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What's Crucial in Night Vision Goggle Simulation ?

Frank L. Kooi*, Alexander Toet

TNO Human Factors, Kampweg 5, 3769 DE Soesterberg, The Netherlands

ABSTRACT

Training is required to correctly interpret NVG imagery. Training night operations with simulated intensified imagery has great potential. Compared to direct viewing with the naked eye, intensified imagery is relatively easy to simulate and the cost of real NVG training is high (logistics, risk, civilian sleep deprivation, pollution). On the surface NVG imagery appears to have a structure similar to daylight imagery. However, in actuality its characteristics differ significantly from those of daylight imagery. As a result, NVG imagery frequently induces visual illusions. To achieve realistic training, simulated NVG imagery should at least reproduce the essential visual limitations of real NVG imagery caused by reduced resolution, reduced contrast, limited field-of-view, the absence of color, and the systems sensitivity to nearby infrared radiation. It is particularly important that simulated NVG imagery represents essential NVG visual characteristics, such as the high reflection of chlorophyll and halos. Current real-time simulation software falls short for training purposes because of an incorrect representation of shadow effects. We argue that the development of shading and shadowing merits priority to close the gap between real and simulated NVG flight conditions. Visual conspicuity can be deployed as an efficient metric to measure the 'perceptual distance' between the real NVG and the simulated NVG image.

Keywords: Visual conspicuity, image fidelity, NVG simulation, simulation assessment

1. INTRODUCTION

Night operations are critical and very common within the military. Night Vision Goggles (NVG's) offer the opportunity to extend military operations to the night. However, the quality of intensified imagery is much reduced compared to normal viewing during the day. Moreover, NVG's cause visual illusions that do not occur during the day[1]. There is a clear need for an entry-level NVG training program to familiarize inexperienced personnel with these fundamental and surprising NVG issues[2]. Here we explain and demonstrate the parameters that determine the perceptual quality of NVG's.

1.1 NVG simulation

In theory, virtual environment technologies offer a safe and effective setting for training night operations[3]. These technologies can in principle be used to accurately depict how various objects (people, vehicles, aircraft, buildings) appear under various environmental conditions such as fog and smoke, and to demonstrate the impact of muzzle flash, headlights/spotlights, and explosions on NVG's. The simulation industry has only recently begun to concentrate on the development and production of high-quality NVG image generators, driven by the military need for realistic NVG simulation. The poor image quality of current NVG's makes it in principle relatively easy to simulate NVG imagery. The field of view does not need to be very large, the contrast not very high, etcetera. High fidelity NVG simulation is therefore easier than high fidelity day view simulation. *Low quality* NVG simulation, created by presenting a greenish representation of the daytime image and by adding speckle noise appears realistic to the untrained eye. However, training night operations with low fidelity NVG imagery is risky, since personnel will not learn the true limitations and illusions that occur with the use of real NVG's. As a result someone trained with a low fidelity simulator may erroneously feel NVG confident. The fidelity of simulated NVG imagery can be described in physical and perceptual terms. The physical description is useful for the database and image designer because it provides the reference, the golden standard. The perceptual description is relevant to the end-user, since for the user the system architecture is

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* kooi@tm.tno.nl; phone +31-346-356242; fax +31-346-353977; www.tm.tno.nl

hidden and the ultimate perception is all that matters. To assess the quality of simulated NVG imagery, the end-user is best off with a list of *perceptual requirements*. These need to include the surprising and illusory aspects of the NVG image. Currently our knowledge of the impact of perceptual illusions on observer performance is limited, probably because it is hard to measure. In this and the accompanying study[4] we make a start by making an inventory of the fundamental perceptual characteristics of NVG's. We use these characteristics to derive requirements that virtual environments should fulfill to simulate perceptually correct NVG's.

2 PERCEPTUAL IMAGE QUALITY PARAMETERS

The basic psychophysical parameters that determine the quality of NVG's are visual acuity, field-of-view, and contrast sensitivity. Using simple psychophysical tests these parameters can easily be measured by observers. By also measuring the same parameters in daytime, the quality of an NVG can be compared to standard daytime vision. Figure 1 illustrates the main NVG degradations compared to daytime vision. Of these three image quality factors, resolution is in fact factor *least* affected by the NVG.

2.1 Visual illusions

Not only is intensified imagery of lower quality, but it is also *different*. NVG imagery therefore induces visual illusions that are not present in normal daytime vision, and these effects are easily overlooked in the simulation of image NVG imagery. Berkley[1] discusses a large number of examples of night vision goggle (NVG) illusions. From the analysis of these illusions we conclude that they are induced by the following four underlying effects:

Reflectivity by chlorophyll. Figure 7e illustrates the contrast reversal in NVG's due to the intense reflections by the chlorophyll in the scene. Chlorophyll is a green pigment found in most plants and is responsible for light absorption to provide energy for photosynthesis. It reflects most of the near-infrared light where NVG's have their peak sensitivity, just outside the visible part. As a result chlorophyll looks very bright in NVG's which gives scenes an unnatural appearance.

Shadows. The degradation of image quality is not uniform all over the scene, but depends on local scene illumination. Details that are normally well lit remain visible at low light levels, whereas details that are in the shadows are much more reduced in visibility when the light levels drop. Figure 7d shows a representative example of this principle. The soldier standing in front of the entrance of the building is clearly visible, both with unaided vision in the daytime and with an NVG at night. When the soldier stands in the doorway he is also visible with unaided vision in the daytime. However, because the light level at this location is significantly less than the mean light level in the rest of the scene, the soldier is no longer visible in the NVG image. This is a result of the compressed contrast representation of NVG's (Figure 1). Chapter 3 quantifies the reduction in target conspicuity.

Color. NVG's do not provide color, just greenish images. As a result untrained observers are inclined to interpret terrain as being vegetated.

Halos. NVG images usually represent luminous objects with bright circles around them, called halos. The size of these halos is independent of the distance to the bright object, and can therefore not be used as a distance cue. Moreover, halos wash out all details in the direct surrounding of the bright object.

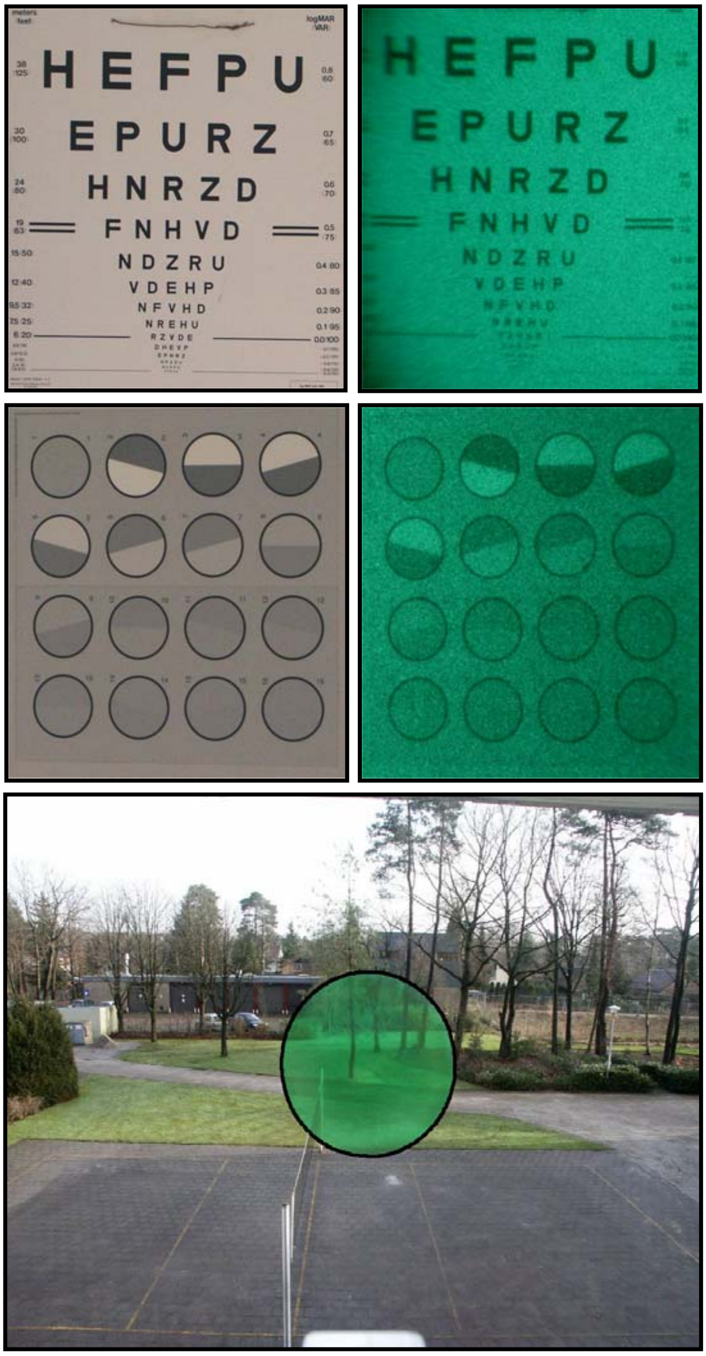


Fig. 1 Representative visualization of the degradation of image quality of a modern NVG relative to normal daylight vision, without the characteristic photon noise. **Upper row**: The naked eye in daytime can read 2 to 5 rows further down than the NVG aided eye on respectively clear and dark nights. **Middle row**: Daytime vision reaches to 4 to 8 times lower contrasts than NVG vision. **Lower row**: Field of view. The greenish inset represents the standard 40° NVG field-of-view, relative to the 180x120°field-of-view of the naked eye. A neutral density filter was used to register the intensified image during the day.

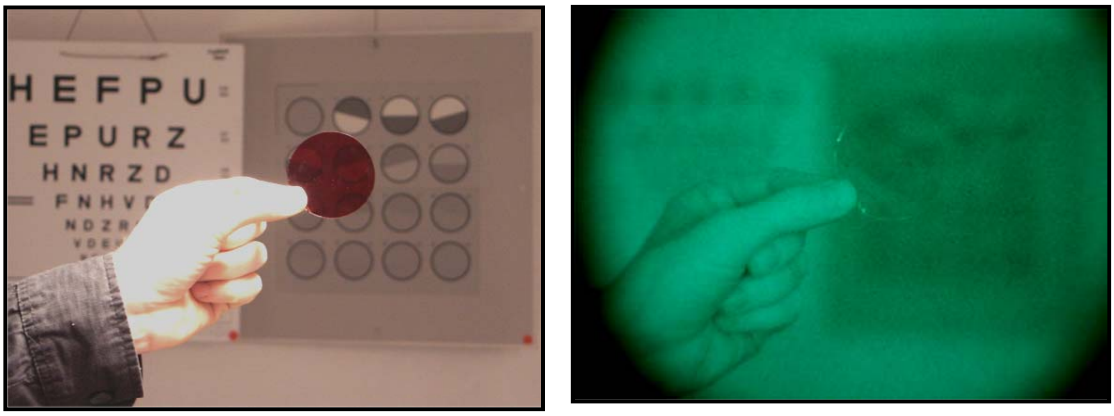


Fig. 2 Laboratory demonstration of the dominant sensitivity of NVG's for red and near-infrared wavelengths. A dark-red filter seriously degrades luminance and contrast in the daytime image (LEFT), but hardly affects the NVG image (RIGHT). The right figure also demonstrates the limited depth-of-view of NVG's.

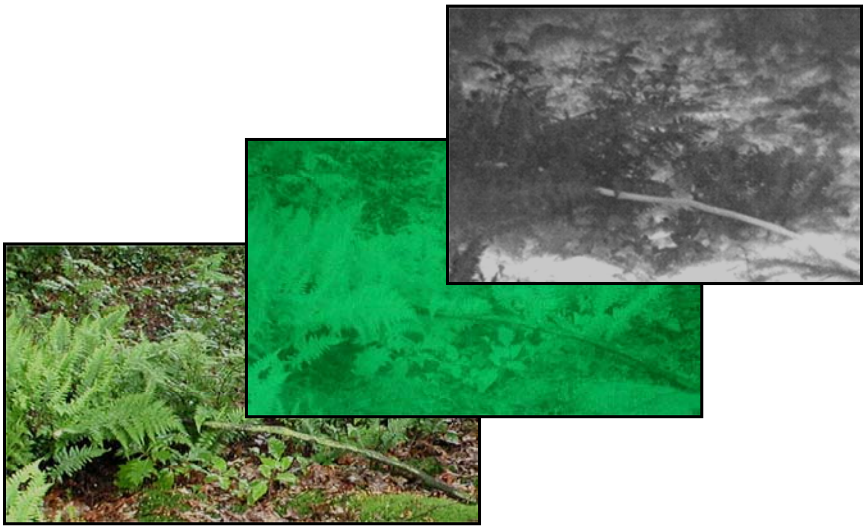


Fig. 3 Real daytime, NVG, and IR images. This figure shows that a natural environment is complex and hard to simulate. Simulation companies therefore prefer to show easily recognizable, man-made structures for advertising purposes.

3 QUANTIFICATION OF NVG SHADING

In this chapter we lay the groundwork to systematically quantify the sensitivity of NVG's to shading. We have chosen a dark hallway to measure the "conspicuity" of a target person and relate it to the amount of shading. This methodology is expanded to simulated imagery by Toet & Kooi elsewhere in this Volume[4], which also describes in more detail the patented conspicuity method which has recently been developed by TNO.

3.1 Conspicuity data

We measured the effect of shading on target conspicuity during the day and with NVG's at the TNO premises in Soesterberg, The Netherlands. Figure 4 shows two NVG recordings of the site. This scene shows the front wall of a building with an open door giving entrance to the dark hallway. We used a white reference board to perform the photometric measurements, shown in the door opening in the inset. The distance between the observer and the doorway was 23.5 m. A person standing at different locations with respect to the doorway served as target, from 2 meters in front of the entrance to 13 meters behind it. Figure 5 shows the results of the photometric and conspicuity measurements. The luminance level drops significantly down the hallway from the entrance of the door (Figure 5a). As a result the luminance of the target decreases with the distance down the hallway, making the target less visible and therefore less conspicuous. Figure 5b shows the conspicuity of the target measured by 3 observers during the daytime, and measured by two observers using a 2nd and a 3rd generation NVG at night. Note that the target conspicuity in the NVG image is much lower than the conspicuity of the target seen with the naked eye in daytime. The trend of the daytime and nighttime data is the same: all curves show a similar slope. Figure 5c replots the target conspicuity data as a function of the local light level. This figure illustrates that the conspicuity of the target in intensified imagery is always lower than in unaided daytime viewing.

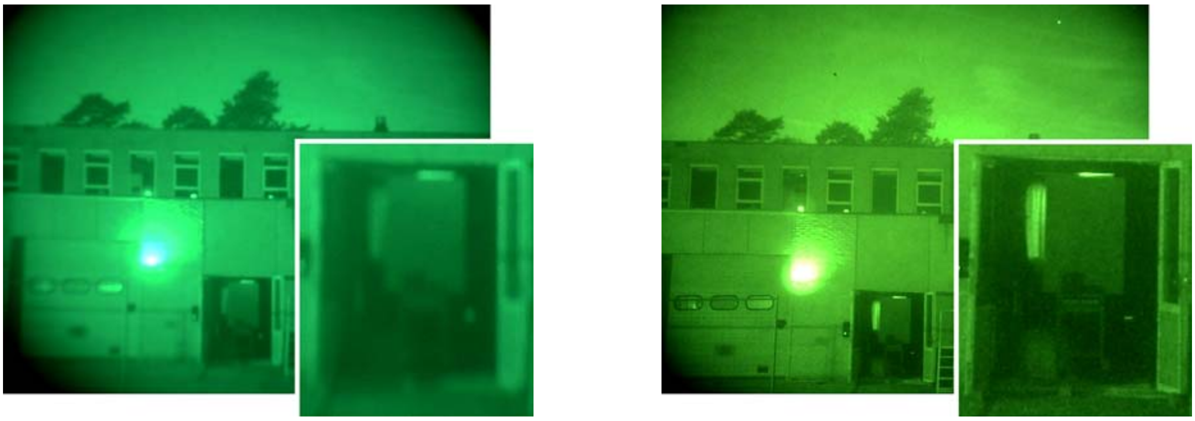


Figure 4. The door opening seen through respectively a second generation (LEFT) and a third generation (RIGHT) night vision goggle. The third generation goggle has significant better contrast in the shaded door opening and slightly better resolution. The dominant light source illuminating the building is a street light to the left and behind the camera. The bright spot represents leakage from an imperfectly shielded lamp. The insets show a magnified view of the white reference board inside the door opening.

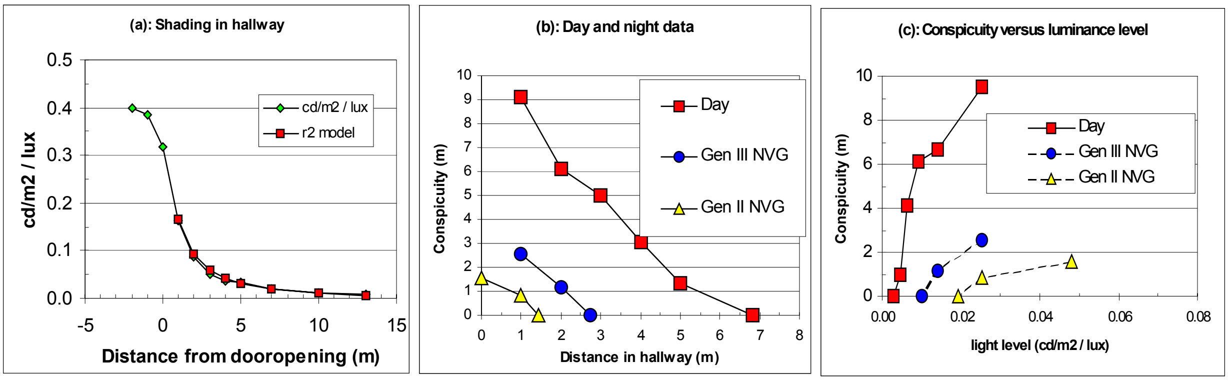
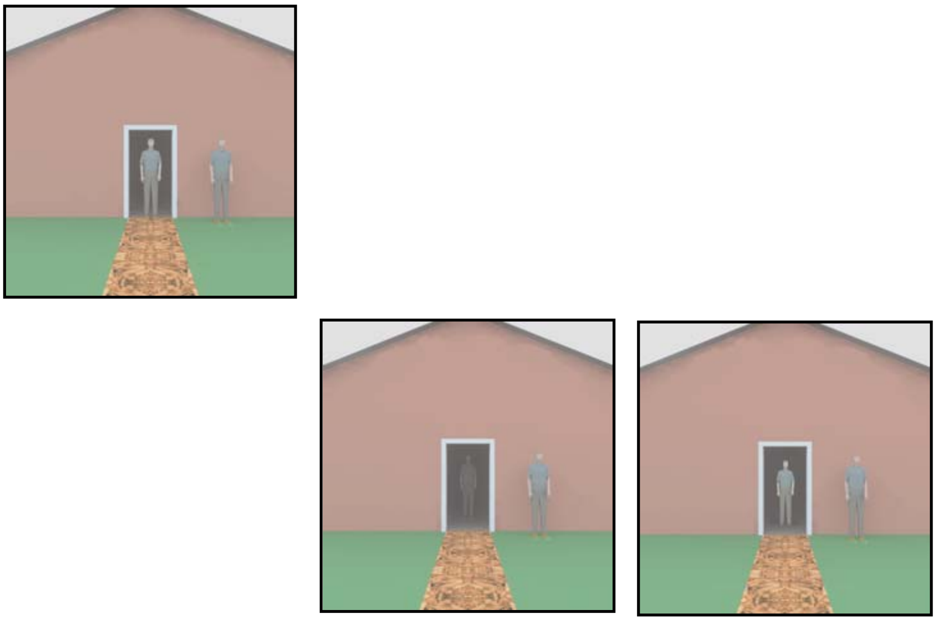


Figure 5. Results of the photometric and conspicuity measurements. (LEFT) The intensity of the light in the hallway drops off with the square of the distance from the entrance. (MIDDLE) The target conspicuity, expressed in meters distance in the frontoparallel plane, decreases approximately linearly with the distance down the hallway. (RIGHT) Replotting the data from figures (LEFT) and (RIGHT), shows how conspicuity increases with illumination level.

3.2 Simulation of (NVG) shading

The dramatic effect of shading on conspicuity argues that it is of prime importance to incorporate shading in simulation, in particular NVG simulation. Figure 6 shows what simulated shading looks like.



(a) (b) (c)

Figure 6. Simulation of the shadow situation shown in Fig. 4. The person in the doorway entrance (a) is depicted brighter than the shaded person standing inside the hallway (b). For comparison, the image on the right (c) shows the result of real-time simulation that does not take shadow effects into account; the person inside the hallway is too bright and therefore easily visible. Ray-tracing programs like Radiance (Lawrence Berkeley Lab) use intricate computational models to calculate the light distribution for each location in the simulated scene. As a result they can produce natural looking shadow effects.

4 DEMONSTRATIONS OF NVG ILLUSIONS

TNO Human Factors has recently developed a series of stand-alone demonstrations that each show one of the fundamental NVG visual limitations. All of these demonstrations consist of physical objects whose geometry is easy to interpret with the naked eye in daylight but hard to interpret with an NVG and nighttime illumination. Experiencing a visual illusion while looking at something tangible makes them very powerful. We think the demonstrations shown in Figures 7 and 8 offer powerful additions to the widely used terrain board. Note that the photographs shown here merely serve to illustrate the illusions, and that they do not come close to the visual impact experienced during an actual confrontation with the physical setup. When viewed in black & white a few of the effects will not be visible. The images in the left column of Figure 7 show the daytime views of the individual scenes, and the images on the right show the corresponding nighttime views as seen through an NVG. The demonstrations have in common that the NVG percept deviates dramatically from the daytime view. In addition, the NVG percept is misleading while the scene during daylight is immediate and easy to interpret correctly. A questionnaire distributed among Chinook flight personnel confirms the practical implications of the demonstrations illustrated here, in particular the lack of visibility in shadows, the lack of color, and the halos [5].

Figure 7a illustrates the *difference in spectral sensitivity* between the unaided eye and the NVG. The setup consists of five differently colored light emitting diodes, arranged according to the rainbow, from blue to green to yellow to orange to red. The inset shows the LED construction. The NVG image is monochrome, showing all lights as green. The NVG is particularly sensitive to red light, also sensitive to near-IR light, and relatively insensitive to blue and green light.

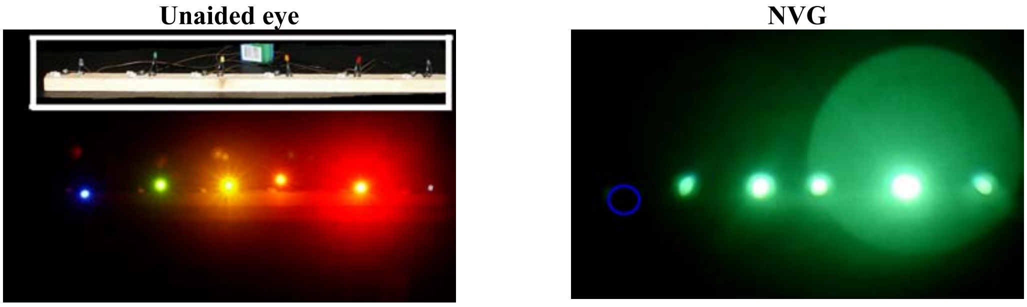
Figure 7b illustrates the effects of the *absence of color and the occurrence of halos*. This figure shows a heliport on an oil rig in the North Sea. In the TNO demonstration, a yellow flickering light representative of an aircraft marking hangs in front of the projected scene. The flickering light is easily visible with the unaided eye in daytime but hard to spot with the NVG at night. The absence of color, the glare due to the presence of halo's, and the reduced visibility of temporal change in the NVG cause this difference. The perception of flicker is is masked by the intrinsic noise of the image intensifier. When the observer moves sideways, the yellow marker distinguishes itself from the background by motion parallax and becomes easy to spot through the NVG.

Figure 7c illustrates how *halo's and the dominance of light sources* can cause a dramatically distorted NVG depth perception. The scene represents setup in the TNO laboratory, consisting of a wire frame to which several light sources haven been attached. With the naked eye the correct geometry is apparent (from left in front to right in back) but with the NVG the perceived geometry flips. When the observer moves sideways it appears as if the construction becomes fluid: the geometry distorts. The correct perspective does not re-appear as is usually the case with geometrical illusions. This demonstration is particularly powerful because the viewer cannot overcome the illusion even when he is aware of the correct geometry.

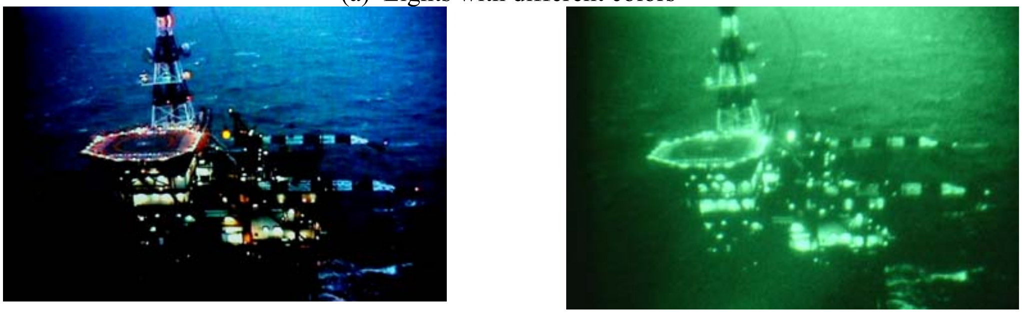
Figure 7d demonstrates the lack *of NVG image quality in shadows*. This scene represents a soldier standing just behind the opening of a doorway. The soldier can easily be seen with the unaided eye in daytime, but is almost invisible when seen with NVG's at night. The difference between black and dark grey disappears as a result of the poor contrast transfer of NVG's. The previous chapter systematically quantifies this effect.

Figure 7e illustrates some dramatic effects of the *high reflectivity of chlorophyll* in the near-IR. The scene shows two piles of bricks in the foreground, with trees and grass in the background. Behind the trees there is a house. At some places the roof of the house and the sky can be seen shining through some of the less dense spots in the leaves of the trees. During the day (LEFT) the dark branches provide a strong contrast with the roof reflecting the light of the sky and the sky itself. This obvious visual distinction disappears in the NVG image (RIGHT) because the trees and roof lack luminance as well as color contrast.

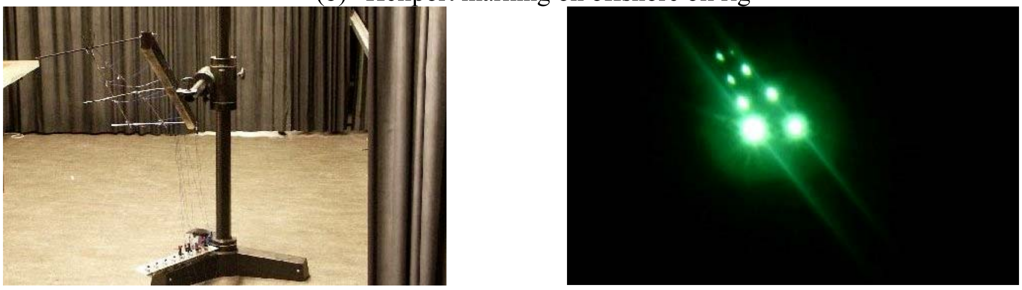
Summarizing, the limitations of NVG imagery can induce a range of powerful and potentially dangerous illusions. The stand-alone demonstrations developed by TNO Human Factors can be deployed to train observers how to cope with the fundamental limitations of NVG's.



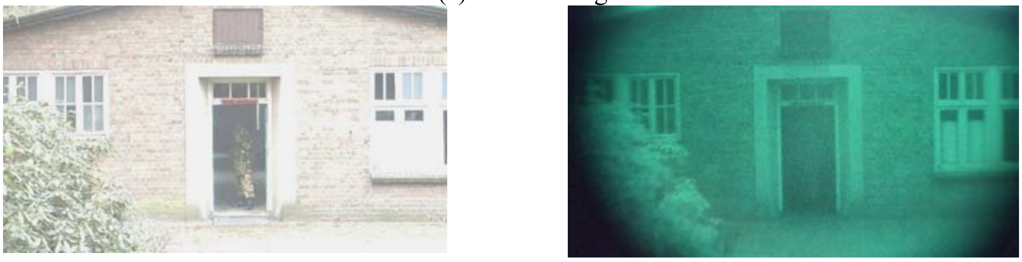
(a) Lights with different colors



(b) Heliport marking on offshore oil rig



(c) Line-of-sight



(d) Man standing in door entrance

(e) Effect of chlorophyll reflection on roof-in-the-background recognition

Figure 7. Illustration of different illusions occurring when viewing through NVG's (see text).

5. ATMOSPHERIC EFFECTS

While flying with NVG's, subtle atmospheric effects easily go unnoticed[1] whereas they are immediately apparent during the day. It is likely that practically all the NVG limitations mentioned in this paper contribute to this effect. The distinction between sky and ground can in specific circumstances dramatically reduce with NVG's. Figure 7e shows one example of this effect. Here we discuss the three contributing factors, demonstrated in Figure 8.

5.1 The high reflectivity of sky and chlorophyll

In normal daytime viewing clouds and fog always are brighter than the ground. A typical reflection factor of sand is 0.1 to 0.3, meaning that it reflects only 10% to 30% of the incident light. When seen through NVG's extremely high reflectivity of chlorophyll (up to 90%) can make vegetation appear equally bright as the sky.

5.2 The green NVG color

The monochrome green color of NVG's makes the color of sky and ground identical. The visual system tends to group objects of similar color together, hampering segmentation of sky and ground.

5.3 The low NVG resolution and contrast

Since NVG's reduce the resolution and contrast of the perceived scene relative to normal daytime vision with the unaided eye, small details and subtle luminance variations go unnoticed when flying with NVG's. As a result texture and subtle shading can not be seen (Figure 1). This will further degrade the ability to discriminate the typically textured ground from the typically un-textured sky. The reduced contrast reproduction in NVG's contributes to the poor visibility of a gradual change in cloud density.

Naked eye **NVG**

Both with fog

Figure 8. Demonstration of the good visibility of fog with the naked eye (LEFT) and the poor visibility of fog through an NVG (RIGHT). The difference in perception in the hands-on demonstration is very convincing. The fog can be produced with a compact standard fog generator. The phenomenon lends itself to be demonstrated in combination with a terrain board. As explained in the text, three NVG characteristics contribute to the effect.

6. CONCLUSIONS

Training night operations with simulated NVG images has great potential since, compared to direct viewing with the naked eye, NVG imagery is relatively easy to simulate and the cost of NVG training is high (logistics, risk, civilian sleep deprivation, pollution). Training is required to correctly interpret NVG imagery. Although the images look natural, their characteristics differ from those of daylight images and regularly induce visual illusions. Simulated NVG imagery should at least reproduce the essential visual limitations: reduced resolution, reduced contrast, limited field-of-view, and absence of color. It is particularly important that simulated NVG imagery also shows three other essential visual effects that induce visual illusions with NVG's, namely the high reflection of chlorophyll, shading, and halos. Current real-time simulation software seriously falls short because of the absence of *shadow effects*. We argue that the development of shading and shadowing merits priority to close the gap between real and simulated NVG flight. Conspicuity can be deployed as an efficient metric to measure the 'perceptual distance' between the real NVG and the simulated NVG image. A number of characteristics of image intensification can be trained efficiently by deploying photo- and video-simulation techniques, with a terrain board, and with the illusion demonstrators shown in this paper. An all-round NVG training program should include each of these methods.

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