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SPIE—The International Society for Optical Engineering

Flat Panel Display Technology and Display Metrology

Bruce Gnade
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Simulated-eye-design camera for high-contrast measurements

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ABSTRACT

Light-measurement instrumentation based upon high-quality charge-coupled-devices (CCD) is currently in use for measuring the characteristics of electronic displays. When such array detectors are used to measure scenes having high contrasts or wide color variations, they can suffer from the effects of veiling glare or lens flare and thereby inaccurately measure the darker luminances because of a mixing of the scene luminances or colors. The simulated-eye-design (SED) camera attempts to reduce the effects of unwanted light contamination by copying some of the characteristics of the eye. This first prototype shows an improvement of a factor of 2.7 in its ability to measure high contrasts over a similar camera that is not filled with liquid.

Keywords: liquid-filled camera, SED, CCD, contrast measurements, light measurements

1. INTRODUCTION

As new electronic display technologies become available, measurements of their characteristics become more important both for the accurate specification of display characteristics and for quantifying display quality in making comparisons between displays. Whenever these measurements are of a full screen of color or gray shade, there are few problems. However, whenever there is high contrast or multicolor subject material being displayed on the screen, an accurate measurement of any detail of the screen can be difficult owing to veiling glare—particularly the darker details can be corrupted with light from the brighter areas. Veiling glare arises from reflection of the light between surfaces of a lens or from reflection of light from some mechanical part of the lens or other part of the camera. For example, consider making a measurement of an isolated black letter on a white screen. The contamination of veiling glare in the instrument's lens system from the white screen can dominate any light coming from the black letter. The same can be said for a variety of measurement methods used to evaluate displays.[1] In Fig. 1 we illustrate how veiling glare may be produced in a camera that might be used for display measurements. In Fig. 2 we show actual photographs from such a camera illustrating the glare produced.

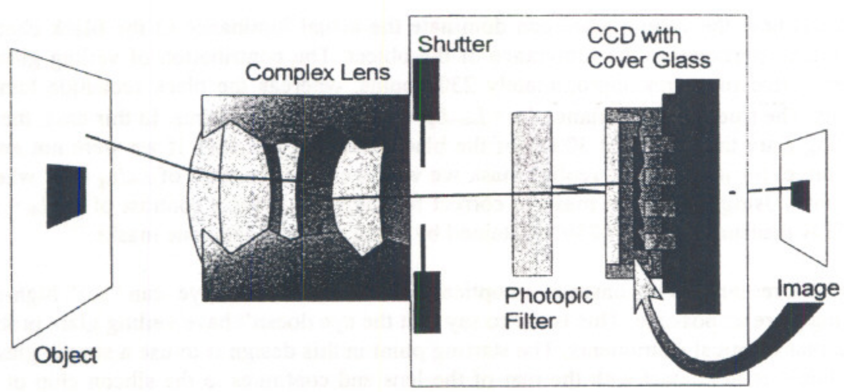

Fig. 1. Conventional photopically-corrected thermoelectrically-cooled (TEC) scientific-grade CCD camera with a complicated lens and many air-solid surfaces that produce reflections. One ray from a white area on the object is shown reflecting off of various surfaces onto the image area of the black rectangle. (This is for illustration purposes only; it is not intended to be a ray tracing.)

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2. SIMULATED-EYE-DESIGN CAMERA

Figure 3 shows two similar camera configurations. Both have a CCD placed on a movable rod to provide focus adjustment. One camera is filled with air. The SED camera is filled with silicone liquid (polydimethylsiloxane, trimethylsiloxy-terminated; viscosity of 1 cm^2/s [100 cs in older units]—about like maple syrup). Since the CCD is exposed to the liquid without the benefit of a protective cover glass, a pure silicon-based liquid is chosen. The lens on each camera is an uncoated 25 mm diameter plano-convex lens with a focal length of 25 mm. Given an index of refraction of the glass lens of $n_1 = 1.673$ and an index of refraction of the liquid of $n_2 = 1.41$ the reflectance R for normal incidence at the liquid-glass interior surface is

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2 = 0.73\%, \quad (1)$$

whereas for a normal uncoated air glass interface the reflectance is approximately 6.3 %.[6] An aperture having a diameter of 5 mm is placed directly in front of each lens. The camera bodies are made from black acetal plastic.

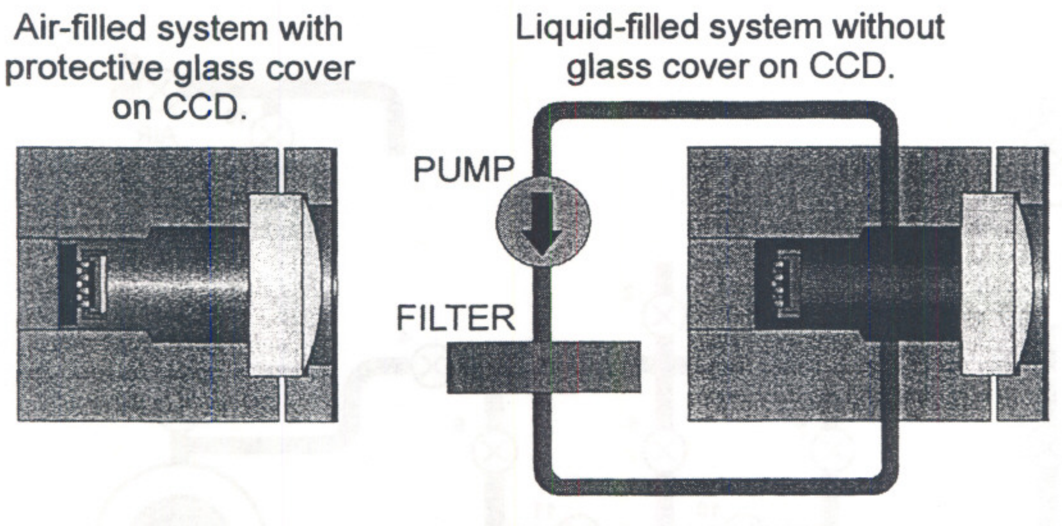

Fig. 3. An air-filled camera compared to the liquid-filled SED camera. A simplified liquid handling system is shown attached to the SED camera.

In future experiments different liquids will be tried that will much better match the index of refraction of the glass (or whatever material is used at the front surface) and further reduce the interfacial reflections or virtually eliminate them. Good antireflection coatings can easily achieve a reflectivity for any surface well below 1 %, it is true; but there are other reasons to employ liquids within the camera. The use of liquids also reduces the reflectance of other dielectric objects (the plastic interior, painted surfaces, etc.) within the camera—this is commonly seen in the way wet sand looks darker than dry sand and in the way wet streets look darker than dry streets. It was decided to use the same lens for both the simple camera and the SED camera for the purposes of comparison. Future tests can compare optimally designed optics for both types of cameras.

The disadvantage in using liquids is that they must be virtually free of particles to be useful for this application. A liquid circulation and filtration system is used to remove particles from the liquid. Figure 4 shows the rather complicated plumbing arrangement employed that permits changing the filter and making modifications to the SED camera without removing the liquid from the system. Table 1 shows some valve configurations for a few of the functions of the plumbing system. When the SED camera is initially filled with liquid it is always filled under vacuum to assure that all voids are filled with liquid. A 9 cm diameter hardened paper filter is used with pore size listed at approximately 20 μm—see Fig. 5. Using continuous filtration, however, virtually all particles are eventually removed from the liquid. We could observe the particle content in the liquid by using a 0.5 mW red solid-state laser beam through the view port (an inexpensive laser pointer will suffice). Particles become rather visible from forward or backward scattering out from the laser beam. Eventually, the liquid became clearer than the glass lens, but such clarity is obtained after several days of continuous filtration. (Extended pumping

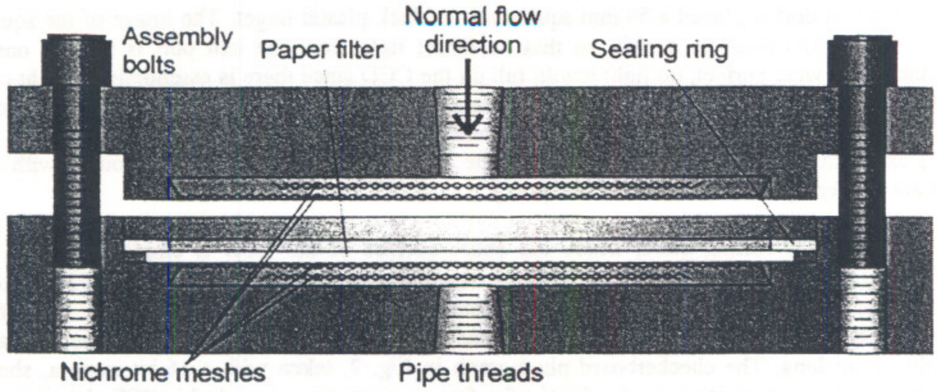

Fig. 5. Cross-section of filter. Nichrome meshes support the filter paper (white) during pumping and vacuum filling. The edges of the larger nichrome mesh hold the mesh in the top metal part so it won't fall out when the top part is inverted for assembly. The view shows the configuration just prior to assembly. The filter and seal are exaggerated in thickness for purposes of illustration.

The front of the lens is placed approximately 55 cm away from the exit port of a cubical uniform light source having an exit-port diameter of 15 cm—see Fig. 6. The maximum nonuniformity across the exit port of the light source is no greater than 2%. The light source is continuously adjustable from zero to 3025 cd/m^2 and is based upon a fluorescent lamp (thus only a minimal amount of infrared light is produced). A photodiode and ammeter monitor the luminance of the source. The linearity of each CCD is checked against the photodiode current and found to be better than 7% based on a comparison of the standard deviation of the ratio of the CCD counts to the photodiode current.

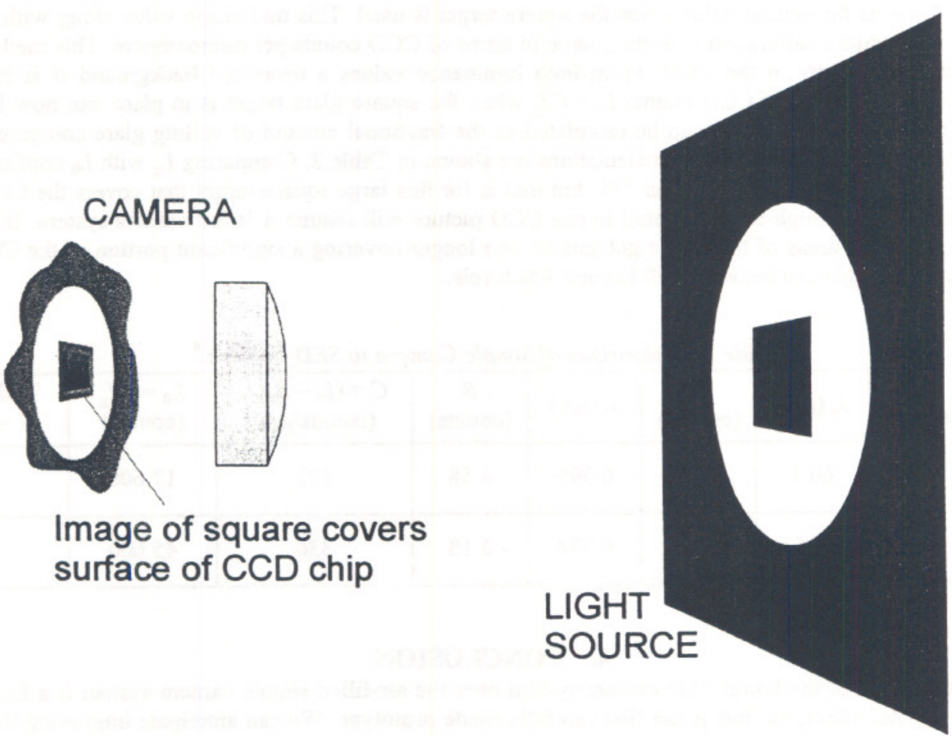

Fig. 6. The cameras view the exit port of a variable uniform light source having an opaque black square target at its center.

as with the human eye) may improve performance. (4) Careful attention should be given to be sure all interior surfaces are as black as possible. This would include the side of the lens that is usually ground. We would polish the side of the lens and paint it black to make it much more light absorbing. (5) It may be possible to use a thin quasi-spherical dome made of plastic instead of the glass lens (much like the cornea of the eye)—indeed, if vacuum filling is not required, a flexible membrane might permit focusing by changing the liquid pressure.[9] (6) If a solid piece of glass can be placed directly on or very near the CCD surface using a suitable index-matching liquid, it may be possible to arrange for a TEC CCD. The thermal gradient may be mitigated by the glass and permit the room-temperature liquid to be sufficiently free of thermal convection. (7) The unprotected surface of the CCD presently limits the kinds of liquids that can be used within the camera. If a coating directly on its surface can protect the CCD silicon, this may allow the use of a more suitable liquid where index matching and particle content can be more easily controlled. (8) Finally, we would want to compare the improved SED camera with a high-quality air-spaced lens system designed for minimizing glare, rather than such a simple camera system employed here. Ultimately, the goal would be to produce SED cameras that will have glare factors significantly less than 0.1 %. Such cameras will greatly enhance the measurement of details of complex images. They will further aid in the metrology of displays that are currently very difficult to measure such as head-mounted displays.

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