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A TECHNIQUE FOR VISUAL DETECTION OF DISTANT OBJECTS IN SPACE BY USE OF OPTICAL FILTERING

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A TECHNIQUE FOR VISUAL DETECTION OF DISTANT OBJECTS IN SPACE BY USE OF OPTICAL FILTERING

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SUMMARY

A new technique is described for visually detecting and identifying distant objects in space by using only sunlight reflected from the target and optical filtering. Visual target enhancement is achieved (without the aid of onboard artificial illumination) by a set of optical filters which cause the target to blink against a nonblinking background. Several optimizing conditions for visual target detection using this technique are discussed.

Results of experimental studies indicate that such a filter technique would allow detection in the sunlit regions at target luminance levels of the order of fourth and fifth magnitude, where beacon power requirements for equivalent illumination are large, and would permit detection independent of target angular motions.

INTRODUCTION

One matter of prime importance in future space missions is the knowledge of what the astronaut will be able to detect visually in space. In particular, it is important to know at what distance (or luminance level) an astronaut can detect visually and identify a target body in space when the target is at such a distance as to appear as a point source of light. For example, in the terminal phase of a visually controlled rendezvous between two space vehicles, target detection is required to control the line-of-sight rate for proper closure between the two vehicles.

Various procedures have been suggested as possible means of visually detecting and identifying a point-source target in space. These procedures make use of

(1) A human's ability to detect the relative motions of a target with respect to a star background

(2) Target color (i.e., chromatic difference between target and star background)

(3) A flashing beacon onboard the target body

This report describes a new technique for visually detecting and identifying distant objects in space by using only sunlight reflected from the target and optical filtering. The filtering technique permits detection of stationary (or nonstationary) sunlit targets which are at such luminance levels as to appear achromatic (colorless).

In the present investigation, basic studies were conducted to determine the technical feasibility of the optical filtering technique. Thus, the tests were not performed as a precise psychological experiment. Also, readily available equipment was used in the studies without a rigorous attempt being made to choose the apparatus so that the filter technique would be optimal. These tests determined man's ability to detect visually a colored point-source target (luminance levels of second to seventh visual magnitude) against a celestial-body background by using two particular combinations of transmitting and obscuring filters as a visual aid. Six engineers served as observers.

PRINCIPAL OF FILTER TECHNIQUE

Visual detection and identification of a point-source target in space is achieved by making the target appear to blink against a nonblinking star background. This sensation is accomplished by viewing the search area (which contains the target) through a particular optical filter, with the result that the target body's light is obscured by the filter while the star background is transmitted. Another filter transmits both the star background and the seemingly achromatic point-source target. Thus, by viewing the search area alternately through the "transmitting filter" and the "obscuring filter," the target appears to blink against a steady star background. This blinking sensation greatly enhances target detection and tracking.

Figure 1 illustrates the principle of the optical filtering technique. The letters NASA are colored as follows: N, red; S, green; and both A's, white. When the letters are viewed by an observer through a magenta (red-blue) filter, the letter S is obscured by the filter while the letters N, A, and A are transmitted. When the letters are viewed through a green filter, all letters are transmitted by this filter except the letter N. Then, by viewing the letters alternately through one filter and then the other, the letters N and S will appear to blink while the A's, being transmitted by both filters, will appear steady or nonblinking.

An optical filtering system with two interference filters and a fluorescent target coating can be constructed from commercially manufactured components. The principle of such a system is represented in figure 2 as percent of reflectance or of transmittance plotted against wavelength. Figure 2(d) shows the visual effect of looking at the fluorescent coating (represented in fig. 2(a)) through the obscuring filter (represented in fig. 2(b)). Figure 2(e) shows the effect when the transmitting filter (represented in fig. 2(c)) is used.

DESCRIPTION OF APPARATUS

The apparatus used in these studies is shown in figure 3. Light from a 100-watt zirconium arc lamp (power-spectral-density curve from ref. 1 shown in fig. 4) was attenuated by a 0.30 neutral density (50-percent transmittance) gelatin filter. The transmitted light was attenuated alternately by two semicircular gelatin filters (a transmitting and an obscuring filter) of 0.254-meter diameter mounted concentrically on a transparent circular plexiglass disk, which was rotated at 1/2 cycle per second by a synchronous motor. This resulting transmitted light fell on a 1.2-meter-square translucent plexiglass screen, 1.07 meters from the source, which acted as a secondary emitter through the 200 1.27-millimeter-diameter holes in the 1.2-meter-square aluminum sheet painted black. Various neutral density filters covering these holes simulated stars of differing magnitudes. A "target filter" which was of complementary color with respect to the obscuring filter attenuated the light passing through one particular hole. Thus, when the obscuring filter was in the light path, light was transmitted through all holes, except for that particular hole which was covered by the target filter. When the transmitting filter was rotated into the light path, light was transmitted through all 200 holes. Thus, as the filter wheel rotated, the target body appeared to blink against a steady star background.

The following table lists the gelatin filters used in the experimental study:

Test	Filter	Page in reference 2	Dominant wavelength, mμ	Excitation purity	Luminous transmittance, percent
1	Obscuring	28	583.6	96.5	81.2
	Transmitting	76	496.9	12.0	66.4
	Target	38	452.7	99.0	.23
2	Obscuring	33	506.6	90.0	8.9
	Transmitting	44	503.0	62.6	18.0
	Target	56	544.8	95.5	1.4

In one series of tests (test 1), a yellow and a pale blue gelatin filter were used as the obscuring and the transmitting filter, respectively, with a dark blue target filter. In another series (test 2), a magenta and a medium green filter were used as the obscuring and the transmitting filter, respectively, with a dark green target filter. Transmittance curves for the filters and plexiglass used in these studies are shown in figures 5, 6, and 7. The curves of figures 6 and 7 were taken from reference 2, whereas the curves of figure 5 were experimentally determined with a spectrophotometer.

The 1.2-meter-square celestial-body background subtended a visual angle of $11\frac{1}{2}^{\circ}$ at 6.1 meters, whereas the 1.27-millimeter-diameter holes subtended a visual angle of less than 1 arc-minute at that distance, and ranged from first to sixth stellar magnitudes.

Figure 8 gives the equivalent visual magnitude of the test target, depending upon viewing distance between observer and star field.

TEST PROCEDURE

Six engineers served as subjects in the investigation. Twenty minutes were allowed prior to beginning each test for the observer's eyes to become dark adapted.

The observer was instructed that, in his searching procedure, he should fixate on a particular star, rather than scan the field continuously. He was informed that the target body would appear peripherally and could not be seen by gazing directly at it (foveally).

At the beginning of each test, the observer was placed at such a distance from the target that visual detection was impossible. The observer searched the entire star field (by fixating on a discrete number of stars) for several minutes until he was certain that detection of the target was not possible at that particular distance. He then advanced 1 to 2 feet closer to the star field and repeated the searching procedure. This operation was repeated until visual detection of the target occurred. The distance from the target was then measured and recorded. These data for peripheral detection are representative of the results which could be expected in the actual space situation (i.e., for the observer to be steadily approaching the target vehicle for which he is visually searching).

Three different star-field densities (i.e., celestial bodies per steradian) in the immediate vicinity of the target body were used in the study. As the viewing distance changed, these three densities changed and thus gave a specific star-field density for each distinct viewing distance.

The greatest distance at which the observer could see the target foveally was also determined. In this series of tests the observer gazed directly at the target, beginning from a close-in position, and retreated steadily until the target light was no longer visible. This distance from the target was then measured and recorded. These tests were not repeated by beginning from a far-out position and advancing toward the target since there existed no assurance that the subject would first see the target foveally, a possibility which would tend to negate the value of the experiment.

DISCUSSION OF RESULTS

Test Results

Figure 9 gives results of the present investigation in terms of equivalent stellar magnitudes at which the target bodies are detected by use of two particular filter combinations. The effect of star-field density is indicated. A comparison is also made between foveal and peripheral detection of a blue target (fig. 10).

These results indicate that the minimum intensity of a blinking light source which can be visually detected is a function of star-field density in the immediate surroundings. Although this will be a factor regardless of the filter combination, it is believed that the effect was overemphasized in the experimental tests. For one thing, the luminous intensity of the background as seen through the obscuring filter was not equal to the intensity as seen through the transmitting filter; thus, there existed some fluctuation of the background intensity as the filter wheel rotated. Also because of the chromatic aberration of the eye and the greater optical scatterings of the shorter wavelengths (ref. 3) the background fluctuated slightly with respect to star image distinctness.

Since the purpose of these tests was to determine the feasibility of the filter technique, available equipment was used and no rigorous attempt was made to optimize the filter system. However, optimizing conditions for target visibility using the filter technique, which would in part minimize the effects of star-field density, are found in the appendix.

These tests emphasize the importance of peripheral viewing when attempting to detect a target body visually. As shown in figure 10, by using peripheral vision the target can be detected and identified two to three stellar magnitudes dimmer than it can by looking directly at it (foveally). These results are in good agreement with reference 6 which states that stars can be detected three magnitudes dimmer by using peripheral vision rather than foveal vision. This difference in sensitivity between the fovea and the periphery is due to the relative distribution of the rods and cones in the human retina. The rods which are located primarily in the periphery, although insensitive to color, are extremely sensitive to light. The color-sensitive cones which are found primiarily in the fovea are much less sensitive to light than are the rods. Figure 11 (taken from p. 107 of ref. 4) compares minimum amounts of radiant flux for both foveal (cone) and peripheral (rod) viewing, as a function of wavelength required for visual perception.

Comparison With Other Techniques

Other techniques have been proposed for visually detecting a point-source target against a celestial body background, such as

(1) The angular motion of a point-source target moving slowly over a star background has been suggested as a visual cue for detection. However, this

motion will depend upon various orbital parameters and, if less than 0.1 milliradian per second for a 3.5-magnitude body, the point source will not be detectable (ref. 5). For target-body magnitudes smaller than 3.5, the minimum detectable rate will undoubtedly increase. Theoretically a body can be seen at no greater distances by using angular motion cues than by using optical filtering techniques. With both techniques the targets will be visible at equal ranges; however, they will be visually detectable at greater ranges by using the optical filters. Also, the use of angular motion as a detection cue has distinct disadvantages during certain space-vehicle maneuvers. For example, during the control of the terminal rendezvous phase, it will be necessary to bring the angular rate to near zero to insure proper closure between the two vehicles.

(2) The use of artificial lighting has also been suggested for detection purposes. If the target body were in the shadow of a near planet, the filtering technique would be useless and an onboard target beacon would be necessary for detection. However, if a fluorescent-coated body were illuminated by the sun, the weight and power penalty imposed by the artificial beacon to give an equivalent illumination would undoubtedly be extremely great. For example, the flashing beacon onboard the 36-inch-diameter Anna 1B satellite (ref. 7) weighs approximately 70 pounds and has an input power of approximately 22 watts with a system life of 20,000 flashes. It is visible as a third-magnitude star at 32 kilometers (20 statute miles). If the 36-inch-diameter satellite, also referred to as 1962 Beta Mu 1, were painted with a fluorescent coating of 80-percent overall reflectance and illuminated by the sun at horizon, it would be visible overhead as a third-magnitude star at 280 kilometers (175 statute miles), disregarding atmospheric attenuation (ref. 8).

(3) The ability of an observer to detect a colored target against a star background could be used during the initial rendezvous phase. From data in reference 9 a green (or blue), red, and white target could be detected and correctly identified 90 percent of the time at 1.8 magnitude. However, by using the optical filters, targets as dim as fourth and fifth magnitude can be detected.

Thus initial target detection can be achieved by using an optical filtering technique while visual tracking of the body can be aided by using the chromatic contrast of the target and background as well as target angular motions. An artificial onboard beacon is also essential if the target is in the shadow of a near planet and, in any case, the beacon is a desirable backup system for the optical filtering technique.

CONCLUDING REMARKS

A study has been made of a new technique for detecting and identifying distant objects in space by use of optical filters.

Test results have shown that stationary (or nonstationary) relatively monochromatic point-source targets, illuminated by sunlight only, can be detected and identified against a celestial-body background at target luminance levels as low as fourth and fifth magnitude by using an optical filtering technique.

If the search area is viewed alternately through a filter that obscures the light from the target and one that transmits it, the target will appear to blink against a steady or nonblinking star background.

The star-field density in the immediate target surroundings was shown to affect the minimum detectable target luminance. The magnitude of this effect is determined by the characteristics of the optical-filter combinations.

A comparison was made of peripheral viewing and foveal viewing in detecting targets in space. Target detection can be accomplished at two to three stellar magnitudes dimmer by using peripheral vision instead of foveal vision.

The results of this study indicate that any object which is to be visually detected and identified in space should be coated with a relatively monochromatic material, preferably a fluorescent blue-green coating, and visually searched for (during the period in which it is illuminated by sunlight) through a matched set of interference filters. Once the target's illumination exceeds 1.8 visual magnitude, the target's color will serve as an aid in visual tracking.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 3, 1964.

APPENDIX

OPTIMIZING CONDITIONS FOR TARGET VISIBILITY

Symbols used in this appendix are defined as follows:

A	target area which is both illuminated and visible to observer, meter^2
D	distance from target to observer, meters
$E_B(\lambda)$	radiant power per angstrom of the target body, watts/angstrom
$E_C(\lambda)$	radiant power per angstrom for celestial-body background, watts/angstrom
$E_S(\lambda)$	radiant power per angstrom of the sun, watts/angstrom
$F_O(\lambda)$	transmittance of obscuring filter, percent
$F_T(\lambda)$	transmittance of transmitting filter, percent
L_O	illuminance of target after filtering by obscuring filter, lumen/meter^2
L_T	illuminance of target after filtering by transmitting filter, lumen/meter^2
$R(\lambda)$	reflectance of target body, percent
S	distance from sun to target body, meters
$V(\lambda)$	relative visibility function, percent
$V_p(\lambda)$	relative visibility function for photopic viewing, percent
$V_s(\lambda)$	relative visibility function for scotopic viewing, percent
λ	wavelength, angstroms

For a blinking point-source target to be most readily detected against a celestial-body background (using optical filters as a visual aid), several optimizing conditions must be met:

(1) The illuminance of the target after filtering by the transmitting filter L_T must be greater than the minimum threshold of vision, 8.32×10^{-9} lumen/meter^2. Thus, where $F_T(\lambda)$ is the transmittance of the transmitting filter as a function of incident wavelength, $E_B(\lambda)$ is the

radiant power per angstrom of the target body in watts/angstrom, D is the linear separation between target and observer in meters, and $V(\lambda)$ is the relative visibility function,

$$L_T = 621 \int_0^\infty \frac{E_B(\lambda)\ F_T(\lambda)\ V(\lambda)\ d\lambda}{D^2} \geqq 8.32 \times 10^{-9} \text{ lumen/meter}^2$$

For an observer whose eyes are dark adapted

$$V(\lambda) = V_s(\lambda) = e^{-\frac{(\lambda - 5125)^2}{3.88 \times 10^5}}$$

The equivalent radiant power per angstrom of the target body illuminated by the sun will be

$$E_B(\lambda) = \frac{R(\lambda)\ E_S(\lambda)\ A}{S^2}$$

where $R(\lambda)$ is the reflectance of the target, $E_S(\lambda)$ is the radiant power per angstrom of the sun, S is the linear separation between sun and target in meters, and A is the effective area in meter^2 of the body which is both illuminated and visible to the observer. The effective areas of various shaped bodies, such as the cylinder and sphere, as a function of viewing distance, target-body attitude, and position of the body with respect to illuminating source and observer are given in reference 8. The radiant power $E_S(\lambda)$ may be approximated by Planck's equation for an ideal blackbody, with the blackbody temperature assumed to be 6,500° K outside the earth's atmosphere (ref. 10). The reflectance $R(\lambda)$ will be a function of body coating and, in cases where this is a fluorescent material, will exceed 100 percent at certain wavelength intervals. Reference 11 discusses reflectance as a function of surface condition.

(2) The illuminance of the source after filtering by the obscuring filter L_O must be less than 8.32×10^{-9} lumen/meter^2. Thus, where $F_O(\lambda)$ is the transmittance of the obscuring filter

$$L_O = 621 \int_0^\infty \frac{E_B(\lambda)\ F_O(\lambda)\ V(\lambda)\ d\lambda}{D^2} < 8.32 \times 10^{-9} \text{ lumen/meter}^2$$

(3) For optimum detection conditions, the illuminance of the celestial-body background must appear equivalent upon viewing through both the transmitting and the obscuring filters. Where $E_C(\lambda)$ is the radiant power per

angstrom of the star background,

$$\frac{\int_0^{\infty} E_C(\lambda)\ F_O(\lambda)\ V(\lambda)\ d\lambda}{\int_0^{\infty} E_C(\lambda)\ F_T(\lambda)\ V(\lambda)\ d\lambda} = 1$$

(4) The transmitting filter should transmit the maximum amount of target illumination. That is, the ratio

$$\frac{\int_0^{\infty} E_B(\lambda)\ F_T(\lambda)\ V(\lambda)\ d\lambda}{\int_0^{\infty} E_B(\lambda)\ V(\lambda)\ d\lambda}$$

should be maximized.

This requirement indicates the importance of using a fluorescent coating for the target vehicle (i.e., for the target's bandwidth where the reflectivity is greater than 100 percent to be in the region of maximum transmittance of the filter).

(5) For maximum usage of scotopic (rod) vision, the target-body color should be in the range 450-575 millimicrons. As shown in figure 11 (ref. 4) the minimum required energy for detection occurs at 512 millimicrons, and increases continuously for wavelengths both greater and less than this minimum value.

(6) In the event that intense target glare may be a problem at short ranges (for example, during a docking phase), it would be desirable for

$$\frac{\int_0^{\infty} V_s(\lambda)\ E_B(\lambda)\ d\lambda}{\int_0^{\infty} V_p(\lambda)\ E_B(\lambda)\ d\lambda} > 1$$

where $V_s(\lambda)$ is the relative visibility function for scotopic (rod) viewing and $V_p(\lambda)$ is the relative visibility function for photopic (cone) viewing.

(7) Two-tenths to three-tenths of a second should be allowed between flashes (i.e., period of obscuring filter) so that the luminous sensations may become somewhat less intense (to avoid the persistence of vision) and allow the flashes to be distinguished. The flash duration (i.e., period of transmitting filter) should be from five-tenths to six-tenths of a second. (See ref. 12.)

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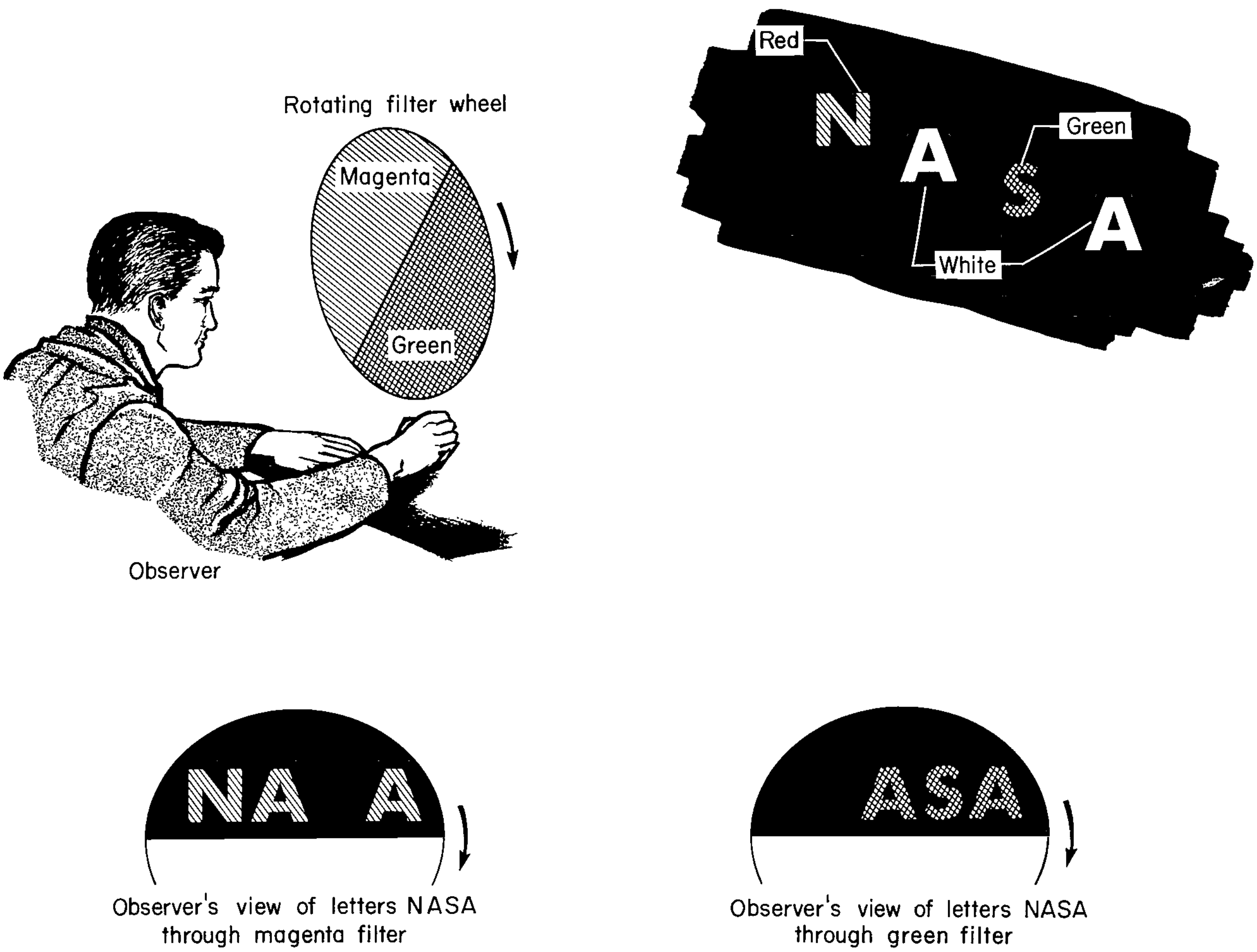
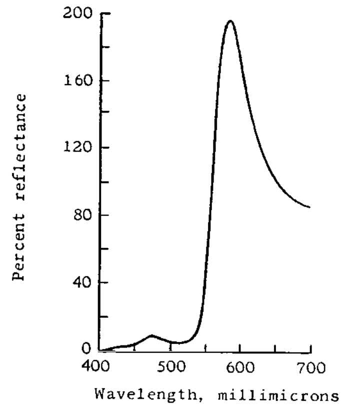
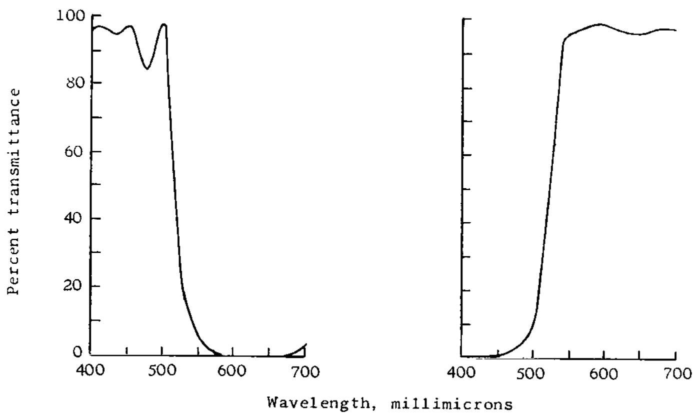


Figure 1.- Basic principle of optical filtering technique.

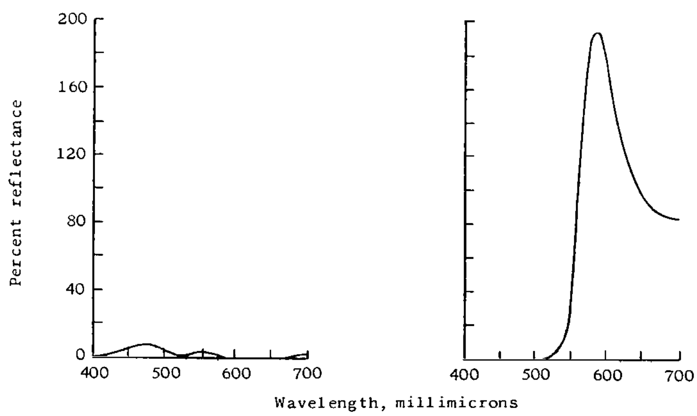


(a) Fluorescent paint.



(b) Obscuring filter.

(c) Transmitting filter.



(d) Fluorescent paint as seen through obscuring filter.

(e) Fluorescent paint as seen through transmitting filter.

Figure 2.- Principle of optical filtering.

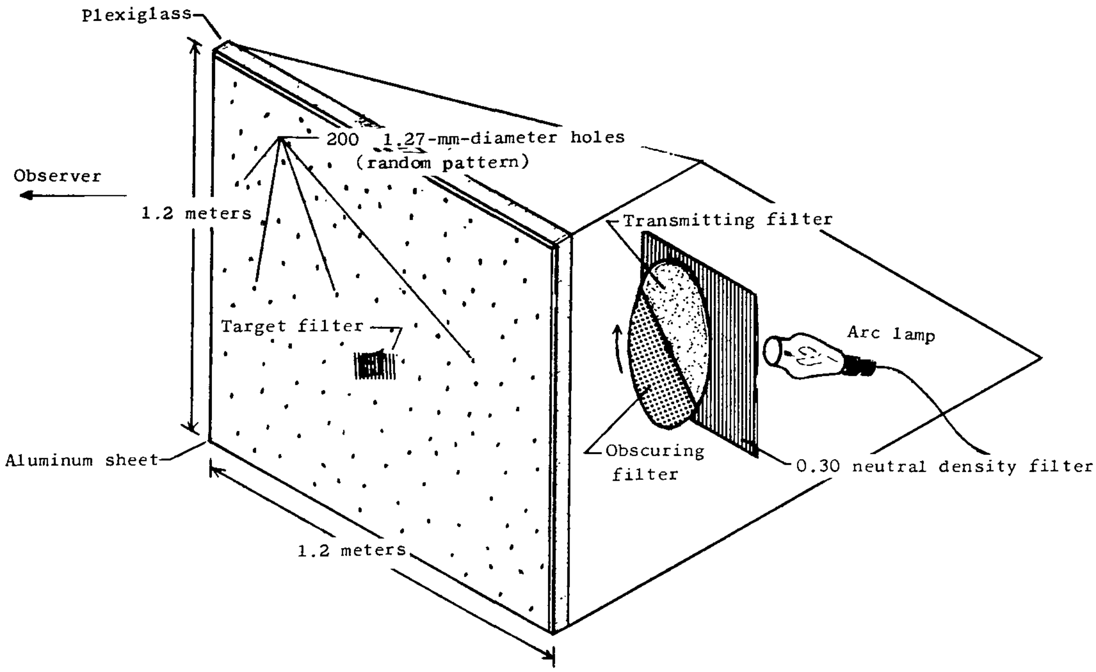


Figure 3.- Apparatus used in tests.

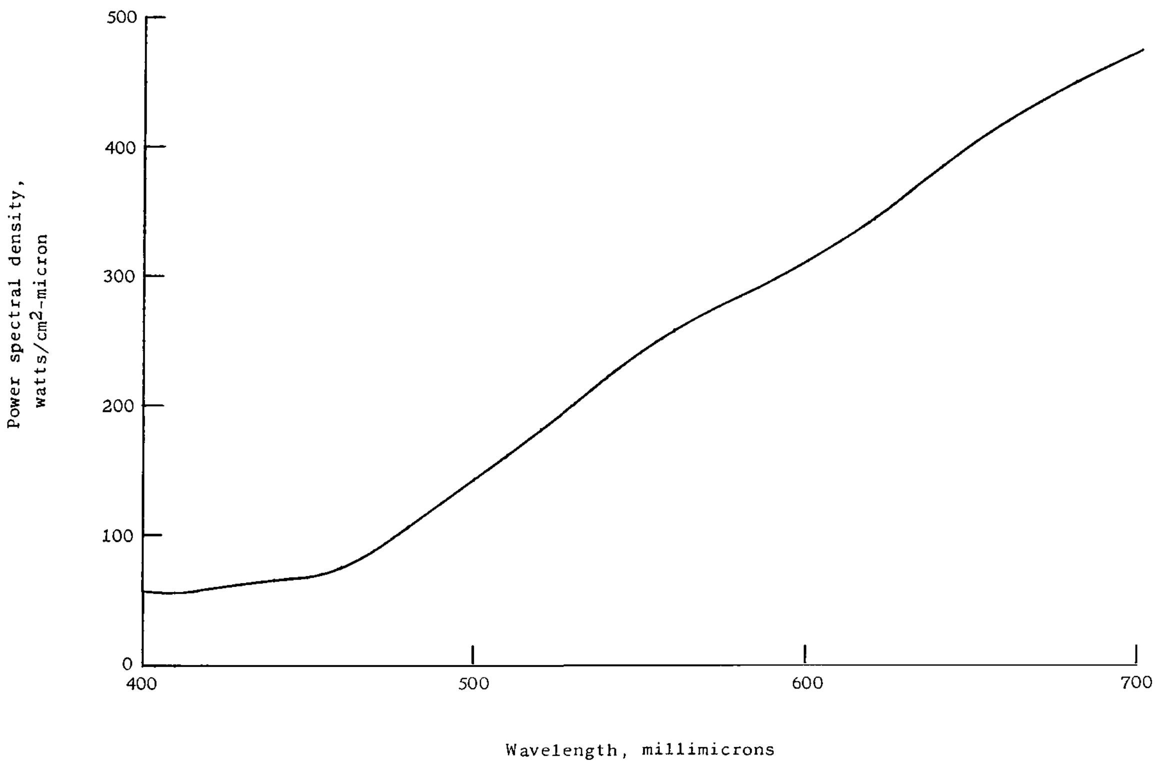


Figure 4.- Power-spectral-density curve for 100-watt zirconium arc lamp as a function of wavelength.

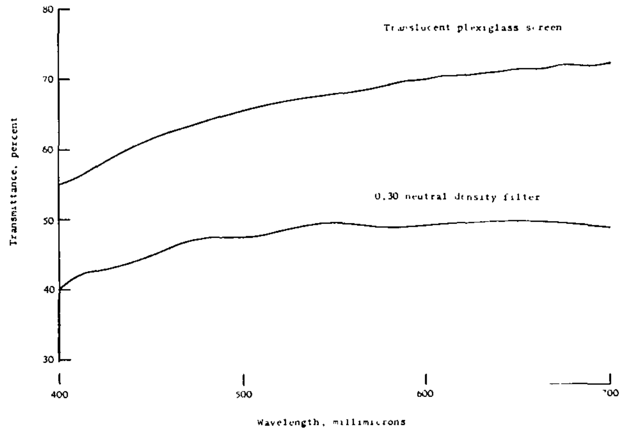


Figure 5.- Transmittance curves for translucent plexiglass screen and 0.30 neutral density filter as a function of wavelength.

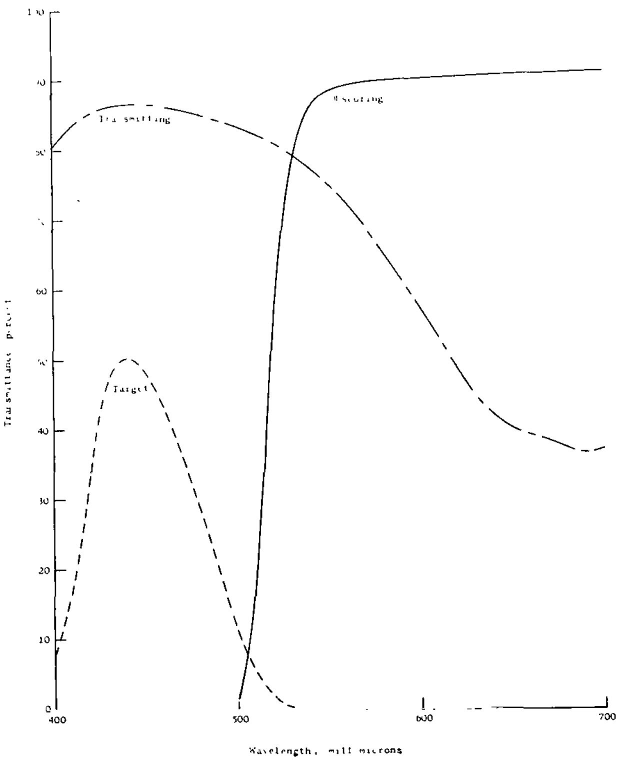


Figure 6.- Transmittance curves for filters used in test 1.

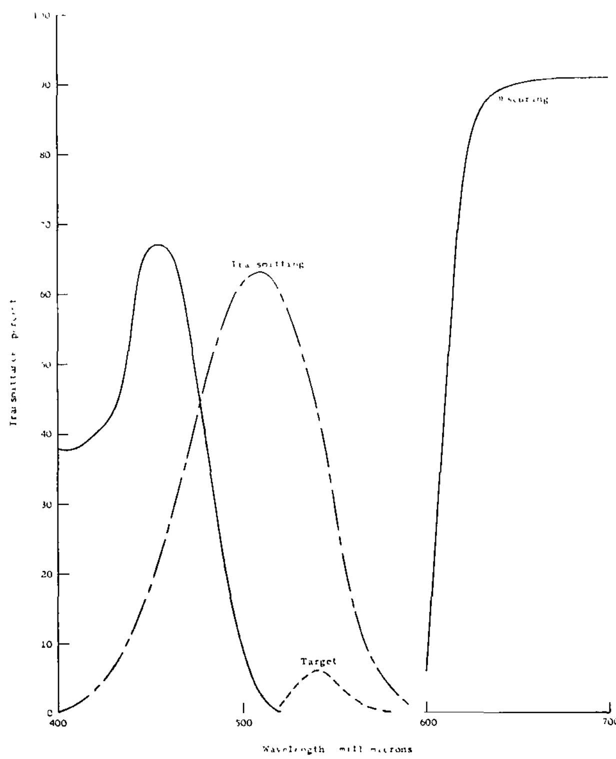


Figure 7.- Transmittance curves for filters used in test 2.

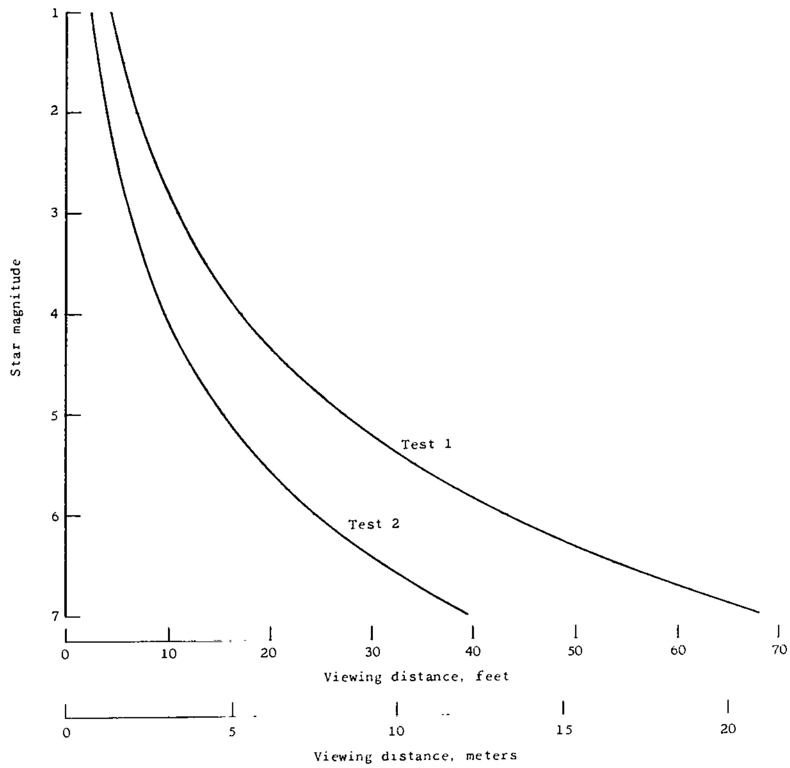


Figure 8.- Equivalent visual magnitude of test target as a function of viewing distance.

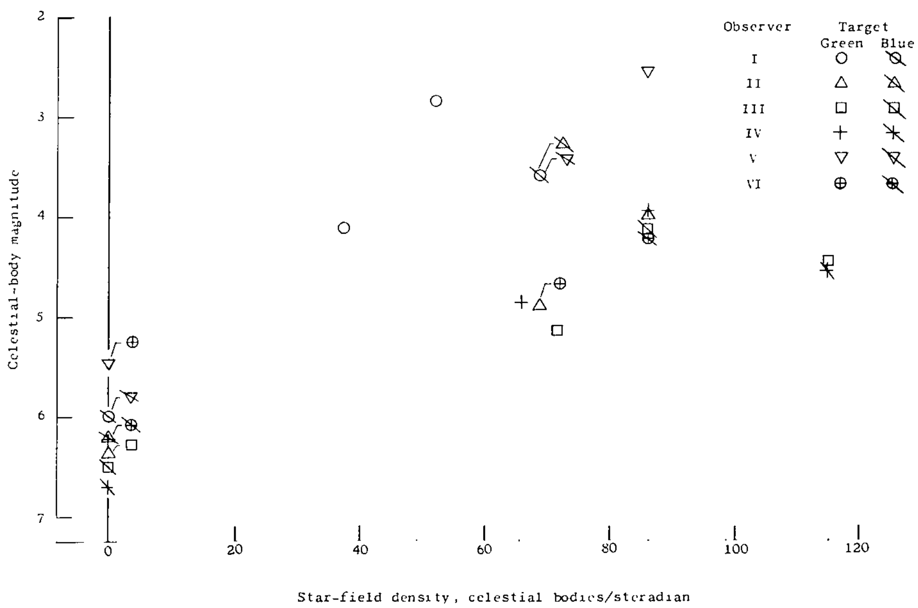


Figure 9.- Minimum target luminosity required for visual detection as a function of star field density in the immediate target surroundings.

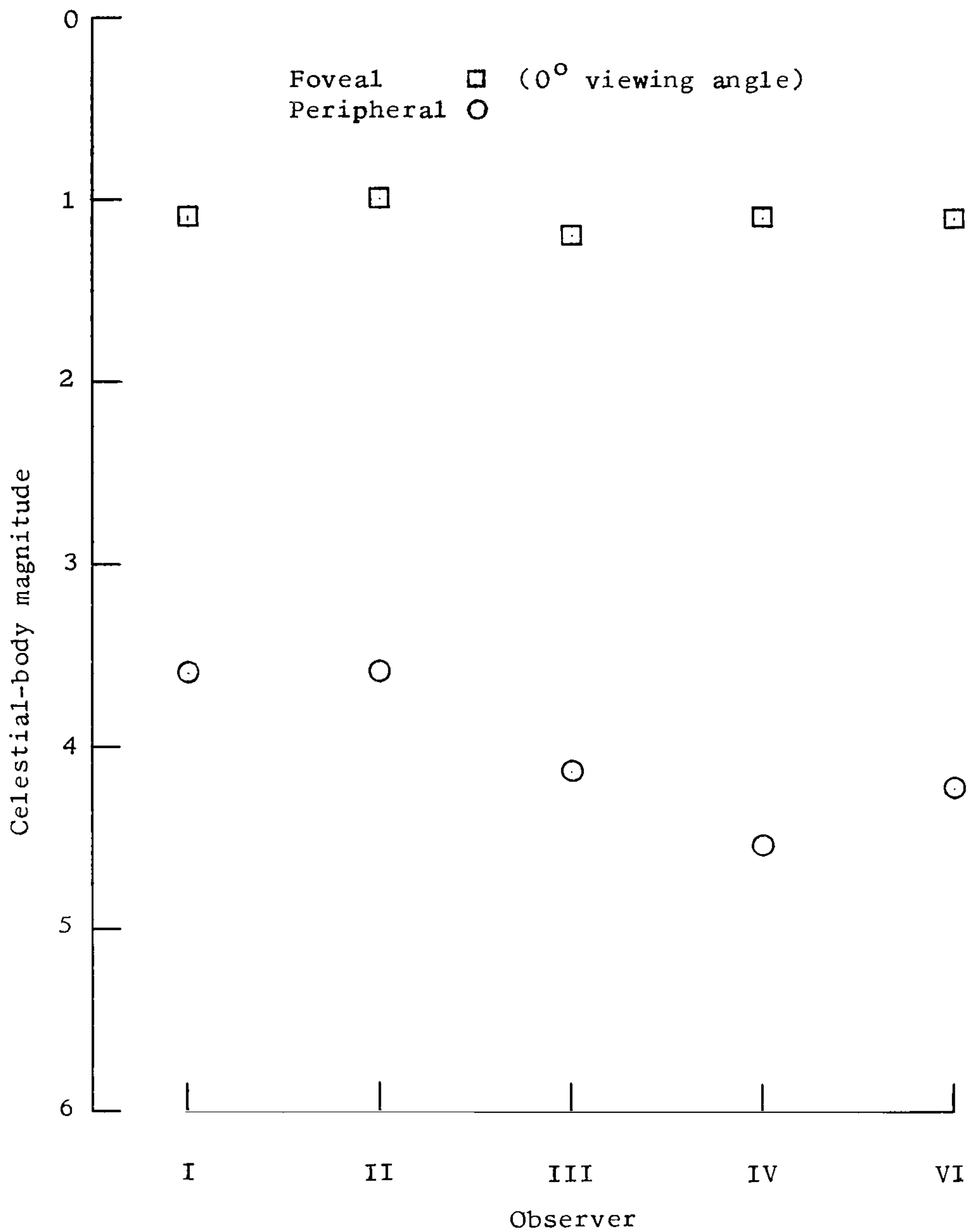


Figure 10.- Comparison between foveal and peripheral viewing in terms of minimum target luminosity required for detection.

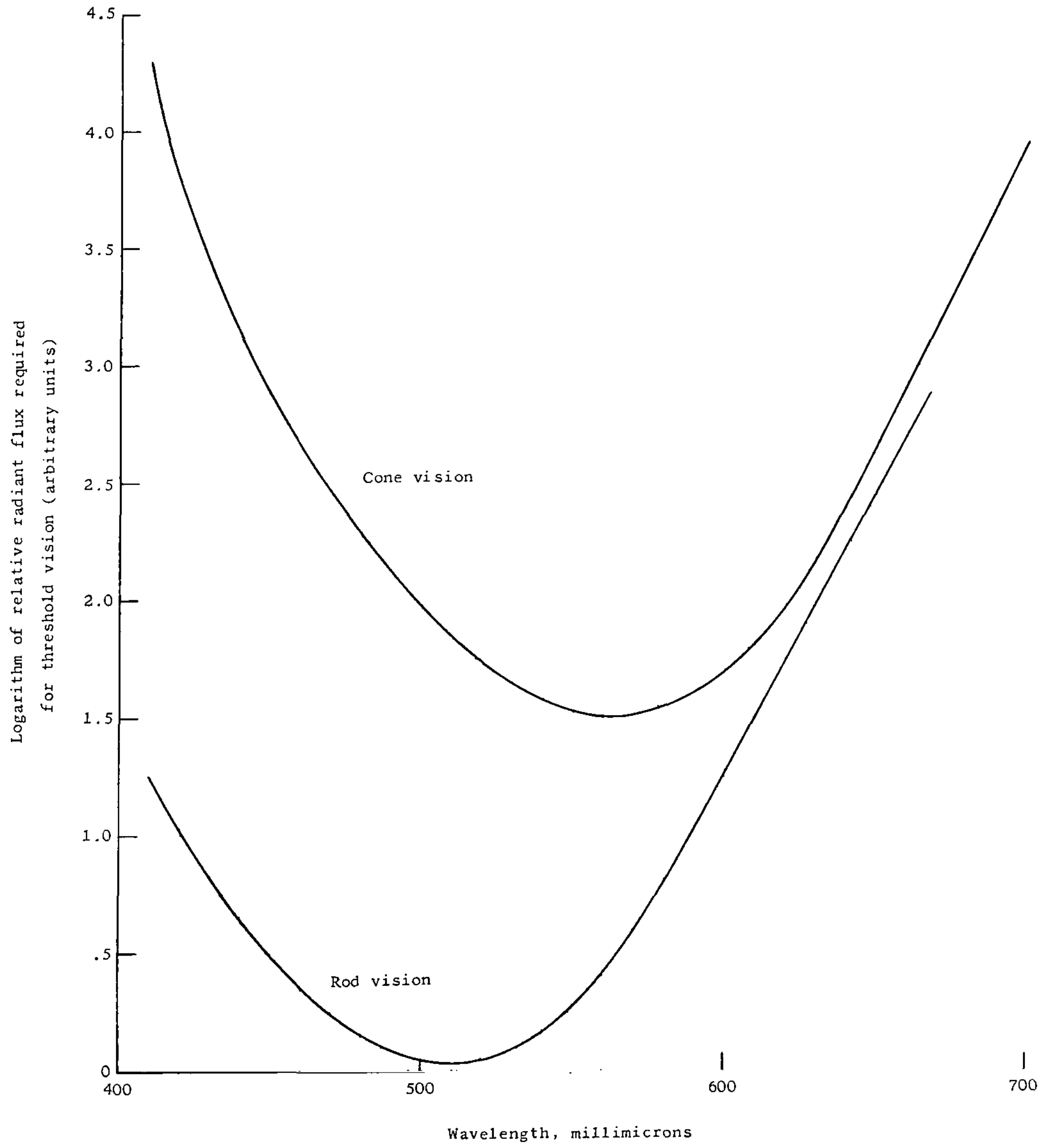


Figure 11.- Relative amounts of radiant flux required to stimulate the rods and cones (from ref. 4).

NASA-Langley, 1964 L-4074