NISTIR 6900

# Evaluation of the Liquid-Filled Camera For Measuring Shadow Detail Part I: Sensor Evaluation

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August 2002

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# PART I: SENSOR EVALUATION

## Abstract

The simulated-eye-design (SED) camera is an attempt to use the technology inherent in the human eye to enable light measurements of complicated objects and virtual images with fewer effects from veiling glare. The interior of a CCD (charge-coupled-device) camera is filled with a liquid or a solid or a combination of the two. A variety of other phenomena are also investigated as a means of reducing the effects of stray light. In order to fulfill part of the obligation to outside agency support* of this activity, several NIST Internal Reports are to be written to describe the project progress. This document is the first of these reports, and describes the evaluation of the sensors used in the camera. Subsequent reports will address various steps in the development process.

## Introduction

Despite advances in electronic photography, such as the advent of the charge-coupled-device (CCD), all cameras still suffer from the effects of veiling glare [1]. Veiling glare results from light reflecting off of internal structures of the lens and camera (iris, shutter,

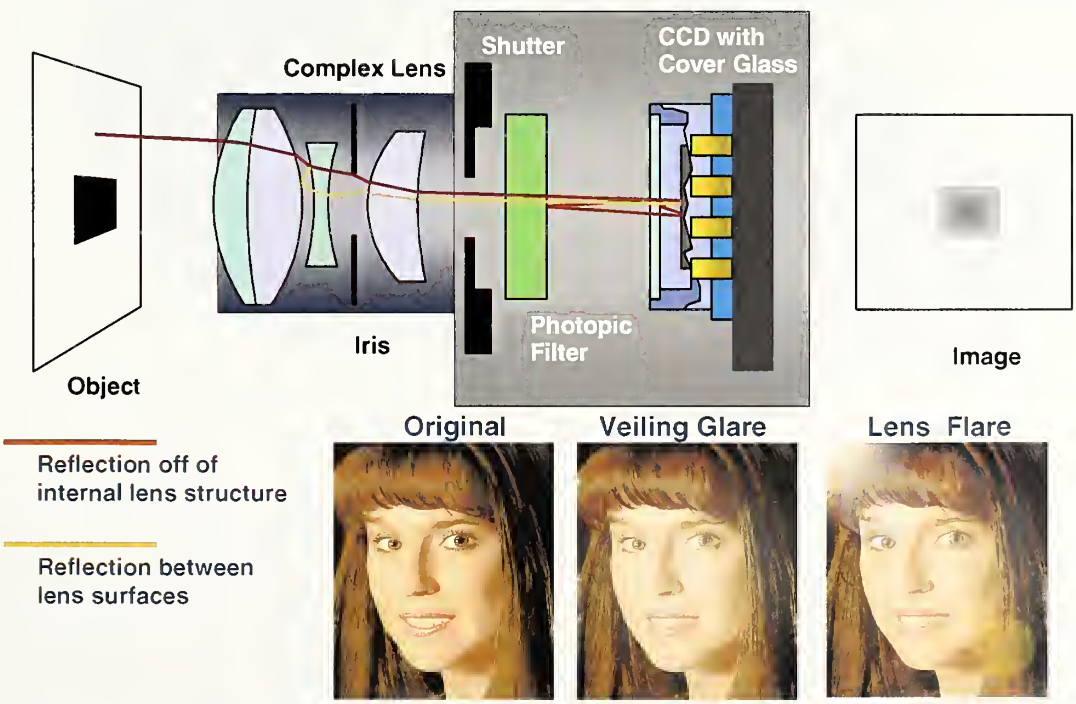


Fig. 1. Stray light within the camera—veiling glare.

* This investigation is funded by the Combating Terrorism Technology Support Office/Technical Support Working Group through the NIST Office of Law Enforcement Standards

camera body interior, and other parts) and between lens surfaces (see Fig. 1). This effect is manifested by an overall "washing out" of the image. Discrete reflections of sources of light, often referred to as lens flare, may also occur. The images in Fig. 1 illustrate the phenomenon.

In many cases, the eye can see a sufficient dynamic range to distinguish shadow and dark detail in all but the most extreme situations, whereas even the best cameras cannot reveal the dark detail readily seen by the eye due to the presence of veiling glare. Often, as with surveillance cameras, shadow or dark details are required for proper identification and analysis of the scene or object under investigation such as a face or terrorist activities occurring in shadows.

The simulated-eye-design camera seeks to reduce the effects of veiling glare by filling the camera with liquid, painting surfaces glossy black, wetting the surfaces, and positioning the aperture inside the system. A comparison of the design of the liquid-filled camera with a simple camera is illustrated in Fig. 2. The first prototype of the SED camera exhibited a factor of three improvement in reducing the glare from an ordinary camera [2]. It is hoped that by careful attention to construction details that a factor of 10 or 100 improvement can be achieved making such cameras more like the eye in their ability to discern shadow detail.

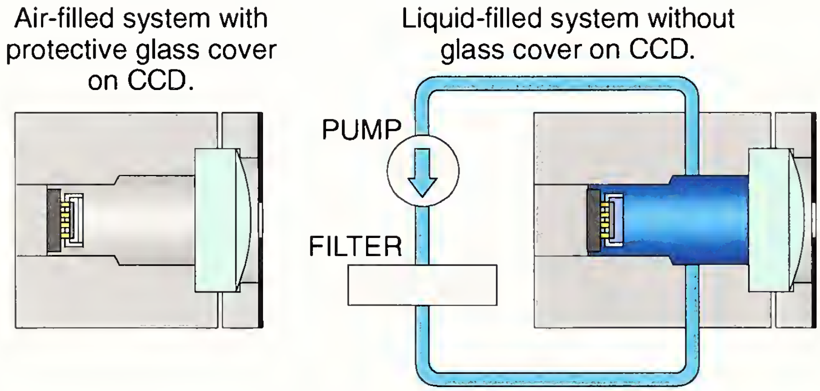


Fig. 2. Simple camera compared with a liquid filled camera.

**Sensor Requirements**

In the earlier prototype [2], the 8-bit CCD used did not provide adequate dynamic range for critical evaluation of the camera performance. The small dynamic range lent itself to streaking and blooming of the pixels and did not provide a measurement of a high-contrast pattern imaged on to the CCD. Thus, we considered a range of 16-bit CCD and complimentary metal oxide silicon (CMOS) cameras, eventually settling on one device. Our choice was based on manufacturer specifications and future availability of the sensor chip. We selected a thermoelectrically (TE) cooled 324 x 243 CCD camera with a frame-transfer electronic shutter and electron-hole recombination antiblooming. Because the camera needs to measure a large dynamic range accurately, the device must be linear—

that is, the camera gain should be constant as a function of signal. Finally, the CCD's sensitivity to stray light (independent of the lens system) should be minimal.

Several non-optical properties were considered, including price, availability of replacement, and ease of removal of the CCD sensor chip. On this last point, the chip was not socketed, and thus must be removed carefully using the appropriate desoldering tools.

## Measurements

The CCD camera was mounted with a 28 mm lens with the aperture set at f/2.8, and positioned to measure the luminance of a 15 cm (6 inch) integrating sphere with a 150 W tungsten-halogen light source. The camera was aligned normal to the source 45.8 cm (18 in) away and focused on the 38 mm (1.5 inch) exit port, so that the image of the source covered most of the CCD pixels. Luminance was varied at the source, using an iris with a precision micrometer, and tracked by using a calibrated photometer. The CCD was TE cooled to 0.0 ± 0.2 °C. All measurements were performed in a dark lab, with black walls, ceiling, and floor, and with reflective surfaces covered with black felt where needed. Fig. 3 illustrates the measurement configuration.

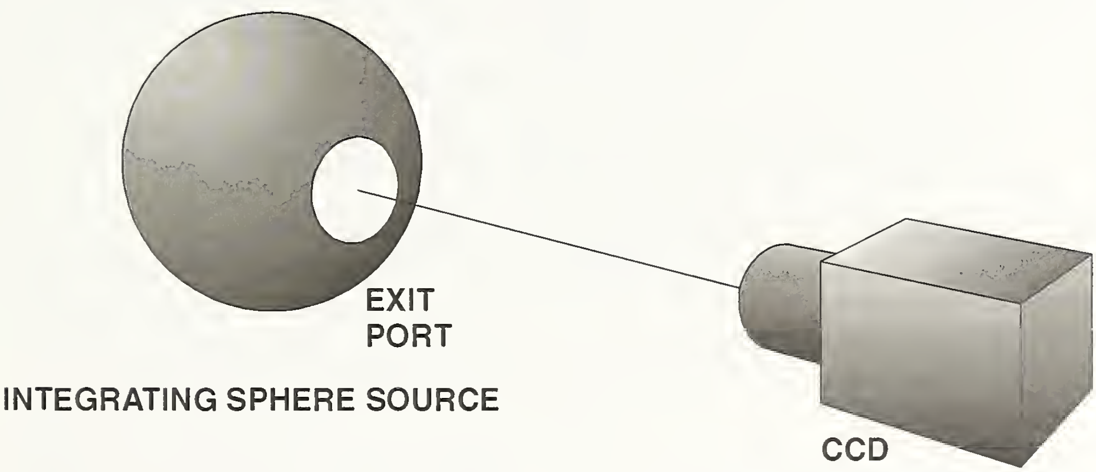


Fig.3. Configuration for the evaluation of the CCD candidate.

**Signal-to-noise.** The photon transfer curve [3] was determined for the camera by measuring the signal and noise while varying the source[†]. The signal over an area of 1000 pixels was averaged (the noise was determined as the standard deviation of the pixels in this area). In all cases, a dark image was taken and subtracted from the light image in order to remove any dark current contribution. The plot of the resulting signal-to-noise data is shown in Fig. 4. In one case, the TE cooler (TEC) set point was adjusted to 0.0 °C, while for the other, the TEC was shut off and the camera temperature allowed to reach room temperature (22.2 °C). The TE cooled data plot indicates the full-well

[†] Unless stated otherwise, the relative expanded uncertainty in all described measurements is estimated to be ± 10 % of the measurand using a coverage factor of 2.

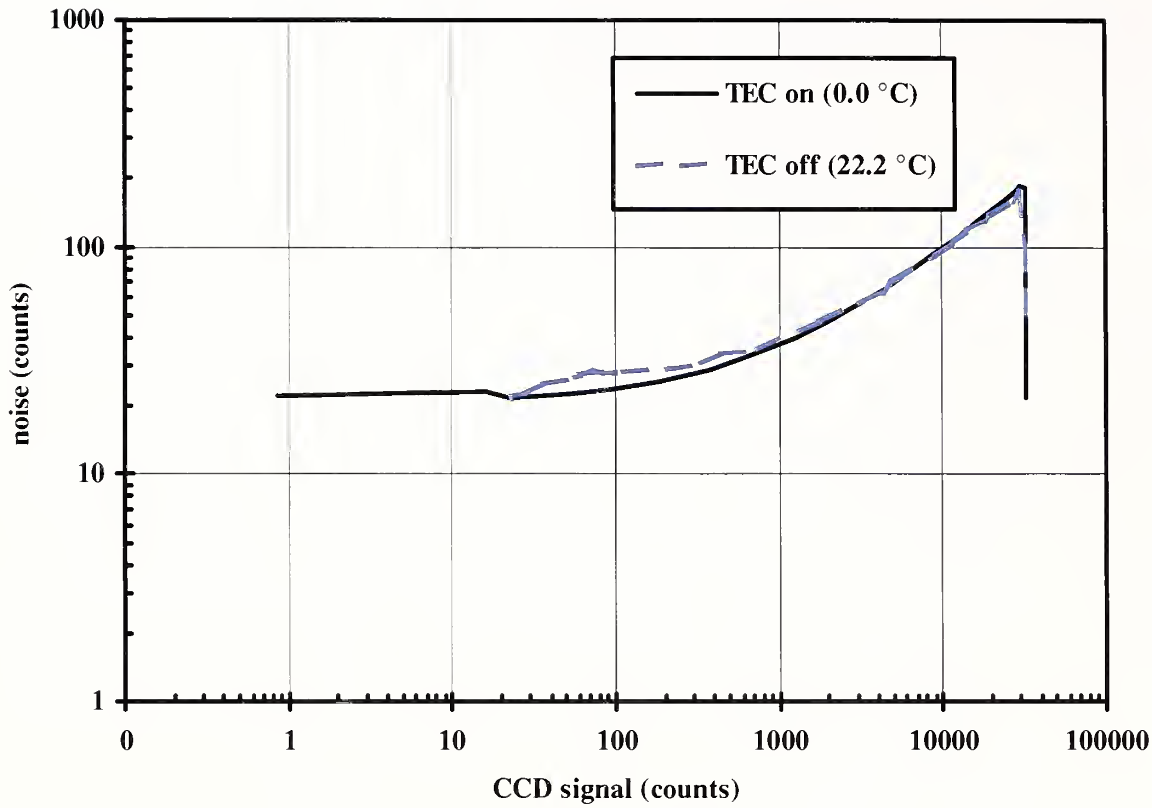


Fig. 4. Photon transfer curve of the candidate CCD.

capacity of the CCD at a signal of approximately 32,000 counts, with a read noise of 22 counts. This provides for a dynamic range of 1455:1 or roughly 10.5 bits. The 16-bit rating for the CCD refers, of course, to the resolution of the camera's analog-to-digital converter (ADC). Note how the rapid drop in noise versus signal indicates the full-well capacity, and the flatting out of the curve signifies the read noise limit of the device.

**Linearity.** Two sets of data were taken: 1) varying the source luminance at a fixed exposure, and 2) varying the exposure at a fixed source luminance. Both sets are plotted in Figs. 5 and 6. As can be seen in Fig. 5, the luminance-to-signal appears fairly linear, giving confidence in the camera's ability to measure luminance within its entire dynamic range with no corrections. Note how the signal response "flattens out" as it reaches full-well saturation.

The signal's dependency on luminance as a function of camera exposure is shown in Fig. 6. In this case, two methods of dark-current subtraction were compared, to provide an evaluation of how the software processes the images. The auto-dark function took a "light" and a "dark" image and subtracted the latter from the former. For the "light-dark" measurements, the light and dark frames were obtained separately, with the dark subtracted via a math function provided by the software. As expected, the light-dark process shows a linear variation with the exposure time in log-log space. Interestingly,

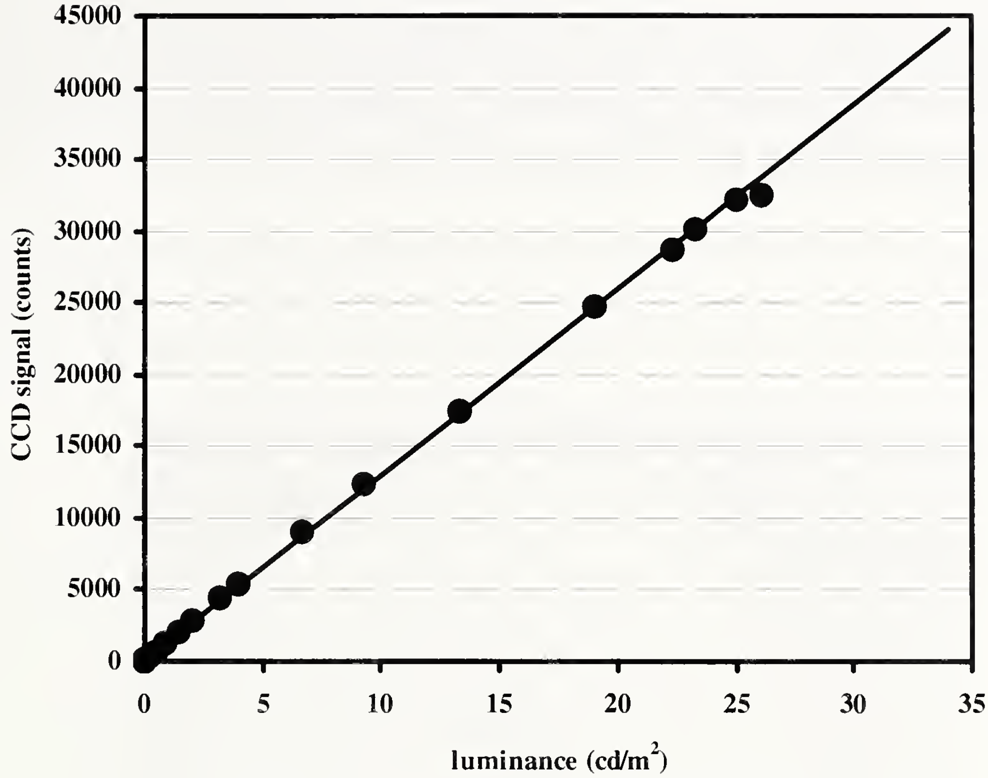


Fig. 5. Linearity as a function of luminance.

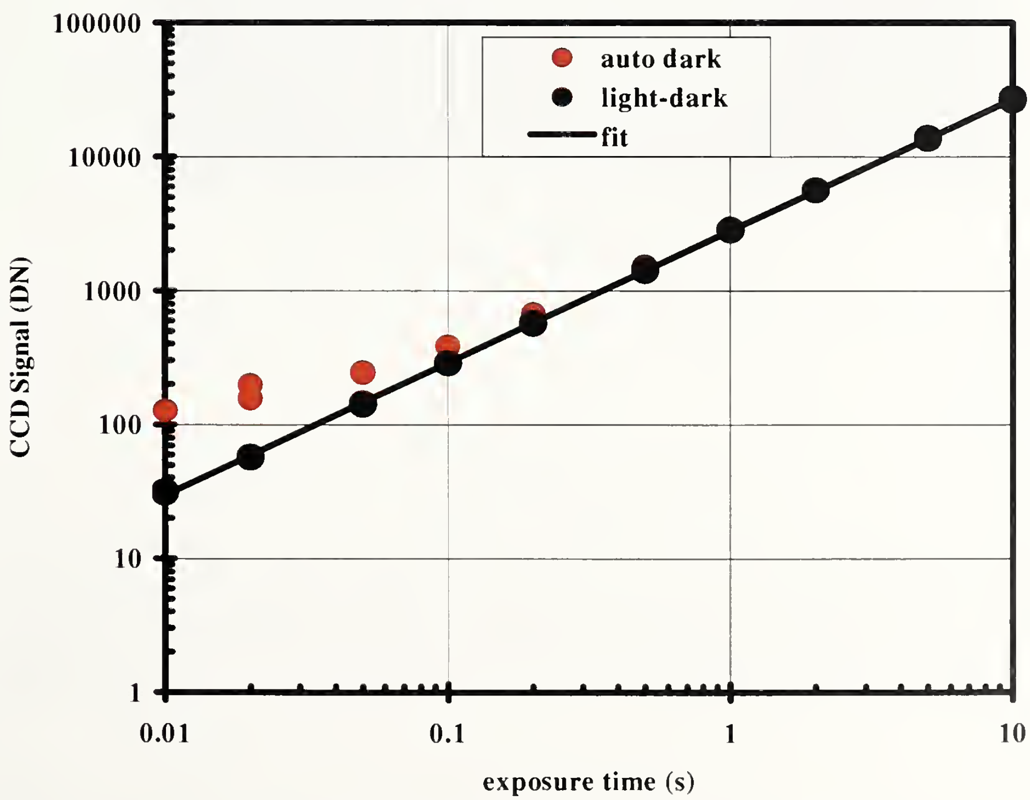


Fig. 6. Linearity as a function of exposure.

the auto-dark data deviates, and in fact, eventually flattens out at approximately a signal of 100 counts as the luminance approaches zero. The images acquired by the camera do not provide for negative signals. Thus, to avoid truncation when subtracting out the dark current, an offset is added.

**Veiling glare**. The veiling glare of the system was determined by using the method recommended by the International Commission on Illumination (CIE) [4]. A glass filter was mounted to the front of the exit port of the source, with a circular glossy black plastic mask placed at its center (see Fig. 7). The mask was ten times smaller than the exit port,

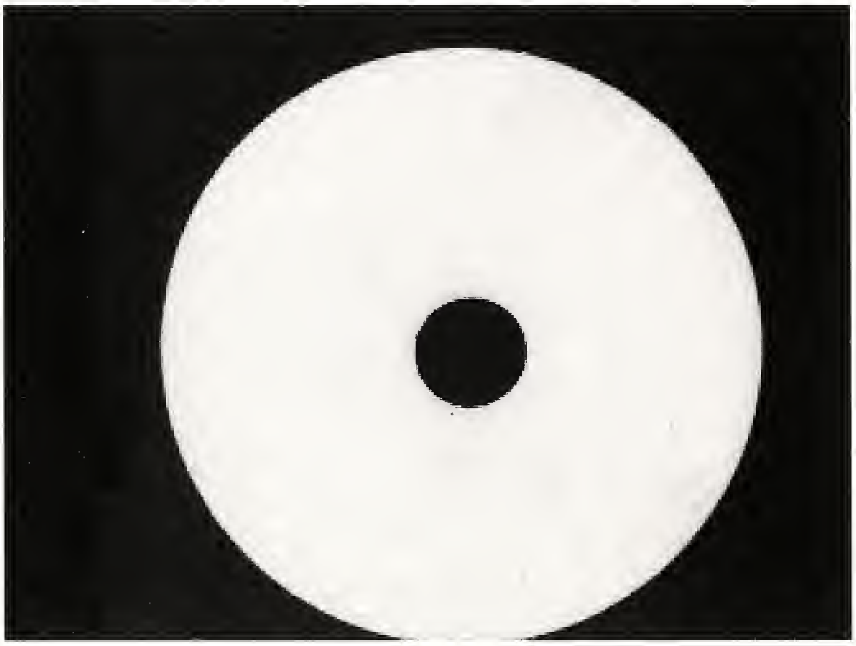

Fig. 7. Gloss trap for determining veiling glare.

to conform to the CIE recommendation. An area of the mask, 10 % less than the mask area, was measured. The same area was subsequently measured with the mask removed. The glare was calculated as follows:

$$f_g = \frac{L_{mask}}{L_{surround} - L_{mask}}$$

where $L_{mask}$ is the measured luminance of the black mask and $L_{surround}$ is the measured luminance of the exit port with the mask removed. The luminance of the source was adjusted to provide an $L_{surround}$ measurement near the full-well capacity of the CCD for a 1 s exposure. Several measurements were taken at different exposures and plotted in Fig. 8.

This graph provides an indication of the minimum exposure time for veiling glare measurements. The plot of the measurements of glare for exposures ≥ 0.01 s has a slope of zero due to the truncation of negative values by the software (as described earlier). This data was taken for a source luminance of 11 cd/m$^2$, which is low enough to allow for an inexpensive light source to be used in its place. A green light-emitting diode (LED) will be used to avoid any errors resulting from chromatic aberrations in the simple lens system.

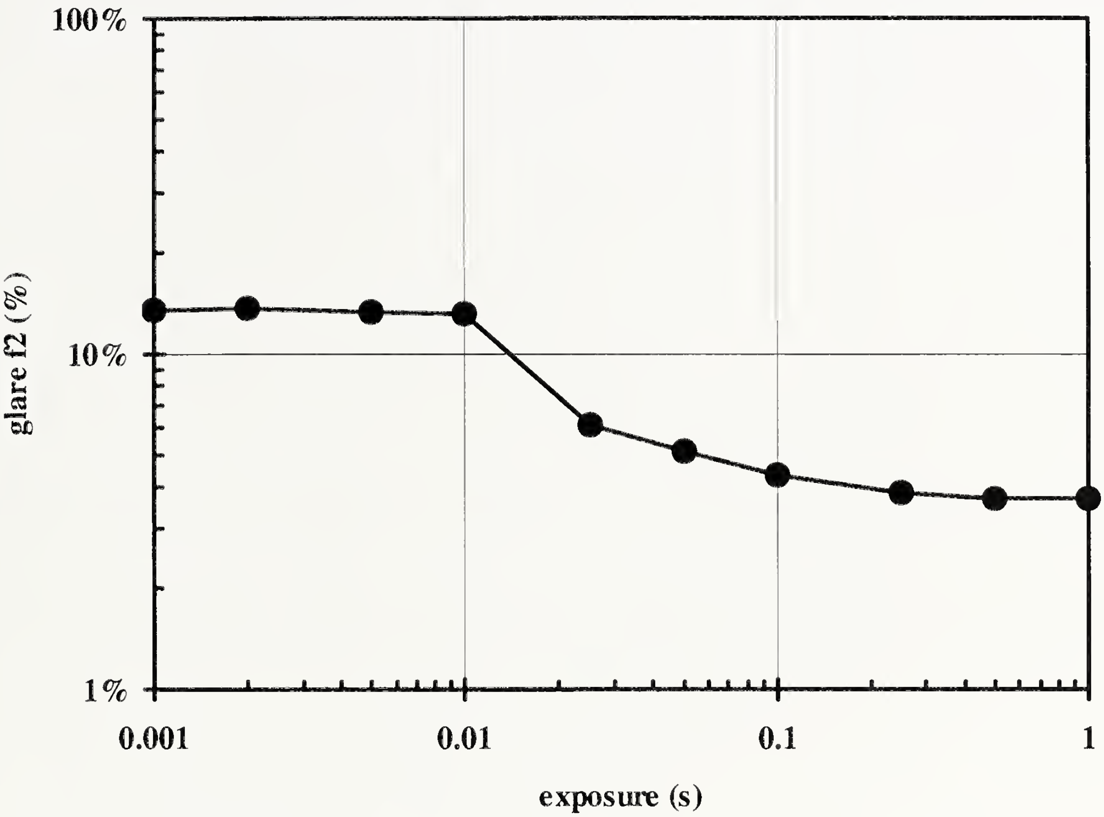


Fig. 8. Veiling glare as a function of exposure.

## Conclusion

The candidate CCD camera would appear to have adequate range to test the effectiveness of the various glare-reducing techniques. A baseline for normal operation and performance limits has been established. Furthermore, the requirements for the light source have been determined: a simple broadband green LED that will avoid chromatic aberration errors. Ideally, a sensor chip that could be easily replaced, and that exhibited a true 16-bit dynamic range, would be preferable to this particular CCD. However, if this study proves successful, we may find camera manufacturers willing to collaborate with NIST.

**Acknowledgements**

The support of Thomas Russell of NIST Office of Law Enforcement (OLES), program manager of the investigation, and Terence Hess, program manager at the Combating Terrorism Technology Support Office/Technical Support Working Group (which funds this research), is greatly appreciated.

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