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AN ALGORITHM FOR UNDERSTANDING OF COLOR VISION

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ABSTRACT

Computing color of the surface is an independent model in computer vision. Perception of color is as important as motion, depth and shape in low level visual processing. Based on the coputational theory and Parallel Distributed Processing theory, a parallel algorithm for realizing subjective color vision (SCV) is presented in this paper.

The paper contains following sections: the computational theory for low level color vision is mentioned at first section; Then PDP algorithm of color vision is described. Finally we give the resultes of the experiments and discussions.

COMPUTATIONAL THEORY FOR LOW LEVEL COLOR VISION

Color vision is a visual mapping that carried with outside information by light wave. For any reflecting surface, the reflectance is its inherit character and regardless of the variety of incident light. If a reflecting surface has same reflectance to all components of light spectrum under an incident light that carried with wide-spectrum light, then we call the reflecting light is full of whole color and the color of surface appears grey. Oppositely if the surface has different reflectance for an incident light which contains a various wavelength, a sort of color will be appeared at the surface. Thus spectral reflectance is a source of the color and the light invariant will be hold. To calculate the relative reflectance of physical surface is main task for low level color visual processing.

Color constancy means that human color perception dose not depend upon various components of incident light. Strictly speaking, Color contancy is not existed everywhere but under some conditions the variety of amplitude to color perception by human is far less than the variety of components of incident light.

Several algorithm described color constancy has been developed before, for examples RETINEX by LAND [2] [3] and REGULARIZATION by POGGIO [4] [5].

The color vision is a typically ill-posed problem. To get a unigue answer several constraints is presented here.

C1: The light incident upon a physical surface is a wide-spectrum light. $\lambda \in (300, 700)$ nm for incident light $\mathbf{I}(x, y, \lambda)$.

C2: In the visual field of an animal, the distrbution of spectral reflectance of physical surface is nonuniform.

$$\mathbf{R}(x, y, \lambda) = \{\mathbf{R}(x1, y1, \lambda_o), \cdots, \mathbf{R}(xm, ym, \lambda_o)\} \cdots \quad (1)$$

for point (x, y), $\mathbf{K}(x, y, \lambda) \neq \text{Const}$.

here: $\mathbf{R}(x, y, \lambda)$ — illumination of reflecting light at point (x, y).

$\mathbf{K}(x, y, \lambda)$ — reflectance at (x, y).

$$\mathbf{K}(x, y, \lambda) = \mathbf{R}(x, y, \lambda) / \mathbf{I}(x, y, \lambda) \cdots \quad (2)$$

here: $\mathbf{I}(x, y, \lambda)$ — illumination of incident light at (x, y).

$\mathbf{K}(x, y, \lambda)$ represents a character of a physcial surface as well as light invariant in reflectance enviorment. We call $\mathbf{K}(x, y, \lambda)$ as absolute reflectance. For an animal only $\mathbf{R}(x, y, \lambda)$ projected on the retina is known and $\mathbf{I}(x, y, \lambda)$ can not be detected. The information source could only be used is

$$\mathbf{S}o(x, y, \lambda) = \mathbf{P}(\lambda) \cdot \mathbf{R}(x, y, \lambda) \cdots \quad (3)$$

here: $\mathbf{P}(\lambda)$ — effectness of detection.

C3: The maximum value is defined 1 and the minimun value is 0 in the set of relative reflectance. Any other value in the set is within range of [0, 1] under F mapping.

$$\mathbf{K}_{\lambda}(x, y, \lambda) = \mathbf{F}(\mathbf{R}(x, y, \lambda)) \cdots \quad (4)$$

here: $\mathbf{K}_{\lambda}(x, y, \lambda) \in [0.1]$

For wave-length λ_o and m points on the surface, the $\mathbf{K}$ set is : $\{\mathbf{K}(x1, y1, \lambda_o), \mathbf{K}(x2, y2, \lambda_o), \cdots, \mathbf{K}(xm, ym, \lambda_o)\}$

The total illumination of reflective light for any point on surface is:

$$\mathbf{R}w(x, y) = \int_{\lambda} \mathbf{R}(x, y, \lambda)\, d\lambda \cdots \quad (5)$$

The illumination set for m points is :

$\{Rw(x1, y1), Rw(x2, y2), \cdots Rw(xm, ym)\}$

After F mapping

$$Kw(x, y) = F(Rw(x, y)) \quad \cdots (6)$$

$$K = \{K_\lambda(x, y, \lambda), Kw(x, y)\} \quad \cdots (7)$$

K constructs a perfect description upon a physical surface. It was called relative reflectance.

Replacing $R(x, y, \lambda)$ by $So(x, y, \lambda)$ and $Rw(x, y)$ by $Sw(x, y)$, here: $Sw(x, y) = \int_\lambda P(\lambda) \cdot R(x, y, \lambda) d\lambda$, We get

$$K'(x, y) = \{K'_\lambda(x, y, \lambda), K'w(x, y)\} \quad \cdots (8)$$

just like formula (7). $K'(x, y)$ is called subjective color vision which is a inner repersentation of color for animal's nerve system and an expected result to our algorithm.

C4: The average value of total input energy is used to be a medium value tested in visual field.

C5: Absolute spectral reflectance is the upper limit of relative reflectance if and only if there exist a point which fully reflects incident light in a visual field.

PDP ALGORITHM FOR COLOR VISION

PDP theory developed by Rumelhart[6] explored the micro- structure of cognitive procedure and simulated human cognition on network layer.

The hypothesizes for using PDP model is reasonable opposed to the real mechanism of human eye perception and described as follows:

(1) PDP is a suitable technique to solve the color calculation problem.

(2) The input of the algorithm is wide - spectrum of incident illumination which contains rich details in the scene.

(3) The connections in same kind of cones are random and have large amount of number.

(4) There are three kinds of cones in human retina mediating our vision. The three calculation system in the human brain are procssed parallelly.

(5) As a result, three groups of relative reflectance are derived with same approach, from that the visual system constructs 300nm —800nm relative reflectance curve in order to realize color perception.

PDP network is organized as follows (Fig. 1):

Three layers: input, hidden and output. Each layer has 100 nodes which on both input and output layer and correspond to 100 points selected randomly in the scene.

Connected model is BP network. The connecting weigth is adjustable and initialized as

$$W1ij = W2ij = \begin{cases} rij \cdot rij & i != j \\ 0 & i = j \end{cases} \quad \cdots (9)$$

here: i, j — number of node. r ij — the distance of selected two points. d

$$net0i = \log 10(inputi) \quad \cdots (10)$$ for input layer.

$$net1i = \sum_{i,j=1}^{100} f(aoi - aoj - \theta) \cdot W1ij \quad (11)$$ for hidden layer

$$net2i = \sum_{i,j=1}^{100} W2ij \cdot aj \quad (12)$$ for output layer.

$$f(x) = \begin{cases} x & x>0 \\ 0 & x<=0 \end{cases} \quad \cdots (13)$$

The activation is given by

$$ai = 1/(1+\exp(-neti/T)) \quad (14)$$

For formula (10) to (14), netoi is output of i node at input layer. inputi is light illumination of i node inputed in scene. aoi, aoj is output of i, j node at input layer. θ is threshold value. W1ij is weight between input and hidden layer. a j is activation value of j node at hidden layer and W2ij is weight between hidden and output layer.

Formula (14) mapped set of input $(-\infty \ +\infty)$ to [0, 1]. here neti is input of node i and T is a constant.

Generalized δ role with teaching mode is used as learning role .

$$Wij(t+1) = Wij(t) + \Delta Wij(t+1) \quad \cdots (15)$$

$$\Delta Wij(t+1) = \varepsilon(\delta pi \cdot api) + \alpha \cdot \Delta Wij(t) \quad (16)$$

$$\Delta Wij(0) = 0 \quad \cdots (17)$$

For hidden unit

$$Wij = W1ij \quad \cdots (18)$$

$$\delta pi = api(1-api) \sum \delta pk \cdot W1ik \quad \cdots (19)$$

For output unit

$$Wij = W2ij \quad \cdots (20)$$

$$\delta pi = (Tpj - api)\, api(1-api) \quad \cdots (21)$$

From formula (15) to (21), here ε, α is constant. Tpj is expected output value for pattern P of i node . api is the active value for pattern P of i node.

Three networks are trained seperately with color R, G, B. They had same characters but weights differed.

EXPERIMENTS AND DISCUSSION

First we designed a psychophysical experiment on color constancy (Fig. 2) .

Mondrian collage is adopt as a scene of the experment[7] . The relative spectral distributions of incident light on the scene can be adjusted freely. Five persons with normal color sensation are chosen as subjects. They match respectively 16 colored blocks selected radomly from the scene with Munsell Book and the procedure is repeated with different incident light. We get the results 85.2% for average color constancy.

Second experiment is under simulation of computer using PDP.

Data can be orgnizeed as follows:

$\mathbf{I}(\lambda)$ — the spectrum distribution of light source.

$\mathbf{F}(\lambda)$ — transparency of color fielter ($\mathbf{F}$R, $\mathbf{F}$G, $\mathbf{F}$B).

$\mathbf{K}(\lambda)$ — relectance of color paper.

$\mathbf{P}(\lambda)$ — spectrum effectness of cones of human eye ($\mathbf{P}$R, $\mathbf{P}$G, $\mathbf{P}$B) .

Physical stimulation is

$$\mathbf{R}(\lambda)=\mathbf{I}(\lambda)\bullet\mathbf{F}R(\lambda)\bullet\mathbf{K}(\lambda) \quad (22)$$

$$\mathbf{G}(\lambda)=\mathbf{I}(\lambda)\bullet\mathbf{F}G(\lambda)\bullet\mathbf{K}(\lambda) \quad (23)$$

$$\mathbf{B}(\lambda)=\mathbf{I}(\lambda)\bullet\mathbf{F}B(\lambda)\bullet\mathbf{K}(\lambda) \quad (24)$$

The nerve representation of human to physcial stimulation is

$$\mathbf{R}'(\lambda)=\mathbf{R}(\lambda)\bullet\mathbf{P}R(\lambda) \quad (25)$$

$$\mathbf{G}'(\lambda)=\mathbf{G}(\lambda)\bullet\mathbf{P}G(\lambda) \quad (26)$$

$$\mathbf{B}'(\lambda)=\mathbf{B}(\lambda)\bullet\mathbf{P}B(\lambda) \quad (27)$$

For m points in the field, inputs to network are

$$\{\int\lambda\mathbf{R}'1(\lambda)d\lambda,\ \int\lambda\mathbf{R}'2(\lambda)d\lambda,\ldots\ldots,\ \int\lambda\mathbf{R}'m(\lambda)d\lambda\};$$
$$\{\int\lambda\mathbf{G}'1(\lambda)d\lambda,\ \int\lambda\mathbf{G}'2(\lambda)d\lambda,\ldots\ldots,\ \int\lambda\mathbf{G}'m(\lambda)d\lambda\};$$
$$\{\int\lambda\mathbf{B}'1(\lambda)d\lambda,\ \int\lambda\mathbf{B}'2(\lambda)d\lambda,\ldots\ldots,\ \int\lambda\mathbf{B}'m(\lambda)d\lambda\}; \quad (28)$$

Three kinds of wave-spectrum of incident light (long, middle, short band) were chosen to be the training set. Each of them projected at an known components of color paper. Applying known reflectance of ($\mathbf{R}$, $\mathbf{G}$, $\mathbf{B}$) of color paper as expected value to train the neuro-network. After training another three kinds of wave spectrum (long, middle, short band) of incident light are to be the testing set. Outputs of the neuro -network $\mathbf{L}$R, $\mathbf{L}$G, $\mathbf{L}$B were obtained while input values standed as formula (28) . The testing data and actual reflectance of the color paper were compared at table 1 . Two results of data is apparently closed each other.

Wherever the n point located and whatever the incident light was (but must be satisfied wide-spectrum) as far as same color at any two points then the output 3 dimensional vectors pointed unique location in color space. Average color contancy 92.07% was obtained by PDP model. The algorithm proved its similar with human perception of color.

REFERENCE

[1] D.Marr : 视觉计算理论, 姚国正, 1982

[2] Land E.H. (1986a), An alternative technique for the computation of the designator in the retinex theory of color vision, Proc. Natl. Acad. Sci. USA, 83, pp3078-3080

[3] Land E.H (1986b) , Resent advance in retinex theory, Vision Res., 26(1), pp7-21

[4] Hurlbert A. , Poggio T. A. (1988) , Synthezising a color algorithm from examples, Sciences 239, pp482-485

[5] Poggio T., Torre V. , et al(1985) , computational vision and regularization theory, Nature, Land. 317, pp. 314-319.

[6] D.E.Rumelhart, T.L.McClelland & the PDP Research Group: Parallel Distributed Processing, Volume 1: Foundations.

[7] Tao.L.M, Yao. G. Z. , et al IEEE Intel-national Symposium on ANN, Beijing, Oct. 1992.

Fig. 1 Model of BP network

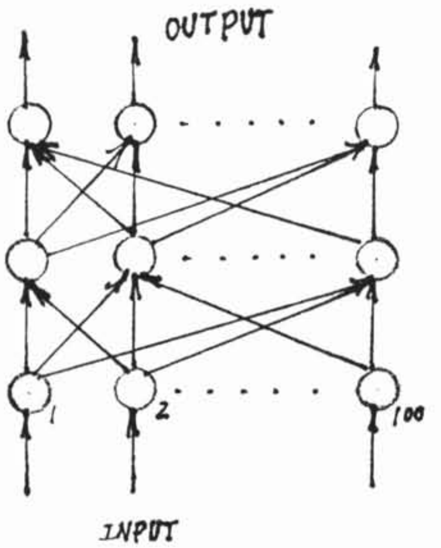
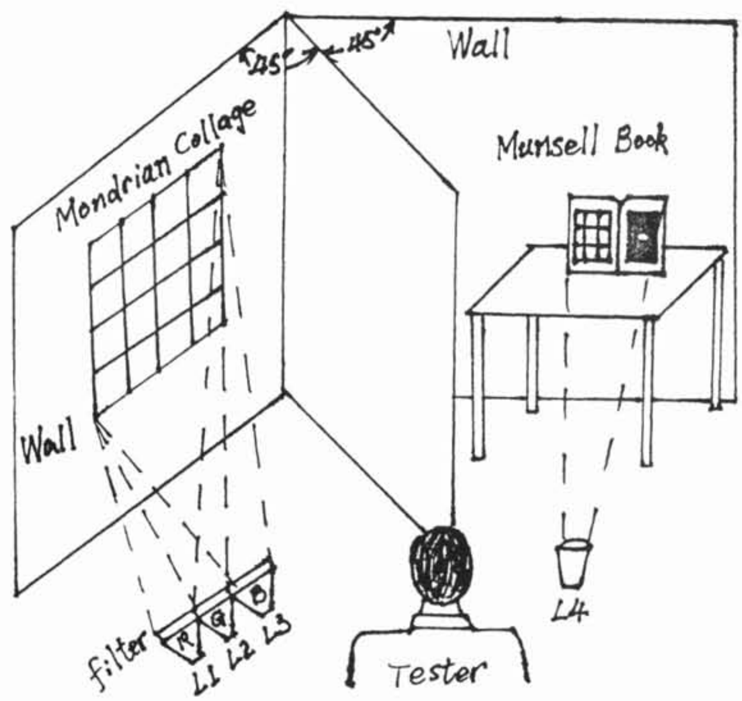


Fig. 2 Enviroment of experiment 2



Tab. 1 Comparing the results from calculation by PDP with actual data.

No.	Results of computation			Actual value		
0	0.089618	0.261096	0.437392	0.503354	0.503010	0.504486
1	0.376728	0.433664	0.652550	0.376785	0.433676	0.652587
2	0.003933	0.081389	0.107652	0.004001	0.081299	0.107782
3	0.564485	0.290698	0.196519	0.564449	0.290713	0.196501
4	0.027417	0.139999	0.563780	0.027665	0.139985	0.563802
5	0.000243	0.000003	0.000009	0.001168	0.001255	0.000798
6	0.498050	0.249868	0.004879	0.497382	0.249768	0.004187
7	0.144900	0.225659	0.586214	0.144980	0.225671	0.586236
8	0.693787	0.710160	0.007699	0.693647	0.710139	0.007748
9	0.732340	0.723275	0.000331	0.732275	0.723263	0.000925
10	0.000008	0.003007	0.319166	0.001109	0.003110	0.319073