A Color Vision System Using Density Profile of Human Cones/Rods

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Abstract

This paper deals with a robotic vision based on human color vision. This paper describes a system that simulates the human retina in the sense that it has cones for color reception and rods for birghtness sensation distributed at a non uniform spatial distribution over the retinal suface. In addition, our system removes the effect of brightness in order perception i.e. achieve color constancy which is the case with the human visual system.

Introduction

Currently, color vision is one of the most important areas of robotic vision development in various fields such as a mobile robots for outdoor navigation and for indoor navigation in a cluttered environmental such as offices or homes.

Basically, in robotic vision, to recognize an outdoor image, color information is not only a physical quantity, but also a psychological phenomena based on brightness constancy and color constancy. This suggests that a human-like robot color vision system should process data using subjective parameters. Although this problem is of great importance, only recently solutions based on human retinal color processing mechanisms have been proposed. A novel model for color vision, based on psycho physical evidence, is needed. This model makes use of some low-level processing technology to achieve a higher level color perception similar to that of the human.

In this paper, a human-based model for color vision is introduced. It has long been known that humans have two independent systems for light sensation in the retina. Historically, one system has been reported as a black and white system in which rod shaped photosensitive cells, in the retina, contain a pigment called Rhodopsin which is sensitive to achromatic stimuli of wavelength $\lambda \cong 500$nm. The other system is widely accepted as a color system in which three kinds of cone shaped photosensitive cells in the retina generate primary color sensations. These three kinds of cones are called the red cones(L cones), the green cones(M cones), and the blue cone(S cones). The reason being that each type of cones contains a certain type of visual pigment which is most sensitive to a certain wavelength; $\lambda \cong 575$nm for the red cones, $\lambda \cong 535$nm for the green cones, and $\lambda \cong 440$nm for the blue cones. In 1983, Dartnall et. al[1] proposed spectral response of the human eye using microspectro photometry.

Moreover, recent studies on the distributions of human and baboon retinal cones/rods have shown that their retinal cones/rods are mapped histochemically against visible light[2,3].

This paper describes a system that simulates the human retina in the sense that it has cones for color reception and rods for birghtness sensation distributed over the retinal surface according to a certain non uniform density distribution profiles. In addition, our system removes the effect of brightness in order perception i.e. achieve color constancy which is the case with the human visual system.

System Architecture

A block diagram of the new human-like color visual information processing system is shown in Figure 1. Figure 2 is a photograph of this system. The new system is composed of a normal lens (LENS), a neutral density filter (ND), an infrared filter (IR), two different classes of prisms (PRISM 1 and PRISM 2), four different bands of optical pass filters (SC 2, SC 3, SC 4 and SC 1), four monochromatic CCD cameras (R CCD CAMERA; a red component, G CCD CAMERA; a green component, B CCD CAMERA;a blue component, C CCD CAMERA;a component of visible light), and a controller(CCD CAMERA CONTROLLER).

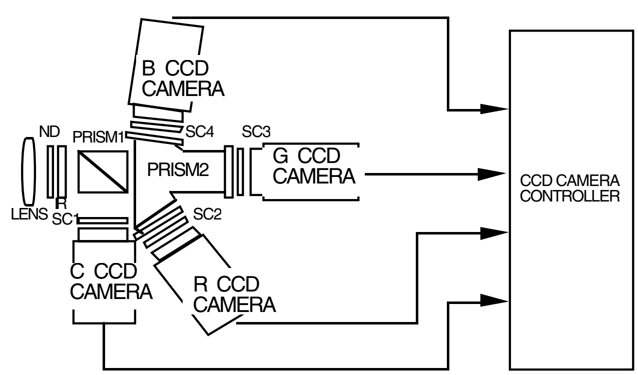


Figure 1. A new type of color information processing system based on human vision

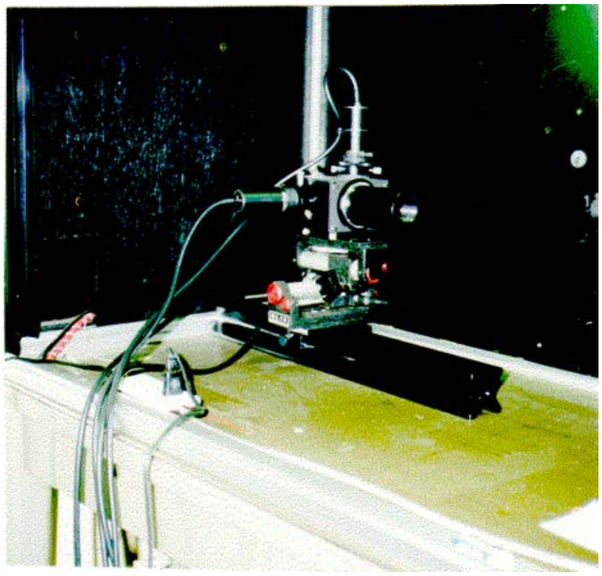


Figure 2. A photograph of this system

In Figure1, visible light passes through the lens, the neutral densisty filter and the infrared filter. Part of this visible light is reflected onto one of the four CCD cameras by Prism 1. The other part of this visible light is reflected onto the trichroic prism, Prism 2, which is used for color separation into R, G and B components. Each component is fed to a CCD camera using optical filters, each camera's spectral sensitivity is set to simulate the human retina spectral response to the correponding color component. After optical filtering, the spectral responses, *x(l), y(l)* and *z(l)* are in substantial agreement with the 1931 CIE color matching functions.

Figure 3 illustrates the spectral responses of this system after optical filtering through, the SC 2 ,the SC 3 and the SC 4 filters (see Figure1). The output signal from the C CCD camera in Figure1 represents the component of the visible light which is received by the rods of the human receptors. This component is the brightness component.

Each CCD camera has a resolution of 576(H)× 485(V) pixels and a 2/3× 2/3 inch picture size. The camera controller processes the outputs of the four CCD cameras R, G, B and C. The R, G, B cameras provide color signals while the C camera feeds the brightness signal to the camera controller.

The vision system is able to detect objects under photopic conditions ($1\text{-}10^{4}cd/m^{2}$) where only the cones are sensitive, mesopic conditions ($10^{-3}\text{-}1cd/m^{2}$) where both the cones and the rods are operational, and scotopic conditions ($10^{-5}\text{-}10^{-3}cd/m^{2}$) where only the rods are responding.

Figures 4 and 5 show the proposed vision system which is based on the human visual mechanism. Figure 4 shows the new concept of color vision system for robot vision. Figure 5 shows an architecture of the processing system. In Figure4, the Red CCD camera, the Green CCD camera, and the Blue CCD camera correspond to the L cones, the M cones, and the S cones, respectively. The C CCD camera in Figure4 corresponds to the rods of human retina. The color information is fed into the neuro board after being preprocessed according to a modified version of the opponent color theory[4]. The luminance signal from the C CCD camera is used to generate a brightness signal Bm which is composed of the luminance signal and a black and white(*Bk/W*) signal from the color components R, G and B. A feed-back loop exsists in the brightness generation system in order to allow the system to adapt to the luminance of the environment.

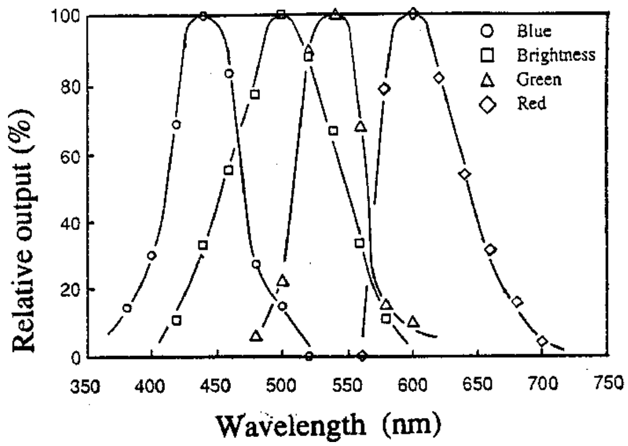


Figure 3. The spectral response of this system

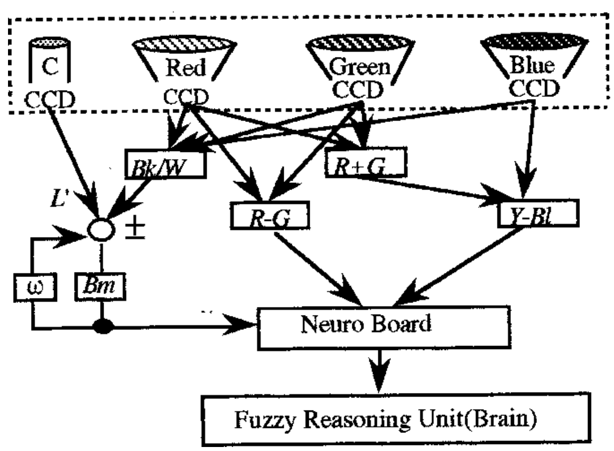


Figure 4.The new concept of color vision for robot vision

The neural visual model comprises three layers. The first layer, the input layer, consists of four CCD cameras (the visual cells), the second layer consists of a pre-processing unit, and the final layer consists of a neural board(horizontal cells, bipolar cells, etc.) for data-conversion which is explained in the following section. After the visual information has passed through the neural visual system, it is fed into a fuzzy reasoning unit(the brain.) for low-level processing which will be presented in a future paper.

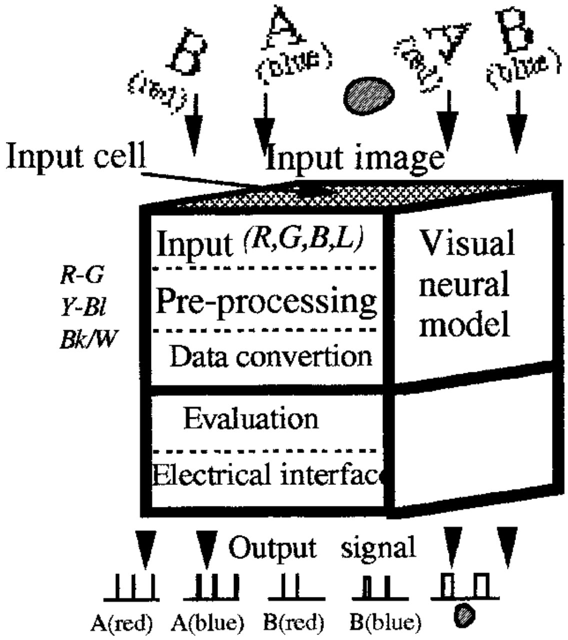
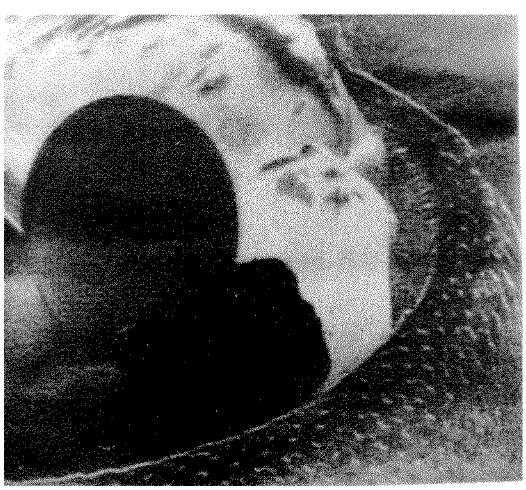


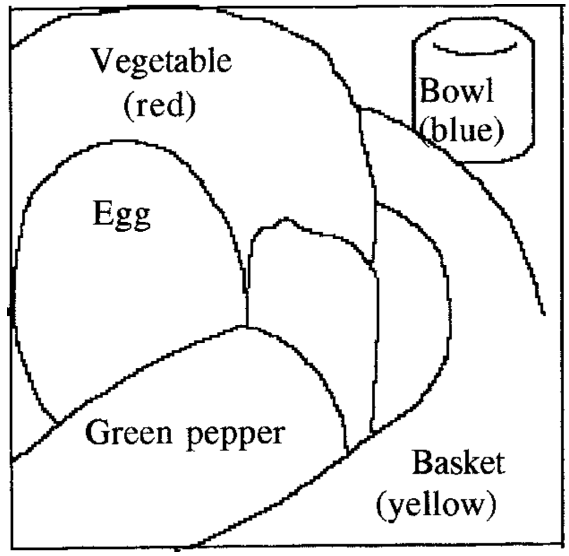
Figure 5. Visual parallel processing model

Experimentation

Figure 6 shows a colored image which was input to the system under different brightness levels (900lx, 564lx and 281lx). The output of the system when the brightness level was 900lx is depicted in Figures 7 A & B. The white component does not exist in the output which shows that our porposed system which is based on the modified opponent color model eliminates the effect of brightness on color information, thus achieving color constancy.

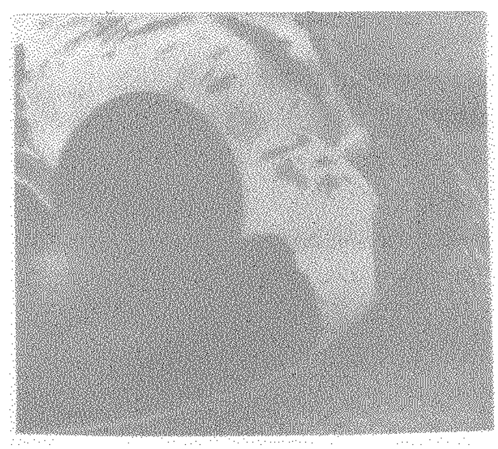


(a) Objects

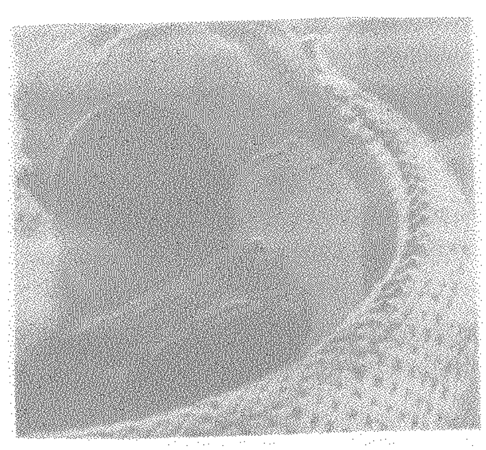


(b) Brief Explanatory Drawing

Figure 6. A Colored Image



(a) R-G Image



(b) Y-B Image

Figure 7. The output of the system

Data Conversion Based on the Cone Density Profile

So far, robotic color vision has been dealing with images of uniform spatial resolution while the rods/cones distribution over the human retina is not spatially uniform. There is a high population of cones is the fovea and the population decreases as the radial distance from the fovea increases.

Such systems with non uniform spatial distribution of receptors achieve high data compression ratios thus accelerating the processing. This is of utmost importance in case of color processing since each pixel has three values as compared with the case of grey level pixels. Recently, an advanced gray level vision sensor with high resolution fovea and a low resolution periphery have been implemented based on a distortion lens[5].

Many bioscientists have discribed the cone density profile for the monkey retina[6,7] and the human retina[8,9,10]. There is very little quantitative data for the profile in case of the human retina. However, it is widely accepted that the porfile for monkey retina is similar to that for the human. Marc[6] obtained a density distribution profile for cones.

Table 1. Each cone profile data from Marc's experiment

Degree(°)	S cones	L cones	M cones	Total
0	2.70	21.78	42.12	66.96
0.4	4.32	18.00	26.64	48.96
0.7	6.30	14.04	20.16	40.32
1.1	6.88	12.60	18.00	37.80
1.4	6.84	11.52	16.56	34.20
1.8	6.66	10.80	15.66	31.68
2.1	6.34	10.37	15.12	30.06
2.5	6.05	10.08	14.40	28.62
2.8	5.58	9.36	13.86	27.36
3.2	5.40	9.00	13.50	26.28
3.6	4.86	8.46	12.96	25.56
5.3	3.78	7.20	11.52	21.96
7.1	2.70	6.12	10.44	19.08
8.9	2.23	5.69	9.36	16.74
10.7	2.05	5.11	8.35	14.94
12.5	2.05	4.61	7.49	13.14
14.2	2.02	4.25	6.84	11.70
16.0	1.98	3.96	6.23	10.62
17.8	1.91	3.78	5.94	9.61
19.6	1.87	3.71	5.83	9.00
21.4	1.87	3.60	5.58	8.46
23.1	1.87	3.53	5.40	8.06
24.9	1.84	3.46	5.26	7.63
26.7	1.84	3.38	5.15	7.38
28.5	1.80	3.31	5.29	7.27
32.0	1.80	3.13	4.68	6.91
35.6	1.80	2.95	4.36	6.70
39.2	1.80	2.88	4.07	6.37

(Unit:1000cell/ mm^2)

Table 1 shows the data obtained from the Marc's graphs. The degree entry Table 1 denotes the distance (angle) from the fovea. The number of cells is expressed as cell per mm^2 devided by a 1000.

After that each cone distribution profile is obtained by applying the multi-regression analysis to Marc's data. These profile are shown in Figure8, each table shows the coefficients of the multi-regression analysis. From the multi-regression analysis, the relation between the number of cells and the distance from the fovea is given by the following formulas:

$$y_L=+8.915\times10^{-5}x^6-0.005x^5+0.093x^4-0.915x^3+4.605x^2+11.888x+21.515,$$

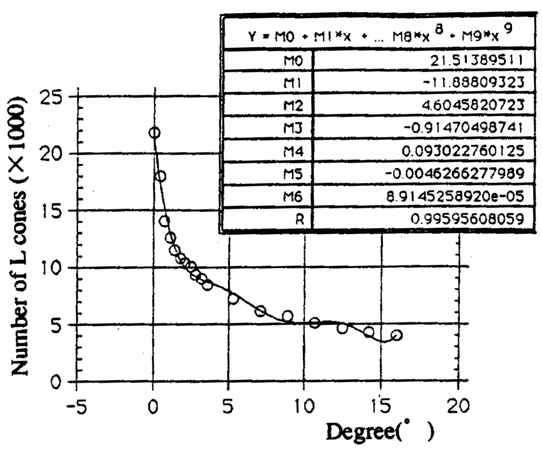
$$y_M=-2.346\times10^{-6}x^9+1.714\times10^{-4}x^8-0.005x^7+0.089x^6-0.897x^5+5.573x^4-20.968x^3+45.648x^2+53.485x+41.98,$$

$$y_S=-7.013\times10^{-7}x^8+5.199\times10^{-5}x^7-0.002x^6+0.027x^5-0.267x^4+1.57x^3-5.245x^2+7.976x+2.497,$$

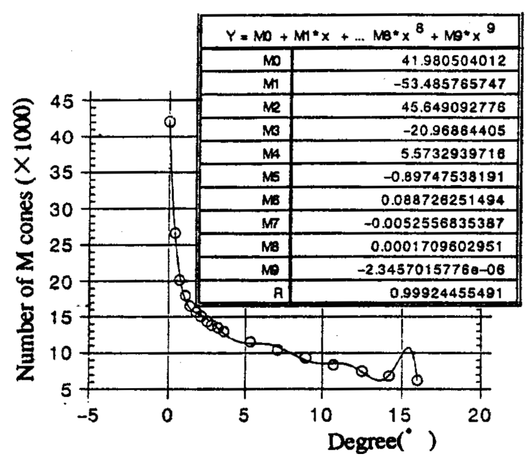
where, y_L, y_M and y_S are the number of L cones, M cones, and S cones, respectively, and x denotes the distance(degree) from the fovea.

Using the above equations, a preliminary experiment was performed to obtain images simulating those obtained by the primate's cones. Figure 9 shows these primary color images. (The images obtained by the L cones, M cones, and S cones, respectively.).

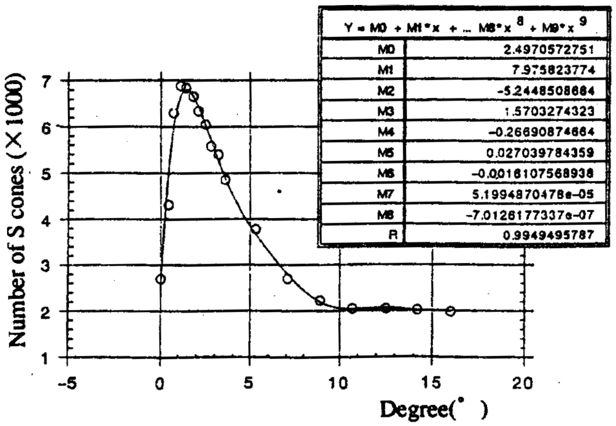
As a result, it can be concluded that the model presented here is a low-level model which would exist at the input layer of a robotic color vision system. How-



a. The results of the multi-regression analysis from L cones



b. The results of the multi-regression analysis from M cones



c. The results of the multi-regression analysis from S cones

Figure 8. The Results of Solution by Employing the Multi-regression Analysis from Marc's Data

ever, the research in this field is still at its infancy and the development is still ongoing in order to build a high performance color image processing system based on the processing done by the human eyes.

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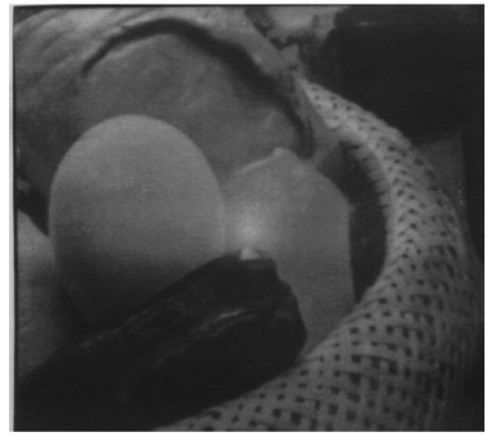
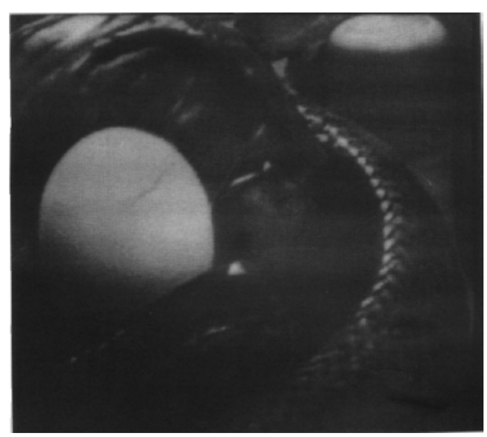


(a) L Cones

(b) M Cones



(c) S Cones

Figure 9. The results of the output images after the multi-regression analysis

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