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Psychophysics of Night Vision Device Halo

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1. Overview and Purpose: In modern Night Vision Devices (NVDs) 'halo' around bright light sources remains a salient imaging artifact. Although a common feature of image intensified imagery, little is known of the perceptual and operational effects of this device limitation. This paper describes two related sets of experiments. In the first set of experiments, we provide quantitative measurements of Night Vision Device (NVD) halos formed by light sources as a function of intensity and distance. This characterization allows for analysis of the possible effects of halo on human perception through NVDs. In the second set of experiments, the effects of halation on the perception of depth and environmental layout are investigated psychophysically. The custom simulation environment used and results from psychophysical experiments designed to analyze halo-induced errors in slope estimation are presented.

2. Background: Accurate simulation of image intensifier physics and NVD scene modeling is challenging and computationally demanding, yet needs to be performed in real-time at high frame rates and at high-resolution in advanced military simulators. Given the constraints of the real-time simulation, it is important to understand how NVD artifacts impact task performance in order to make rational engineering decisions about the required level of fidelity of the NVD simulation. A salient artifact of NVD viewing is halo, the phenomenon where the image of a bright light source appears surrounded by disc-like halo. High-fidelity physical modeling of these halo phenomena would be computationally expensive. To evaluate the level of approximation that would be sufficient for training purposes human factors data is required.

3.Experiment Series 1, Halo Metrics: A custom built light source and optical bench were designed to present variable intensity NVD stimuli at a range of distances. For each condition, three measurements of halo angular size were obtained. Two subjective measures were used to estimate apparent halo angular size. A digital camera and image processing algorithms were used to obtain estimates of the objective (physical) angular size of the halo image displayed on the NVD phosphor screen. All measures were cross calibrated to each other, and to standard targets at known distances to get commensurable data in terms of visual angle at the NVD.

The results suggest that that if a point source is bright enough to generate a halo, then the size (but not intensity or transparency) of that halo is approximately constant with respect to distance and intensity, at least until secondary halos are apparent. Any change in apparent size is small compared to the more salient effects of halo disappearance or double halo appearance as the source intensity is decreased or increased respectively.

4. Experiment Series 2, Psychophysical Experiments Simulating Helicopter Approach: The finding that primary halos do not change appreciably in angular size with changes in distance to the generating source lends them interesting properties as perceptual stimuli. Specifically, halos of light sources in the scene appear to be associated with the generating light sources and localized in the scene but do not undergo the same perspective transformation as other stimuli encountered in our normal visual experience. Thus, we might expect that halos might be subject to a variety of perspective-based illusions. For instance, a halo should appear to shrink as a light source is approached, and an isolated bright halo should appear nearer than a dim one even if further away. These predictions of the visual perception of isolated halos have been verified informally in our lab. With a mobile observer navigating through a complex environment, the effects of halos on perception are more difficult to predict. In the present experiments we examine how halos may act as visual stimuli to influence the perception of objects and scene layout in more complicated visual scenes. To simulate these environments under controlled laboratory conditions a custom NVD simulation environment was developed.

4.1. Simulation Environment: Based on physical models of NVD operation, three-dimensional computer graphic simulations over modeled terrain were rendered by a cluster of PC workstations. Scenes were modeled in 3D Studio Max based on digital terrain maps. An in-house developed virtual environment application programming interface (VE 2.2) was used to control and configure the simulation, display, and input devices. The simulation is primarily visual and aircraft dynamics were not modeled. Extensive use of state-of-the art shader language techniques allowed real-time generation of the modeled NVD halo. The experiments were conducted in a large format stereoscopic virtual immersive environment.

4.2. Procedure: In one set of experiments, observers (N=5) were required to judge their attitude with respect to the ground during simulated flight over terrain. The modeled world contained a large flat plateau with a landing strip in the centre. The plateau was surrounded by simulated mountains that were unpredictable in location, height and distance on the plateau to prevent their being used as visual cues. The surfaces were rendered with halo or non-halo inducing light sources distributed on the ground plane. The intrinsic texture and perspective cues to depth in the scenes were varied by changing the regularity and configuration of the light sources. To explore the effects of observer motion the simulation was either static (simulating a hover), or depicted lateral motion or a simulated level flight approach. During the simulation, observers were instructed to estimate the slope of the ground (in pitch) with respect to the virtual camera. Following the test stimulus, a full-cue daylight scene was displayed with random pitch angle. The observers were given control of the pitch of the virtual camera, and were asked to match the attitude of the virtual camera to their estimate.

In another set of experiments, the same observers viewed a simulated approach to the runway, and estimated the aimpoint or touchdown point given their current heading. After viewing the approach sequence, the simulated approach stopped and the observers moved a visual marker to align with the estimated touchdown point.

4.3. Results: Observers perceived increasing slant with increasing simulated slant in the daylight conditions and in night time conditions with regular patterns of lights. Irregular patterns of lights conditions resulted in a weak correlation between perceived and simulated slant. When slant is perceived and halos are present, subjects report a strong impression of an increase in the perceived size of the halos with simulated distance although halos are constant size over the image. This is appropriate size constancy as found in Emmert's law. There is little conflict here as the strong slant cues dominate and the halo invariance is seen as a size gradient. Subjects report that they can 'see through' the halo to the slanted surface suggesting they can segregate the slant of the surface from the frontal slant specified by the halo. This subjective report is consistent with the finding that subjects are able to estimate surface slant in the presence of halo as accurately as in halo-free scenes.

5. Conclusions: NVD halos generated by light sources in a scene have a size that is approximately invariant with intensity and distance. Objective and subjective measures of halo geometry indicate that halo size, when halo is present, is relatively invariant of target distance or intensity. This property results in perceptual distortions and strong illusions with isolated stimuli. In complex scenes, systematic distortions of slant are predicted due to an imposed texture gradient created by the halo. We investigated this hypothesis in psychophysical experiments. The results suggest that perception of slant and glideslope in complex scenes is remarkably tolerant of texture gradients imposed by NVG halo. These results will be discussed in terms of NVG simulation and of the ability of human operators to compensate for perceptual distortions.