Research on Improvement of Optical Model of Human Vision

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Abstract. In retrospect, visio-nal researches mostly focused on vision sensitivity. However, a vision model suitable to human eye shall be built to further explore human eye visio-nal characteristics. Most of the vision models in the fields of optometry and physiological optics must be modified to bring them more closer to actual human eye characteristics. While the aforementioned potential problem would not impede the visual capability of a person with normal eye sight, it tends to cause significant implication for a patient with retina illness during the initial syndrome and recuperation period after surgical operation. Under some special circumstances, such as in a battle field when lack of light is norm due to weather and landform conditions, human eye recognition capability would be significantly compromised as well. The CSF (Contrast sensitivity function) curve is proposed to be applied to the analysis in evaluating human eye recognition characteristics problems. this is the first literature to incorporate CS(con-trast sensitivity) correction into human vision multi-parameter model. The modified modeling is validated by the experiment results showing the modified model is closed to human eye’s CSF curve.

Keywords: human vision, contrast sensitivity, optical model, MTF

1. Introduction
To understand distributional features of human eye contrast sensitivity, three types of environments, photopic, middle and scotopic, are analyzed alongside with different spatial frequencies (3, 6, 12, 20cpd) to calculate contrast, sensitivity’s trending curve. Modified factors are incorporated to make the improved human vision multi-parameters model more attuned to actual vision characteristics. Thanks to technology’s evolution and progress, the circumstances of human vision exposed to outer environment are getting more and more complicated. Not a few researches demonstrate the intimate relationships between human eye contrast sensitivity and retina functions [1-3]. Furthermore, some deterioration on retina or eye functions cannot be effectively identified through traditional eye sight tests [4-6]. Under extremely hostile environment, impact from contrast sensitivity has a substantial consequence on vision capability. As such, contrast sensitivity has become a hot research topic lately. This paper consists of four section, Section 2 of the paper explores human vision multi-parameters model and contrast sensitivity. Section 3 compares the human recognition and draws some the experiment result. Section 4 discussion and summarizes conclusions about the results.
2. Method and Experiment

Normally, eye vision test is performed by measuring the spatial recognition capability on tiny object for human eye’s macular fovea. This test method’s effectiveness is limited even though it is simple, accurate, standardized and still popularly adopted to this day. Using vision capability chart only to assess vision function is simply not comprehensive enough, especially under hostile environment where identifying objects with contour is not a maximum limit of criteria of importance. Under this scenario, contrast sensitivity’s physics of optics is much more of relevance to vision capability assessment.

CS assessment takes CSF (Contrast sensitivity function) as benchmark to investigate the recognition capability of human eye on spatial frequency sine-grating under varying brightnesses between observed object and background. With vision function more comprehensively understood, CSF serves as an ideal indicator to evaluating vision capability. This paper explores the human eye vision multi-parameters model and incorporates CS factors into system modeling without precedent. Its results can serve as good reference for future researches on vision capability under various hostile environments.

2.1. Development of the human vision multi-parameter model

In the earlier human vision model [7,21-22], when light enters the eye, the photon's brightness signal is detected by the eye's optical transfer function MTF (M_{opt}), and then filtered by the modulation transfer function MTF (M_{lat}) of the horizontal suppression process, assuming that the optical transfer function MTF (M_{opt}) is determined by the discrete structure of the lens and the retina, while the laterally inhibited modulation transfer function MTF (M_{lat}) is determined by the nerve conduction pathway. Figure 1 shows the architecture diagram of the model. In order to describe the human vision and transmission behavior more completely, internal noise, external noise and integration characteristics, is added to the figure.

MTF is the optical transfer function of the human eye, and CSF is the contrast sensitivity function of the human eye. The trends between the two are the same, but because CSF is affected by lateral inhibition, the curve of CSF has an inversion at low spatial frequencies, while MTF There is no reversal.

Consider the factors of both eyes and adding the correction of (\sqrt{2}), the CS_{eye}(f) of the human eye model is finally derived [23-24], as shown in Eq. 1.

$$CS_{eye}(f) = \frac{1}{k^2} \frac{M_{opt}(f)}{2F \left( \frac{1}{X_0^2} + \frac{1}{\eta T} + \frac{1}{N_{max}} + \frac{f^2}{N_{max}} \right) \left( 1 + \frac{\Phi_0}{\eta p E} \right)}$$

(1)

The definition and description of various parameters are as follows:

- \(M_{opt}(f)\): the optical MTF,
- \(k = 3\): signal-to-noise ratio,
- \(f\): spatial frequency,
- \(T = 0.1s\): integration time of the eye,
- \(\eta = 0.03\): quantum efficiency of the eyes,
- \(p\): photon conversion factor in the light source,
E : the retinal illuminance (troland),
X0: angular of the object,
X_{max} = 12°: maximum angular-size of the integration area,
N_{max}=15 cycles: maximum number of cycles that the eye can detect information,
Φ0 = 3 × 10^{-8} sec deg^2: spectral-density of the neural noise,
f_0 = 7 cycles/deg: spatial frequency of the lateral inhibition.

2.2. Improvement of human vision multi-parameter model
The contrast sensitivity factor of the human eye is added to the human eye multi-parameter model experiment, considering the difference in the contrast sensitivity of the human eye to low frequency or high frequency, therefore, four different spatial frequency from low to high are defined in the experiment (3, 6, 12, 20 cyc/deg) to obtain the correction factor of contrast sensitivity.

One hundred observers who participated in the experiment watched four different spatial frequencies (3, 6, 12, 20 cyc/deg) on the monitor, and the observer’s position was about 2.5 meter from the screen (SONY 50-inch monitor), the age of the observer is between 22 and 24 years old (the experimenter's corrected visual acuity is greater than 0.8).

Observers must make judgments for all randomly appearing images, even when image recognition cannot be determined. The time interval required for observer recognition and the result of the judgment are recorded.

Monitor background brightness setting is 34 cd/m^2 (Brightness scale : 45, Contrast scale : 0) · test-object gray level= 0 · background gray level= 255 · The brightness of direct light projection is 100 lux at photopic condition. Have observer face monitor and they are untested eye covered. Use matlab to generate black and white band, consisting of four rows of vision objects, each of which are composed of 16 black and white bands. CS at left-most hand one has maximum value, the rest 15 bands’ CS values decrease gradually. All tests are conducted by evaluating right hand eye first. CS values at photopic, middle and scotopic vision conditions are tested respectively. The experiment is shown in Fig. 2, left and right hand eyes’ spatial frequency CS average presented in Table 1, binocular CS average and CS normalized are presented in Table 2 and Table 3.

Fig. 2 Diagrammatical representation of the contrast sensitivity factor experiment

| Environments eyecyc/deg | 3   | 6   | 12  | 20  |
|--------------------------|-----|-----|-----|-----|
| Photopic                 |     |     |     |     |
| Right                    | 1.55| 1.78| 1.47| 1.09|
| Left                     | 1.55| 1.77| 1.49| 1.08|
| Middle                   |     |     |     |     |
| Right                    | 1.41| 1.60| 1.28| 0.75|
| Left                     | 1.41| 1.59| 1.23| 0.72|
| Scotopic                 |     |     |     |     |
| Right                    | 1.41| 1.50| 1.07| 0.68|
| Left                     | 1.40| 1.51| 1.09| 0.72|

CSs Show maximum values at middle spatial frequency among three environmental eye distributions, three are no substantial differences between left and right hand eyes’ average CS values under photopic, middle and scotopic environments. (p-value > 0.05 after variant analysis).
| Environments | eye(cyc/deg) | 3   | 6   | 12  | 20  |
|--------------|-------------|-----|-----|-----|-----|
| Photopic     |             | 1.55| 1.78| 1.48| 1.09|
| Middle       |             | 1.41| 1.60| 1.26| 0.74|
| Scotopic     |             | 1.41| 1.51| 1.08| 0.70|

Table 3 Binocular CS normalized total average comparison in different spatial frequencies

| Environments | eye(cyc/deg) | 3       | 6       | 12      | 20      |
|--------------|-------------|---------|---------|---------|---------|
| Photopic normalized |             | 0.87    | 1.00    | 0.83    | 0.61    |
| Middle normalized     |             | 0.79    | 0.90    | 0.71    | 0.42    |
| Scotopic normalized     |             | 0.79    | 0.85    | 0.61    | 0.39    |
| Total average(CS factor (‘z’ )) |             | 0.82    | 0.92    | 0.72    | 0.47    |

CS values exhibit decrease trend under photopic, middle and scotopic vision environments, except low (3 cyc/deg) and high (20 cyc/deg) frequencies where CS values show no significant differences between middle and scotopic environments, the rest scenarios demonstrate substantial differences (p-value < 0.05 after variant analysis).

The CS normalized curve-fitting (Fig. 3 and Eq. 2.) was observed for different spatial frequencies degraded by decreasing illuminance and contrast.

![Graph](image)

**Fig. 3 CS normalized curve for different spatial frequencies**

\[ z = \left[ 1.29(1 - \frac{0.915}{\ln(x)}) \right]^2 \] (2)

The “x” values are as follows:
- x = 22: spatial frequency is 3 cyc/deg,
- x = 32: spatial frequency is 6 cyc/deg,
- x = 15: spatial frequency is 12 cyc/deg,
- x = 7: spatial frequency is 20 cyc/deg.

3. Results and Comparison

The experimental design uses 4 black-white bands with an aspect ratio of 7:1, and the background is a fixed brightness. Each test target uses the Matlab program to generate an image, and displays it in a random position on the monitor during the experiment, and records the observer's image. The ratio that can be correctly identified, the experimental equipment is shown in Figure 4, including screen display (SONY, 50 inches), computer workstation (HDMI interface card, 500 W power-supply) and Minolta spectrometer (CS-1000). Observe low-frequency images with both eyes, the viewing angle is 19°×14° (horizontal and vertical), and the observation distance is 72 cm. When the observation distance of other frequency images is 324 cm, the field of view is 4°×3°. [7-20].
First select a specific spatial frequency, gradually reduce the contrast and continue each experiment. Table 4 shows the test parameter settings and experimental results. Figure 5 shows the comparison between the experimental results and the theoretical model of human vision (the square points represent the experimental value, and the continuous curve represents the theoretical model of human vision).

Table 4 Test parameter settings and experimental results

| Spatial frequency (cyc/deg) | View angle | Monitor size | Background brightness | Test times |
|----------------------------|------------|--------------|-----------------------|------------|
| 0.5, 0.8, 1 (Low frequency) | 19° × 14° (Low frequency observation distance 72cm) | SONY, 50 inches | 10 ft-L (34 cd/m²) | 12,000 times (100 observation) |
| 2, 3, 5, 6, 7, 8, 9, 10, 20 (Other frequency) | 4° × 3° (Other frequency observation distance 324cm) | Monitor setting (Matlab windows is max.) | Brightness : 45, Contrast : 0 | Background gray-level = 255 |

**Experimental results : Gray-level and CS**

| Background brightness (cd/m²) | Spatial frequency (cyc/deg) | CS | Gray-level of target |
|------------------------------|-----------------------------|----|----------------------|
| 34 cd/m² (Gray-level = 255)  | 0.5                         | 0.68 | 240 |
|                              | 0.8                         | 0.78 | 241 |
|                              | 1                           | 0.84 | 242 |
|                              | 2                           | 0.89 | 243 |
|                              | 3                           | 0.93 | 244 |
|                              | 5                           | 0.96 | 245 |
|                              | 6                           | 0.96 | 245 |
|                              | 7                           | 0.93 | 244 |
|                              | 8                           | 0.89 | 243 |
|                              | 9                           | 0.78 | 241 |
|                              | 10                          | 0.68 | 240 |
|                              | 20                          | 0.42 | 233 |

Fig. 4 Diagrammatical representation of the experiment
Fig. 5 Comparison of results obtained by the human vision experiment values with those obtained by the human vision multi-parameter CS correction model

4. Summary
The depth and breadth that should have been covered in this paper by no means could not be contemplated. Fortunately, three types of CS in photopic, middle and scotopic are duly investigated to analysis the varying trend of CS and spatial frequency statistically. The author takes the initiative to modify human vision multi-parameter correction model by incorporating CS factor into the system. The modified modeling is validated by the experiment results showing the modified model is closed to human eye’s CSF curve. The research results can be a valuable reference for subsequent research in optometry and physiological optics.

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