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Experimental Validation of an NVD Parametric Model

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1. Overview and Purpose: As part of the effort to create realistic synthetic imagery, it is important to accurately model fluctuations in the NVG output signal for weak, uniform input irradiance. The NVG model was designed to facilitate comparisons with laboratory experiments. In particular, the model created synthetic "weak-signal NVG images" of a scene one photon event at a time by a statistical treatment of the creation of photoelectrons at the photocathode of the NVG. Temporal and spatial statistics of such synthetic imagery could be compared in detail to laboratory experimental results. More intense NVG images were treated as the sum of a sequence of weak-signal images, where the NVG parameters could vary between images. This methodology allowed the modeling of point spread (optical and NVG halo) and automatic gain control in a manner that was convenient for comparisons with experiments. This work describes a weak-signal model that was used to create synthetic imagery. The synthetic imagery was then evaluated using statistical parameters calculated from the imagery. Comparisons were made with laboratory measurements, down to the single-photon level of signal. Of particular interest was the spatial/temporal probability of photoelectron creation.

2. Background: In military simulators, frame rate and spatial resolution considerations can limit the time available for the generation of each frame of an NVD scene model. It is expected that there will be a concomitant reduction in image 'fidelity'. For psycho-physical experiments, small effects can sometimes bias the results in a highly nonlinear manner, so that image 'fidelity' is expected to be important. Hence, it is desirable to verify that synthetic images (from a simulator) being used for such experiments are free of spatial or temporal anomalies that are generated by the simulation process itself. A 'laboratory model' of NVG output need not have severe constraints on frame rate or spatial resolution, and so can take the time needed to accurately model the physical processes within the NVD. An image-generation process that closely follows the physical processes involved in the NVD is expected to provide better 'fidelity' than a generator for which operating speed or other parameters are the most important design criteria.

An important example is the signal shot noise due to the Poisson random process by which photoelectrons are generated. The fundamental physics of the creation of an isolated photoelectron is well known. With a sufficiently weak input irradiance, each channel of the image intensifier of the NVG can be considered independent, and sequential signals on the same channel can be made far enough apart (on average) as to also be independent. This approach uses the assumption that photoelectron events pass through the NVG very rapidly compared to the average time between events or to the time for recovery of an NVG channel after an electron-multiplication event.

The ‘weak-signal’ assumption was met for typical irradiance conditions by choosing a short-enough time duration (a ‘time slice’) for the application of the model. The process was repeated for subsequent time slices. Between time slices, the state of the NVG (eg the gain) could be varied to match the expected physical effects. The photosignals from different time slices were summed to give the total output over the desired integration time (eg 50 msec). While this method for modeling NVG output is easily justified from a physics standpoint, it can take significant computational time if the time slice is small compared to the integration time, and so the method is not generally useful for a real-time simulation. However, the realism of the model is expected to be excellent, and can be compared to experiments at the lowest level of signal – the creation of a single photo-electron. Measures for ‘realism’ are needed, and these measures must be quantitatively verifiable in the laboratory.

Suitable laboratory physical (as opposed to psycho-physical) experiments can validate such a ‘time-slice model’ and can point out statistical characterizations of the synthetic imagery that are sensitive indicators of inappropriate model behaviour. Once a robust set of characterizers has been developed, it can be applied to simulator outputs to identify potential anomalies.

3. Laboratory Evaluation System:

a) Photon Events: To measure the statistics of the (highly non-uniform) images created from weak photosignals from a uniform source, **t**he response of an NVG to individual photon events was measured by reimaging part of the fluorescent screen of the NVG onto a photomultiplier. The photomultiplier noise was readily distinguished from the NVG signal at the output of the fluorescent screen by a binary threshold on signal amplitude. (The means and halfwidths of the two amplitude distributions are generally very different.) This method was a sensitive measure of NVG temporal response at light levels low enough that individual photon events were well separated in time. Both the experiments and the weak-signal model measured individual photo-electron creation events, and so the model could be compared to experiment at the most fundamental level.

b) Halo Imagery: For measurements of the spatial response of an NVG to a localized light source, a camera replaced the NVG eyepiece and recorded an image of the fluorescent screen (of the NVG). The amplitude of the light source could be varied over 5 decades by pulse-width modulation.

c) Temporal Behaviour: A ‘pump-probe’ configuration of the light source in the camera setup was used to examine the temporal behaviour of the NVG parameters, particularly the automatic gain control (AGC), at higher signal levels.

4. Statistics of Photon Events: The photomultiplier apparatus was able to measure the response of the NVG to single-photon events with a time-resolution of better than 10 microseconds. The spatial resolution was adjustable. Only a single, contiguous region of the fluorescent screen of the NVG was imaged at any time. From the time decay of the single-photon events, the decay constant of the fluorescent screen was determined. Histograms of the time between photon events and event amplitudes validated the Poisson nature of the photodetection process in the NVG and provided experimental data for sensitive comparisons of modeled imagery against those from a physical NVG.

5. Halo Imagery and temporal behaviour: A commercial digital camera was used to record the output of the fluorescent screen of the NVG in response to a light source whose range, aperture and intensity could be precisely controlled. Average intensity was precisely varied by changing the duty cycle of the LED light source, which was operated in pulsed mode. The apparatus could model halo phenomena. A second, synchronized, light source was used to set the state of the automatic gain control of the NVG. By control of the timing of the light sources, the temporal behaviour of the automatic gain control of the NVG was experimentally determined.