $\mathbf{D}=\mathrm{diag}(\sigma_1, \sigma_2, \ldots, \sigma_n)$, where σ_i is a standard deviation in the component.

Eq. 1 is usually used for the texture images. However, in this study, this model is used in images that are homogeneous or consist of several homogeneous regions. In the last case, the model is used for each region segmented before the modeling.

To provide the spectral and color parameter change that affect the image appearance, the following relationships are used. The vector $\boldsymbol{\sigma}$ is presented as follows:

$$\boldsymbol{\sigma} = \alpha\beta\boldsymbol{\sigma}_v + (1 - \alpha)\boldsymbol{\sigma}_c \tag{2}$$

where $\alpha = (\sigma_{max} - \sigma_{min})/\sigma_{max}$ is the relationship between constant and variable parts of standard deviation and $\boldsymbol{\sigma}$ is a contrast variation coefficient, σ_v is a variable component vector of σ, σ_c is a constant component vector of σ.

Finally, $\mathbf{g}(\mathbf{x})$ is centered by substracting its mean as follows:

$$g(\mathbf{x}) = g(\mathbf{x})\text{-}E(g(\mathbf{x})) \qquad (3)$$

value of the right-hand side is computed and substituted in $\mathbf{g}(\mathbf{x})$, $E(\mathbf{g}(\mathbf{x}))$ is the expectation value of $\mathbf{g}(\mathbf{x})$. $\mathbf{g}(\mathbf{x})$ is defined through gamma-Charlier histogram transform of $\mathbf{f}_s(\mathbf{x})$ and a kurtosis vector $\mathbf{k}$ as follows [1]:

$$g(\mathbf{x}) = H(f_s(\mathbf{x}),k) \qquad (4)$$

where $\mathbf{f}_s(\mathbf{x})$ is a normalized image of $\mathbf{f}(\mathbf{x})$, with zero mean and unit standard deviation for each component, the elements of $\mathbf{k}$ are kurtosis, calculated in components. To affect the image appearance through histogram transform, the kurtosis change is used as follows: all kurtosis elements are proportionally modified according to the given maximum of the kurtosis value α, β and $\mathbf{k}$ are used for modifying the colorfulness and vividness change in the tests.

Experiment

Experiments were performed on spectral images from Ref. [7]. Five images – *inlab1, inlab2, inlab5, jan13am* and *rleaves* were selected. Each image has the following dimensions: 256x256 in the spatial dimension and 31 components in the spectral dimension. The fragments with a size 128x128 and 31 components of these images were used in the test.

Colorfulness

First, a set of test images was produced using the colorfulness parameter. The term includes both contrast and color saturation. Thus, colorfulness was varied through standard deviation, using Eq.2. By changing the α and β coefficients it was possible to receive new values for constant and variable parts of the standard deviation. This procedure was applied to the images with values of (α,β) equal to (0.55,1), (0.75,1), (1,1.3), (1,1.6). Fig.1 shows how the colorfulness change affects the color reproduction of a spectral image.

Figure 1. inlab2. A color reproduction of the original image (left) and processed image (α = 1, β = 1.6) (right)

Vividness

The second set of tests was produced through variation of the vividness parameter, closely related to highlight reproduction in an image. As the highlight was modified through kurtosis change, the test images were produced with the help of Eq.3 (with k_{max} equal to 5, 10, 30, 60). Fig. 2 shows the effect of the vividness change in color reproduction of a spectral image.

Figure 2. inlab 5. A *color reproduction of the original image (left) and modified image (k_{max} = 80) (right)*

Both test sets were evaluated by 20 color-normal persons using a 1 to 10 scale. Where 1 was assumed as the lowest quality and 10 the highest. The means of all of the scores for both colorfulness and vividness were computed. The results are presented in Tables 1 and 2. In Table 1 Image 1 and Image 2 have parameters (α,β): (0.55,1), (0.75,1), Image 3 is the original, Image 4 and Image 5 have parameters (α,β): (1,1.3), (1,1.6). In Table 2 Image 1 and Image 2 have the following values of k_{max}: 5, 10, respectively. Image 3 is the original, Images 4 and 5 have respectively, k_{max} equal to 30, 60.

Table 1. Mean Values of Quality Judgments in Colorfulness Change

Quality	Image 1	Image 2	Image 3	Image 4	Image 5
Inlab1	2.67	4.50	6.00	6.00	7.17
Inlab2	2.67	4.83	7.00	7.83	8.67
Inlab5	3.00	4.50	5.67	6.83	7.67
Jan13AM	3.33	4.83	7.00	7.67	8.17
Rleaves	2.50	3.50	4.83	4.83	5.83

Table 2. Mean Values of Quality Judgments in Vividness Change

Quality	Image 1	Image 2	Image 3	Image 4	Image 5
Inlab1	2.56	4.00	6.44	7.19	8.19
Inlab2	5.88	6.12	7.94	4.29	3.76
Inlab5	3.18	4.71	5.76	7.29	8.12
Jan13AM	4.29	5.88	6.71	7.41	5.59
Rleaves	4.65	5.82	5.94	4.76	5.00

The experiment showed that there is a close relationship between the quality judgment and the parameters of the spectral color appearance model.

Analysis showed that the test persons prefer the enhanced color images to the images with less colorfulness. This corresponds to the results obtained by other studies.[4] However, a novel result was that the highlight (vividness) parameter has a maximum at some point.

Fuzzy Logic System

On the basis of the results obtained during the experiments, a Mamdani Fuzzy Inference System (FIS) using *min* and *max* for *T-norm* and *T-conorm operators* was synthesized.[3] It has two crisp inputs: Colorfulness and Vividness. These are presented by values αβ, and k, respectively. Output is Quality on a 1 to 10 scale. Since a crisp output value is needed, the obtained results are deffuzified. For the defuzzification method the centroid of area z_{COA} is used as follows:

$$z_{COA} = \frac{\int_z \mu_A(z) z dz}{\int_z \mu_A(z) dz} \qquad (5)$$

where $\mu_A(z)$ is the aggregated output membership function. The system is based on nine rules, which help to model the test persons behavior.

For the tuning of the system several shapes of membership functions for both input and output variables were tested. The experimental results have proven that 'bell' membership function yielded better results in an average case for the input variables and trapezoidal for the case of the output variable 'Quality'. Membership function plots are shown in Fig. 3.

These membership functions led to a three-dimensional overall input-output surface presented in Fig. 4. At that point we have received interesting results that correspond to those received in section Experiment. On the one hand, colorfulness parameter behaved as was expected, increasing monotonically. On the other hand, vividness produced a clear maximum on the output surface in the case of the images with small details of different colors (inlab1, inlab5).

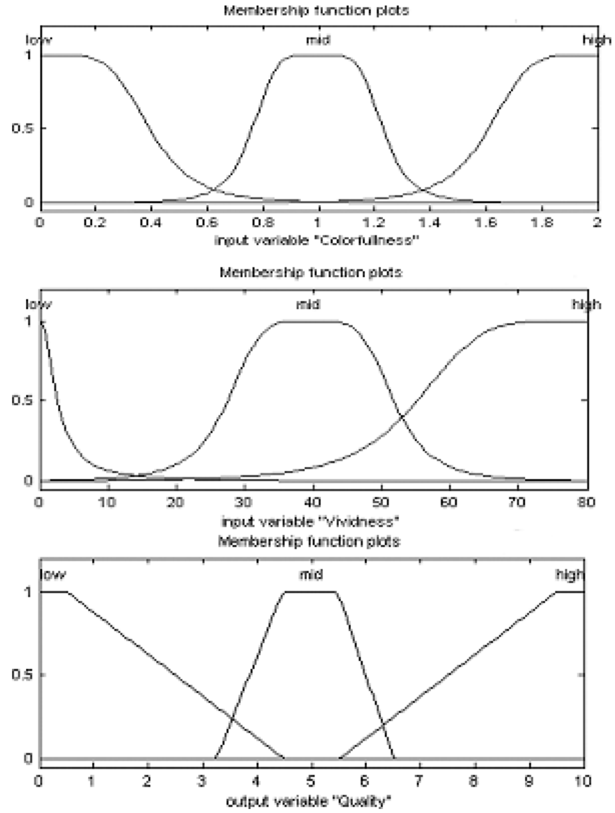

Figure 3. Membership function plots. Input variable Colorfulness, Vividness and Output variable Quality (from top to bottom)

An experiment similar to the one presented is given in Ref. [6], where a Fuzzy Expert System to facilitate the discrimination of the human observer qualities for the purpose of visual detection in gray level images was created. It was shown that the system behaved as expected for an average case.

Next, a test for the expert evaluation model using the designed system is discussed.

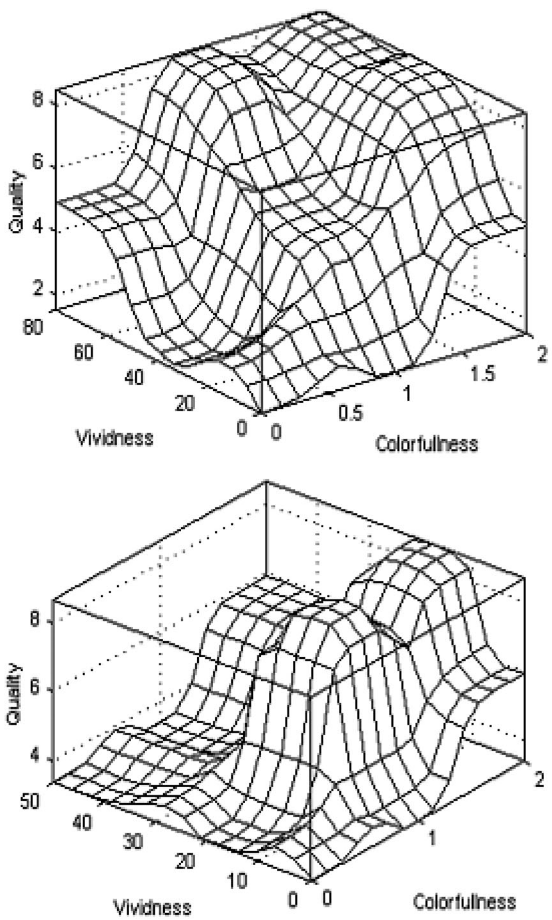

Figure 4. Overall input-output surfaces. inlab2, jan13am, rleaves (top), inalb1, inalb5 (bottom)

Table 3. Results of the Fuzzy Logic System Testing

Colorfulness	**1**	**2**	**3**	**4**	**5**
Inlab1	0.67	0.33	1.00	1.67	1.00
Inlab2	0.25	0.67	1.08	1.58	1.67
Inlab5	0.67	0.33	1.00	1.67	1.00
Jan13AM	0.75	0.67	1.08	1.33	0.92
Rleaves	0.50	1.33	2.17	2.92	2.58
Vividness	**1**	**2**	**3**	**4**	**5**
Inlab1	0.80	0.74	0.70	0.00	0.30
Inlab2	1.33	0.26	1.66	1.60	1.29
Inlab5	0.80	0.74	0.70	0.00	0.30
Jan13AM	0.94	0.05	0.32	2.66	1.08
Rleaves	0.39	0.21	1.34	1.05	0.21

Experimental Results

A set of tests was performed to prove that the described Fuzzy Logic System is capable of modeling the behavior of an expert in a quality estimation task.

The tests were done in the following manner: the FIS was rebuilt to incorporate the expert's judgments for all of the images except one. Thus, the new system evaluated four images out of five. Then, the parameters of the image, which was not left out, were input into the new system. The judgment predicted was substracted from the judgment, received using a full set of the original five images. Then a similar operation was performed on the four other. The obtained values are given in Table 3. Thus, each image one by one was used as a test image in a Fuzzy Logic System trained with the rest of the images. The procedure was performed for each of the parameters separately.

Each cell of Table 3 contains the value of the difference between the expert judgment and the judgments modeled in the test. Table 3 is divided into two parts. The upper part in Table 3 gives the results for the cas e when the vividness parameter remained constant and the colorfulness was varied. The lower part of Table 3 has a constant colorfulness and a variable vividness. In the first column, the name of the test image is given, and in the first row, the number of the image with modified parameters (see section Experiment) is given.

The results show that the proposed Fuzzy Logic System models the behavior of the human expert in a quality estimation task. The average error did not exceed ten percent of the judgments in an average case. To get a more accurate prediction of the image quality a larger training set is needed.

Conclusion

In this paper, a spectral color appearance model was considered. The model was used in color image quality estimation when a color image was reproduced from a spectral image.

A statistical spectral image model was used in the study. According to this model the highlight appearance in the image was closely related to the kurtosis value, and contrast and saturation were connected by the standard deviation. Varying the statistical parameters of the image a set of test images was obtained. The images were evaluated by twenty color-normal test persons. And the evaluation results were input into a Fuzzy Logic System.

To conclude, it is possible to say that test persons prefer more enhanced images to those with little colorfulness. However, in the case of highlights the behavior is not so straightforward. The quality values have a clear maximum at some point in the vividness variation. This means, that in human evaluation the optimal values of highlight in the image are neither the high nor the low.

The study has shown that the spectral-color relationship and Fuzzy Logic Inference were efficient in color image quality evaluation.

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Biographies

Diana Kalenova received the engineer degree in Information Technology in Economics from St. Petersburg State University of Telecommunications in 2001 and is currently doing her M.Sc. in Information Technology study at Lappeenranta University of Technology, Finland, in the framework of the International Master's Program in Information Technology. Her work is primarily focused on spectral image analysis, color appearance models, statistical characteristics of images and image quality issues.

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Timo Jaaskelainen received a Ph.D. degree in 1981 in physics from University of Joensuu, Finland. In 1991, he joined the Department of Physics, University of Joensuu, Finland, as an associate professor. Since 1994 he has been a professor in the same department. He is also the head of department. His research interests include optical material research, optical metrology, color research and information optics.