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Research Article

A Reticule Design to Enhance the Detection Range of a Telescope for Moving Objects

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Abstract

In this work a stationary opto-mechanical reticule is designed to be utilized with a terrestrial telescope to improve its detection range for moving objects. The design calculations based on the psycho-physical characteristics of the human eye. The results obtained show that the optimum ocu-reticule co-performances may be obtained for the case where the object angular velocity fluctuates between (10^{-2} rad/s) and ($5*10^{-2}$ rad/s), or may be extended with certain limits , to a decade more or less than the pronounced value .

Keywords: *Reticule Design, Detection Range etc.*

1. Introduction

The purpose of an optical instrument is to improve the performance of the eye by improving the details perceived in the observed scene especially under low contrast. Some magnification of the object makes it easily identifiable but the field of view is usually reduced in proportion. If magnification exceeds the diffraction limit no further enhancement of details is possible. In any optical system design the magnification has to be considered with all other interdependent factors which often lead to a compromise. In general, relatively lower magnifications and larger fields of view are used for surveillance instruments, whilst relatively higher magnifications and smaller fields of view are necessary for target acquisition. However, the question now is, for an optical design of a telescope, is there any probability of enhancing its detection range? The answer may be given in the following theoretical proposal in this paper.

2. Theory

Considering the visual system as a part of a communication system, the transfer, spatial, and temporal characteristics are the most important parameters of interest, while the noise of the system , usually , considered next in importance where in conjunction with the other parameters , sets the limits on the system performance. The study of these parameters is usually based on psychophysical concepts.

2.1. Human eye response to luminance

The transfer characteristic of the visual system, that is, the dependence of the brightness on the stimulus luminance, is called the brightness function. It is strongly depends on the adoption level, its time duration, and on the object field size. But it is little influenced by the wavelength and location on the retina (Mansfield,R.J.W.1973)

In the lowest luminance levels, to about ($2*10^{-6}$ cd m^{-2}), the response is almost linear, while at higher levels, the response varies roughly with (1/3) power (Cornsweet T.N.1974)

The dependence of absolute threshold on the object size is given by Ricco's law(Campell F.W. and *et al* 1966), which states that the threshold luminance, (L), varies inversely with the solid-angle, (Ω),subtended by the object, at threshold i.e,

$$L\,\Omega = \text{constant} \tag{2-1}$$

This relation is true for objects of angular subtend well below (1 degree) while objects of angular subtend (1 deg.)

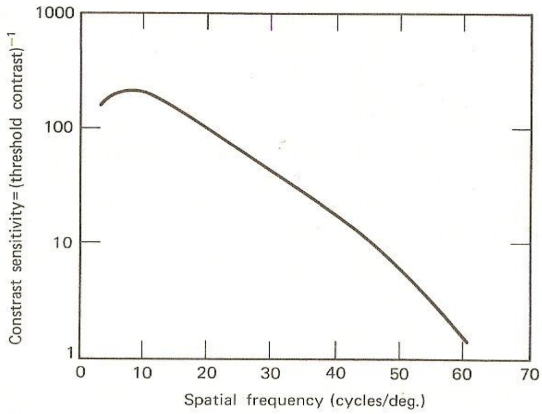

Fig.(1) Human eye Contrast Sensitivity {After Ref. (De Valois R.L .et al 1974) }

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or more Piper's formula is applied, which is given by :(at threshold)

$$\sqrt{\ } L\ \Omega = \text{constant} \quad (2\text{-}2)$$

Similarly, the product of flux (Φ) and view time (t) show a reciprocal relationship, i.e.

$$\Phi\ t = \text{constant} \quad (2\text{-}3)$$

2.2. Spatial Characteristics

In the optical stage diffraction, aberration, and scattering contribute to the spreading of the light in the retinal image of a point source. The total diameter of the point spread function , (PSF) for white light , and a pupil diameter of (2mm) ,is found to be approximately one arc minute ,while it almost equal to the Airy disc (Fry, G.A.1970). However, for this case, about half of the image flux falls within a radius of (1.2mm) of point source image. The radius is doubled for a (6.6mm) pupil diameter (Rodgers A.L. *et al*,1983).

Spatial threshold performance of an optical system is usually stated in terms of resolution. It is the system ability to separate or resolve two close objects, that is, to recognize them as two. In vision, the term acuity is often used instead .The visual acuity of the eye is a measure of its ability to perceive details in a scene and it is the ophthalmic analogue of the resolution. Acuity is defined as the reciprocal of the visual angle subtended, at the eye, by the resolved object details. When the visual angle is measured in minutes of arc, the reciprocal is called decimal acuity(Levi, L.1980).

Fig. (1) shows the contrast threshold as a function of the spatial frequency for different luminance levels (Campell, F.W.1968).

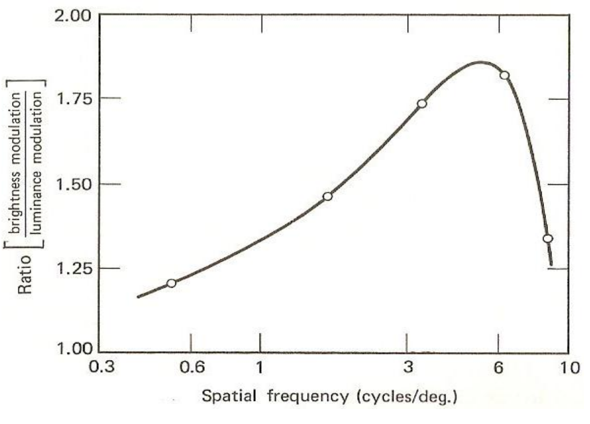

Fig.(2) Brightness-to-Luminance Ratio {After Ref. Patel, A.S.(1966)}

The reciprocal of the threshold contrast is called the contrast sensitivity .It represents the spatial frequency response of retina-brain section of human visual system (Patel, A.S.1966), that is, the optical transfer function, (OTF), of the visual system.

Contrast sensitivity maximizes at (1-6 cycles/deg.), fall off at lower frequencies due to ocular and at low frequencies due to aberrations, diffraction, and finite receptor size, Fig. (2).

2.3. Temporal characteristics

The frequency, of periodic signals, at which the flicker ceases to be perceptible, is called the critical flicker frequency (CFF).The flicker phenomenon is often described by means of de-Lange curve, which show the threshold modulation as a function of (CFF), Fig.(3) (De Valois R.L .et al 1974). At intensity levels above (0.5 Td) these curves start at a threshold modulation of (0.6-0.7) at low frequencies, rise to a peak somewhere between (5 & 20 Hz) and then drop rapidly.

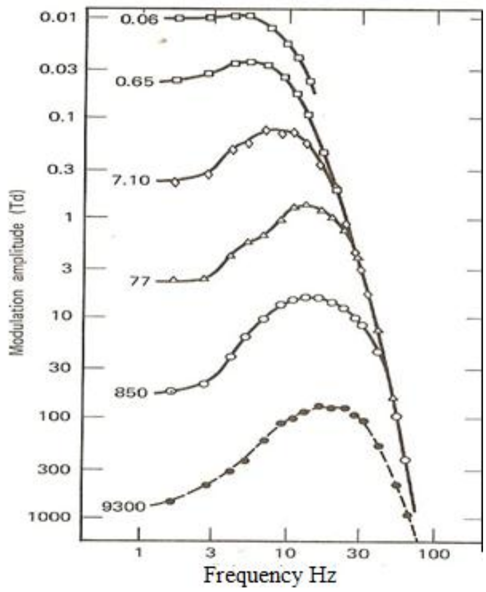

Fig (3) Threshold Modulation as a function of CFF .{ After Ref. (De Valois R.L .et al 1974) }

The frequency response of the visual system is another characteristic of spatiotemporal behavior, signals varying sinusoidaly both in time and space. Suprathreshold experiments showed that at low frequencies (~ 2Hz) the perceived modulation of sinusoidal luminance pattern was more than two folds. While at (~ 5Hz) it appeared to be equal to that of the steady pattern, and at (10-20 Hz) it dropped to about half this value (De Lange , H.,1958).

Ocular motion is another important example of the spatiotemporal interaction where any motion of the eye, while viewing a bar pattern ,resulting in image motion across the retina will translate the spatial pattern into a temporal one .The eye's motion prevents the fading of the image, which quickly disappears when it is stabilized on the retina .The coupling between spatial and temporal effects introduced by the eye motion optimizes the visual response to luminance fluctuation and the ocular scanning may contribute to edge enhancement(Kelly,D.H.1961).

2.4. The Spectral Characteristics

A representative curve of the change in wavelength, required to make the difference just noticeable, is plotted as a function of wavelength in Fig. (5) (Hilz ,R. *et al* 1970) It shows that the maximum sensitivity appears, mainly at the wavelengths (0.49µm) and (0.59µm) and also at (0.44µm).

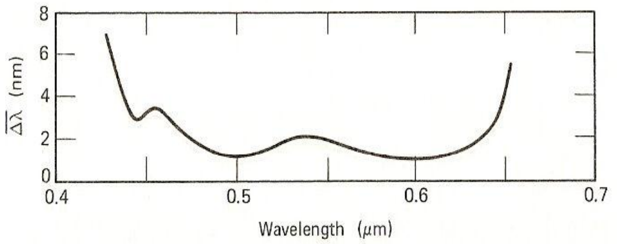

Fig (5) Human s eye Spectral Sensitivity. { After Ref. Hilz ,R. et al(1970) }

3. Utilization of a Reticule in a Telescope

A reticule is an opto-mechanical chopper, occasionally it referred to as an episcotister (Biberman,L.M.,1966).It suppresses unwanted signal from the background of the object scene by converting a DC-signal to an AC-one, that is, improving the signal–to– noise ratio .The use of a reticule to increase the detectability of a particular target in the presence of extraneous background details is called spatial filtering. This type of filtering is used to enhance the signals from object of larger subtending angles. The reticule is placed at the image plane of the optics ,and its center coincides with the optical axis .There must be a relative movement between the reticule and the object's image .Therefore two types of reticules may be used to initiate this relative motion, a rotating reticule or stationary reticule.

The movement of the object across the spatial patterns of the reticule creates temporal frequencies while improves the eye response, within certain limits, and an enhancement in the detection range of the overall optical system is expected.

3.1. A Suggested Design for a Reticule Pattern

A suggested reticule pattern designed for a tripod binocular terrestrial telescope is descried below. Its field of view (7deg.) and focal length (280mm), that is, the image plane diameter is about (34.25mm). A proper reticule pattern for this case is of a concentric annular circles Fig.(6). These annular circles are divided into three groups of different spatial frequencies which are successively increasing toward the reticule center.

The external group consists of five concentric circles of one millimeters width for each of them. they are ordered in pairs, from the external circle toward the center, alternatively, as a transparent –semitransparent annular circles are made yellowish,the complement of the blue color, where the sensitivity for the eye , at these wavelengths at ,the low spatial frequencies, is the best as indicated in Fig.(3). The spatial frequency is made to be (2.5 cycles/deg.) (or 0.5 cycles/mm). The spatial frequency of this the intermediate group is doubled (5 cycles/deg). Similarly the internal group spatial frequency is (6.25 cycles/deg).

3.2. The Temporal Frequency Calculations

If the object under investigation crossing the scene at an angular velocity, ω, then the temporal frequency υ^t , results from crossing the image reticule's annular rings, can be estimated using the relation (Ali,R.N.,2004).

$$\upsilon^s \; f \omega = \upsilon^t \qquad (3\text{-}1)$$

where f is the focal length and , υs, the spatial frequency of the reticule, for each group of its annular rings.

The temporal frequencies produced at external group of the annular circles (υs=2.5 c/deg.) varies from (1.4 Hz for ω=0.01rad/s.) to (14 Hz for ω=0.1rad/s.). For the intermediate group (υs= 5 c/deg.), the temporal frequencies fluctuates between (2.8 Hz for ω=0.01 rad./s.) and (33.6 Hz(for ω=0.1 rad./s). Finally the calculated temporal frequencies for inner group of the annular rings (υs =6 c/deg.) fluctuate. between (3.4 Hz for ω=0.01 rad/s) and (17 Hz for ω=0.05 rad/s).

Fig.(6). The reticule design

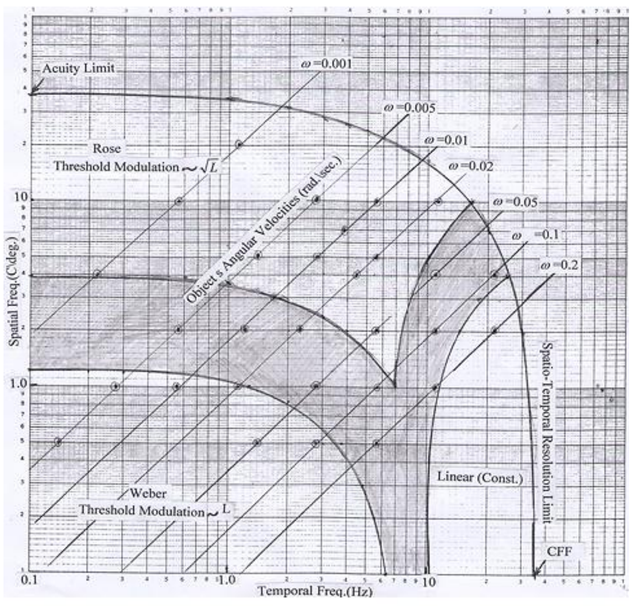

Fig.(7) The applicable range of the targets angular velocities

The spatial frequencies have been selected to fit the band of the best spatial response of the eye, that is (1-6) cycles per degree. Consequently the temporal frequencies obtained fluctuate between (1.4 Hz and 16.8 Hz) in the range of angular velocities of (10^{-2} rad/s) to($5*10^{-2}$ rad/s). However the best response of the eye to the temporal frequencies (2-5 Hz) and the critical flicker frequency is about (20Hz).

4. Discussion

The results obtained in this work are utilized in a suggested design of a reticule pattern that can be applied to terrestrial or astronomical telescopes to improve their detection ranges against moving objects.

The reticule design is illustrated in Fig. (6). Calculations of the spatial and temporal frequencies results utilized in this reticule are summarized in Fig. (7). the device performance against moving objects can be deduced from this figure. The ranges of object's angular velocities that expected to induce the optimum performance of the eye-telescope system fluctuates between (5*10-2 rad/s) and (10-2 rad/s). The best performance may be obtained at the angular frequency (2*10-2 rad/sec), where spatial frequencies of (1 to 6 c /degree), the optimum response of the human eye, produce temporal frequencies of (1.12 Hz) to (6.72Hz) . This is approximately fulfills the requirements of the human–eye response to the temporal frequencies (2-5Hz).However, one may work properly in the spatial frequency range of about(1-8 c/deg), and temporal frequency range of about (1-9Hz). It can be seen from Fig (7) that these frequency ranges located at the Rose region of the threshold – luminance relationship, that is threshold modulation is proportional to the square root of the object luminance. The relation between the ratio of the brightness modulation to luminance modulation, and the spatial frequencies is illustrated in Fig (2), which shows that the best ratio , takes place at the spatial frequency (6 cycles/degree) , is about (1.8).

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