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Methods for NVG Visual Acuity Determination

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Abstract: *Visual acuity (resolution) is the most important and frequently stated characteristic of night vision goggles (NVGs). It is often used as the main parameter to compare the quality of different kinds of NVG. The resolution of the optoelectronic systems is typically defined in military standards as the maximal spatial frequency of a standard line pattern that can be resolved by an observer at a certain illuminance level and the target contrast. An analysis of methods for resolution measuring of the optical visual system using a variety of targets and measures of visual acuity is described. The typical values of NVDs resolution depending on the generation of the image intensifier tube (IIT) type are shown.*

Keywords*: Measure of visual acuity, resolution limit, angle of resolution.*

Introduction

The wave theory of light defines that the image of a point object formed by an optical system with a circular aperture stop, will be a circular disc surrounded by fainter rings (Fig. 1). The central disc contains about 85% of the light in the diffraction pattern and is referred to as the Airy disc [1]. Airy disc is dependent on the pupil size and the wavelength of light and is of the order of 90 s of arc in a typical eye.

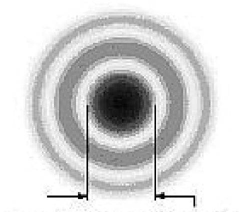


Fig. 1. Diffraction pattern for a circular aperture

This phenomenon limits the resolution of the optical visual system, i.e. the ability to obtain separately images of two close situated point objects.

The image of point A located on the optical axis of an ideal optical system, is point A', on the same optical axis (Fig. 2).

When the optical ways of the light rays are different by $\lambda/2$ (λ – wavelength of light), the light is fading and a minimum of the light intensity is

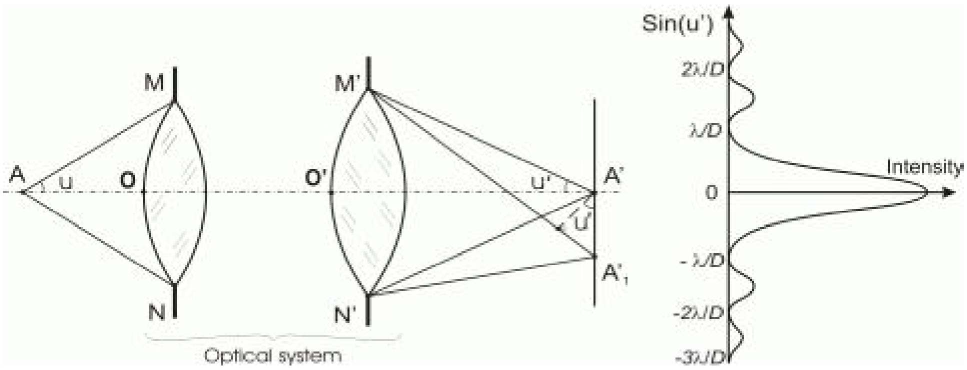


Fig. 2. Transform of the point object by an ideal optical system

observed (point A'_1). The lengths of the light rays coming from the end points of the spherical wave are different by λ':

(1) $$\lambda' = M'A_1' - N'A_1' ,\ r' = A'A_1',$$

(2) $$M'A_1' = M'A' + r'\sin(u') ,$$

(3) $$N'A_1' = N'A' - r'\sin(u').$$

In the case when $M'A' = N'A'$, (2) turns into

$$2r'\sin(u') = \lambda.$$

Because of the well known fact that $\lambda' = n'\lambda$, (where n' is refractive index of the image optical medium) the radius of diffraction spot is

(4) $$r' = \frac{\lambda}{2n'\sin(u')}.$$

Therefore the diffraction pattern of a point source of light, if highly magnified, consists of a central bright disk surrounded by a concentric series of diffraction rings (the secondary maximums and minimums), even when it is obtained by the ideal optical system. The diffractive spot radius is decreasing with the increase of the outgoing aperture angle u (where $n \sin(u) = NA$ – numerical aperture).

According to Raleigh's criterion (diffraction limit) for circular apertures, two points are optically resolved if their angular separation θ is:

(5) $$\theta \geq \frac{1{,}22.\lambda}{D},$$

where λ is the wavelength of light, D – the diameter of the pupil.

Raleigh's limit in lines per mm (lp/mm) is:

(5a) Raleigh's limit = $1/(1{,}22\ F\lambda)$ lp/mm,

where F is the focal ratio (the ratio of the focal length f to the diameter D of a lens system), λ – the wavelength of light in mm [2].

For chosen λ = 587,6 nm and D in the range from 2 up to 8 mm, θ for human eye is: $0.090 \leq \theta \leq 0.358$ mrad or $0.3' \leq \theta \leq 1.23'$ of arc (Fig. 3).

When the objects are not points but with some complex shape – the resolution of the optical visual system is defined as maximum spatial frequency of the periodical

Fig. 3. Diffraction limit determined by angular separation θ

structure test target, in the image of which, a periodical structure could be still perceptible. The limit frequency ν depends on optical transfer function of the system, contrast sensibility of the receiver, shape and contrast of the targets and is defined by

$$\nu = \frac{1}{d}. \tag{6}$$

In (6) d is the distance between two different points distinguishable by the optical device:

$$d = \frac{\lambda k}{NA}, \tag{7}$$

where λ is the wavelength of the light, NA – the numerical apertures, k – a coefficient, depending on contrast sensibility of the receiver.

The maximum resolution of an optical visual system needs a definite level of light intensity of the image. The dependence of the illumination of the image E and the luminance (brightness) of the object L is

$$H = \frac{E}{L}. \tag{8}$$

For the optical devices, which use image intensifiers tubes (IIT) it is necessary to ensure illumination of the screen above the threshold level (ΔE_0) which means that (8) must satisfy:

$$H \geq \frac{\Delta E_o}{L_{\min}}, \tag{8a}$$

where $L_{\min}$ is the minimum luminance of the object.

The resolution of the optical visual system must be in co-ordinance with the resolution of the human eye. The standard definition of normal visual acuity (20/20 vision) is the ability to resolve a spatial pattern separated by a visual angle of one minute of arc [3]. The visual angle of one minute of arc is 1/60°. It is defined by diffraction of the light from the eye pupil ($D \approx 2$ mm) and by the structure of the eye. Therefore, the minimum angle of the optical device resolution must be better or equal to the human eye resolution angle:

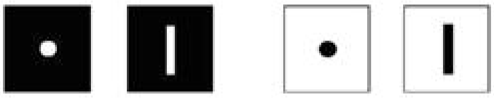
$$\theta_{\text{opt. device}} \geq \theta_{\text{eye}}.$$

Methods for human eye visual acuity determination

Visual acuity is the spatial resolving capacity of the visual system. It is the ability of the eye to see fine details. There are various ways to measure and specify visual acuity, depending on the type of the acuity task used. Visual acuity is limited by diffraction, aberrations and photoreceptor density in the eye [4].

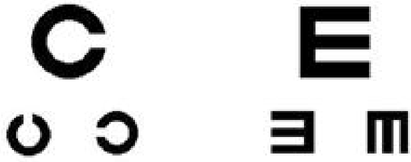
Target detection requires only the perception of the presence or absence of an aspect of the stimuli, not the discrimination of target detail (Fig. 4).

The Landolt' *C* and the illiterate *E* are other forms of detection used in the visual acuity measurement. The task required here is to detect the location of the gap (Fig. 5).



a b

Fig. 4. Bright test object on a dark background (a), Dark test object on a bright background (b)



a b

Fig. 5. Landolt' *C* (a), Illiterate *E* (b)

Snellen's letters are constructed in the way where the size of the critical detail (stroke width and gap width) subtends 1/5th of the overall height. A person's visual acuity in terms of Snellen's notation, is the determination of the smallest line of letters of the chart that can be identified correctly and is

$$VA = \frac{D'}{D}$$

where D' is the standard viewing distance (usually 6 m) and D is the distance at which each letter of this line subtends 5′ (each stroke of the letter subtending 1′, Fig. 6).

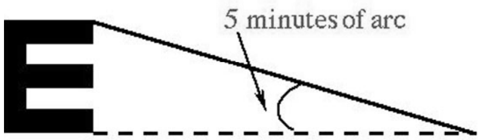


Fig. 6. Visual acuity of 6/6

The reciprocal of Snellen's notation equals to the angle (in minutes of arc), for which the strokes of the letter subtend at the man's eye. This angle is also used to specify visual acuity (Fig. 6) and is called "the minimum angle of resolution".

Target resolution thresholds are usually expressed as the smallest angular size at which subjects can discriminate the separation between critical elements of a stimulus pattern, such as a pair of dots, a grating or a checkerboard (Fig. 7).

Target localization involves discriminating differences in the spatial position of segments of a test object, such as a break or discontinuity in contour. Visual acuity measured in this way is called Vernier's acuity and the discontinuity is specified in terms of its angular size. Vernier's acuity thresholds are typically around 5-10″ of arc (Fig. 8).

a b c

Fig. 7. Double dot target (a), Acuity grating (b), Checkboard (c)

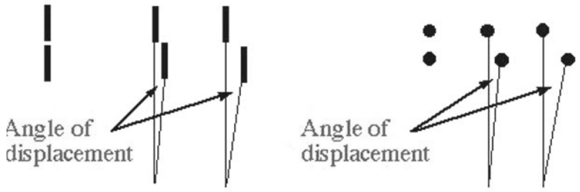


Fig. 8. Vernier’ acuity

Methods for determination of the night vision devices (NVDs) visual acuity. Visual acuity measurements using Landoldt’s method

Resolution acuity is sometimes called “minimum separable acuity” [5]. It refers to the ability of the human eye to detect a separation or gap between objects. The image in Fig. 9a illustrates a gap detection stimulus. The gap is made progressively smaller until the two bars cannot be distinguished from a single bar. Fig. 9a illustrates a stimulus for measuring grating acuity. The bars of the grating are progressively narrowed until the pattern cannot be distinguished from a uniform gray field. Fig. 9b is the familiar Landoldt’ *C* stimulus. The stimuli *C* are made smaller until the direction of the notch cannot be reliably indicated. Resolution acuity thresholds are typically around 0.5′ of arc.

Landolt’s test stimuli are closely-sized computer-created, high contrast printed using a high resolution, photo-grade laser printer [6]. The print out of each target was mounted on 18x18 cm squares of foam board. Each target varied in gap size and represented, when converted, a specific Snellen's visual acuity value (20/xx). The back of each target was labeled with four different bar code patterns. Each bar code contained identification information for that particular target such as target number, target type, the corresponding visual acuity (20/xx), the target contrast, and the gap orientation.

a b

Fig. 9. Gap detection stimulus (a), Landolt’ *C* stimulus (b)

Resolution assessment using a USAF 1951 target

Visual acuity (or more precisely resolution) is probably the most important and frequently stated characteristic of night vision goggles (NVGs). It is often used as the main parameter to compare the quality of one NVG to another. Resolution of the optoelectronic systems is typically defined in military standards as maximal spatial frequency of a standard line pattern that can be resolved by an observer at a certain illuminance level and the target contrast. This definition was chosen because it is possible to estimate probability of detection, recognition and identification of military targets with the evaluated image intensifier [7]. The baseline military method uses a commercially available USAF 1951 Tri-bar resolution chart (Fig. 10) with medium or high contrast. The target consists of multiple "elements", each of which is a pattern of three horizontal and three vertical bars. The "elements" are arranged into "groups" of six elements each. Each subsequent element is larger, or smaller, by a factor of the square root of two (1.41421). The "groups" and "elements" are numbered (Fig. 10). The width of one dark bar and one white space is defined as a "line pair".

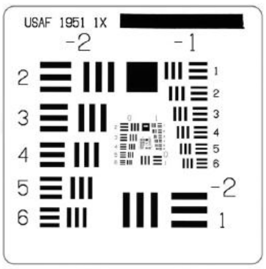


Fig. 10. USAF 1951Tri-bar Chart

The chart is set up and the observer looking through the NVGs while resolving an element in a target group midway between the largest and smallest groups when the chart is irradiated as specified.

When resolution measurements are made at an outdoor range, the distance from the observer to the USAF-1951 target must be a measured distance. The measurements are then reported as angular resolution, where the units are line pairs per milli-radian (lp/mrad). Line pair is also called a "cycle", such that it could use the unit cycles per milli-radian (cy/mrad). The tri-bar target sizes can be converted to equivalent Snellen's acuity values by determining the angular subtense of the bar size as measured from the viewing distance [8]. An angular subtense of 1′ of arc corresponds to Snellen's acuity of 20/20; 2′ of arc is 20/40, and so third.

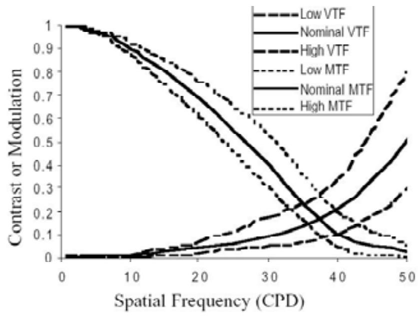
Resolution assessment using a 50% contrast, square-wave grating NVG resolution chart

A square-wave grating pattern NVG resolution chart having a contrast modulation (Cm) of 50% + 10% is used [9]. The NVG resolution chart contains horizontally and vertically oriented square-wave grating patterns that determine Snellen' acuities of 20/20, 20/25, 20/30, 20/35, 20/40, 20/45, 20/50, 20/55, 20/60, 20/65, and 20/70 when resolved at a viewing distance of 6 m. The chart is set up outside the mockup at a distance of 6 m from the test subject and irradiated as specified.

Limiting resolution

Limiting resolution is defined as the spatial frequency at which the modulation transfer function (MTF) of the NVGs and the visual threshold function or VTF intersect (Fig. 11) [10]. This intersection point occurs at the highest spatial frequency that the

Fig. 11. Idealized NVG MTF (upper thick solid line) and VTF



NVG can transmit with sufficient contrast so that the human eye can see it. This spatial frequency can be converted to an equivalent Snellen' acuity or another convenient resolution unit.

Step-back method

To refine the square-wave grating pattern to obtain smaller step sizes between resolutions, a variation was developed and constructed (Fig. 12) containing six pairs of vertically and horizontally oriented square-wave gratings [11].

While looking through the NVGs at the pattern from a distance of 9m, the observer selects the smallest resolvable target pair. Then the observer slowly steps backwards until the selected target pair is no longer resolvable. The observer then steps forward until the square-wave pair could barely be resolved. This final viewing distance is then used to calculate the exact Snellen' acuity of the selected target pattern. The spatial frequencies of the square-wave patterns are sufficiently close together in spatial frequency that the observer would not have to step back more than 0,9 m (10% of the baseline viewing distance), thereby minimizing the effect of possible objective lens misfocus [10, 11].

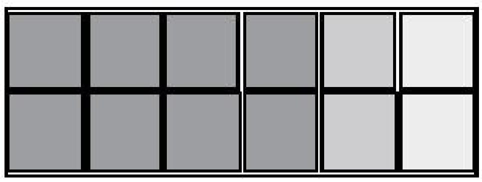


Fig. 12. Example of the square-wave chart used in the step-back method. Chart used in the step-back method

Conclusion

There are four different types for measuring the visual acuity, each of them relating to the ability to discriminate a different aspect of the details:

- Minimum visibility: ability to detect a point source of light (as stars for example).
- Minimum perceptibility: ability to detect small objects against a plain background (small black dot, disc, or bar on a dark background, or white targets on a dark background).

- Minimum separability (minimum angle of resolution) is the ability to see that two or more objects very close together are separate (two or more parallel bars, double dot target, checker-boards).
- Minimum distinguishability (localization acuity): ability to distinguish discontinuities or irregularities in object contours. This is the ability to see two vertical lines placed one above the other as being displaced sideways (Vernier' acuity).

Most acuity tests measure the size of the smallest pattern detail:

- At discs targets, the task of the observer is to detect target presence. With patterns containing bars and with Landolt-C and E letters, the pattern is rotated from one presentation to the next and the observer must report **target orientation**.
- When testing letter charts, the observer is 6m from the eye chart usually. Acuity is expressed as a ratio, such as 20/40 (**Snellen's acuity**). The ratio indicates that the tested person can barely read at 6 m since a normal (or 20/20 vision) person can barely read at 12 m. Vision 20/20 is assumed to be the ability to resolve a target detail of 1′ arc at 6 m.
- For targets with repetitive regular elements, spatial frequency is the number of cycles (1 black bar plus 1 white bar equals 1 cycle) subtending to 1 degree. Acuity is reported as spatial frequency, given as **cycles/deg**.
- **Minutes of arc** of visual angle subtended at the human eye. Numerically higher acuity values will indicate better vision. Visual acuity is usually expressed as decimal acuity, which is the reciprocal of the minutes of arc of visual angle subtended by the smallest discriminable detail. "Normal" visual acuity is widely taken to be 1.0, resolution of 1′.

The USAF 1951 test target was developed for use with the U.S. Government specification Mil-Std-150. It is one of the most commonly used resolution targets for lenses as well as for measurement of resolution of military NVGs. The resolution of the optoelectronic systems depends on the resolution of the ocular and objective lenses and it greatly depends on the generation of IIT, i.e. its resolution. The typical values of the resolution of NVGs are given in Table 1.

Table 1

Generation of IIT	Resolution of the NVGs, lp/mm
Gen I D-2M; D-2MV; American Technologies Night Cougar Goggles	30 – 40
Gen I+ Viper Single Eye Goggle System	22 – 40
Gen II ATN NVG7; AN/PVS-5C - E8000	41 – 45
Gen II+ ATN NVG 7; AN/PVS-5C - E8200	36 – 45
Gen III AN/PVS-7B-Night Quest 5001, AN/PVS-7B – 1700-4C; AN/PVS-7B – 1700-4CX; AN/PVS-7B – 1700-4P; ANVIS 9; AN/PVS-5C – E8600P	45, 51, 64

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Методи за определяне разделителната способност на очила за нощно виждане

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(Р е з ю м е)

Разделителната способност е най-важната характеристика на оптоелектронните уреди (ОЕУ) и в частност на очилата за нощно виждане (ОНВ). Тя често се използва като основен параметър за сравняване качеството на различните видове ОНВ. В настоящата статия са представени по-важните методи за определяне разделителната способност на ОНВ, както и измерителните единици. Основният метод за определяне на разделителната способност на ОЕУ е методът, използващ тест-обект (мира – USAF 1951 Tri-bar Chart), а измерителната единица е брой линии на 1 mm. Показани са типичните стойности на резделителната способност на ОНВ, в зависимост от поколението на използвания електронно-оптичен преобразувател (ЕОП).