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Measurements of Static Noise in Display Images

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ABSTRACT

The appearance of noise on a display is an important usability issue. Sources of noise include electrical interference, display driver artifacts, resampling artifacts, transmission artifacts, compression artifacts, and any intrinsic noise artifacts produced within a display device. Issues for the severity of the noise problem include total magnitude of noise, noise spatial frequencies, proximity of the noise spatial frequencies to the spatial frequencies of the desired information content and the human-eye response to that information content, uniformity of the distribution of noise, and appearance of any visible or regular patterns in the noise. Whatever the source, an accurate method to measure noise may be required to properly assess the influence of the noise. We investigate the intricacies of using a digital camera to accurately measure noise in a static image on a flat panel display (FPD). The electro-optical transfer function of the FPD is measured. A known noise pattern is displayed and measured using the digital camera whereby the predicted noise is compared to the measured noise. Complications and limitations in the metrology will be discussed.

Keywords: array-device measurements, CCD measurements, display measurements, display metrology, narrow-frustum probe, image noise measurements, stray light control, stray-light-elimination tubes, frustums, veiling glare.

1. INTRODUCTION

The measurement of display image noise is a valuable tool in determining how effective a display will be in presenting text and image information to the user. Noise measurement is especially challenging, because noise features are highly transient and small in area. Charge-coupled-device (CCD) cameras offer promising potential for noise measurements because of their ability to image large areas of the display and capture transient phenomena. However, there are concerns about measurement errors, resulting from factors such as reflection and light scattering in the camera optics, that may affect the usefulness of such measurements. It is important to identify the sources of error and get an idea of the magnitude of the problems they can be expected to cause, as a step toward proper use of the measurement data and the implementation of measurement techniques that minimize the errors.

The method chosen to look for measurement errors is an incremental approach using increasingly challenging measurement scenarios with smaller image features, and the use of a reference measurement method using narrow-frustum stray-light-elimination tubes (SLETs) or NFSs. A collection of test patterns is created to serve in place of image noise artifacts. The patterns have features of various sizes, some much larger (and thus easier to measure) than typical noise features, others scaling down to small clusters of pixels. The reasoning behind this choice of test images is that larger features are easier to measure using the reference method, and errors that appear when measuring larger features are likely to be even worse with smaller features. In other words, testing with larger features is a good starting point. With a range of sizes of features, it can be determined how measurement errors scale with feature size. Backgrounds of various grayscales ranging from white to black are used to check for contamination of feature measurements by light from surrounding features. Measurements made using NFSs test both for uniformity of display performance with different test images and for accuracy of the reference measurement method itself. The SLET-based measurements are then compared to measurements taken with the CCD camera system being tested.

2. EXPERIMENT

A scientific-grade, thermoelectrically-cooled, 16-bit CCD camera with photopic correction filter is employed to make the luminance measurements on the patterns. The CCD camera is fitted with an f/2.8 60 mm focal-length lens and 1.7× adaptor. The lens is stopped down to f/16 yielding an effective aperture of e = 3.8 mm. The distance from the front of the lens to the screen is z_d = 328 mm. The exposure time is 5 s. In Fig. 1 we show the three arrangements used in this study using the CCD camera. In order to determine the actual luminance of the various patterns, a NFS is used. Gloss-black frustums have been

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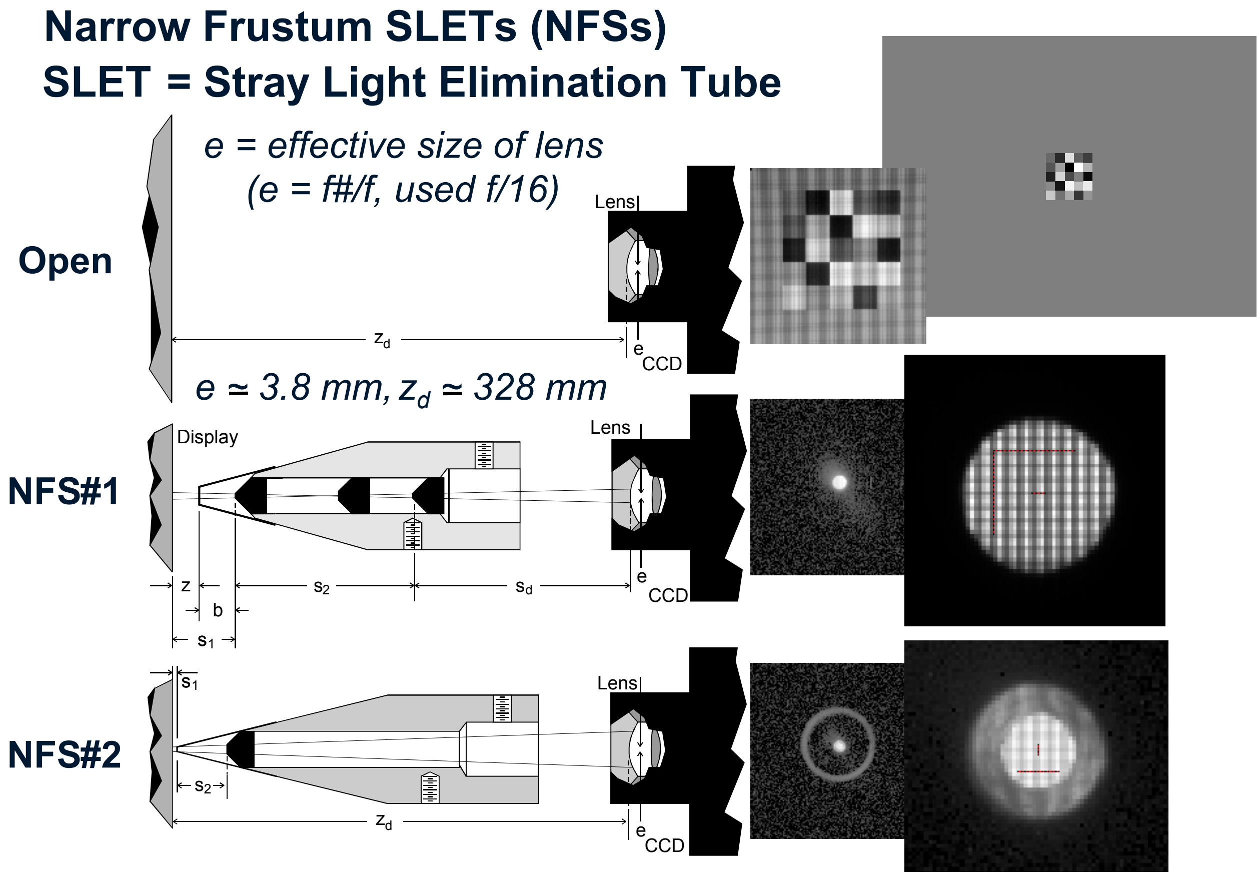


Fig. 1. *CCD camera arrangement with and without NFSs. The noise block on a medium gray background is shown at the upper right, the images produced by the CCD camera for each configuration are shown next to the camera drawings, and magnified views through the NFS apertures are shown at the right.*

used to eliminate veiling glare in making accurate light measurements as well as reduce apparatus reflections back onto the screen [1]. The original idea for NFSs was published by Badano [2]. A photograph of the apparatus is shown in Fig. 2. A gloss-black frustum (cone with the apex cut off) will offer the least perturbation on making an accurate measurement of luminance because very little light is reflected back onto the screen. For measuring the luminance of a dark square on a white background, minimizing back reflections from the apparatus is very important.

Two versions of NFSs are employed. One, NFS#1, has three interior frustums. The outer two interior frustums have apertures of 4 mm and the central interior frustum has an aperture of approximately 6 mm. These frustums are used to limit the region viewed and to control any stray light contributions from the edge of the main narrow frustum. The surfaces are all gloss black to control the reflections and channel them into traps rather than attempt to simply reduce them as is done using matte-black surfaces. The second NFS, NFS#2, employs a small aperture (about 1.5 mm) in the narrow frustum with a second wider frustum placed behind it having an

Fig. 2. *The NFS is supported by two adjustable concentric tubes. A 120° apex gloss-black frustum surrounds the NFS to reduce reflections from the apparatus and light entering the tubing. The entire tubular assembly will swing away to permit an unobstructed view of the display by the camera.*

aperture of about 3 mm. As seen in Fig. 1, the camera cannot see the first aperture in NFS#1, but can see the interior gloss surface of the tip of NFS#2.

Figure 3 shows the device used to vacuum form the frustums from plastic discs. Tubular sections screw together to hold a gloss-black vinyl-plastic disc in place. The disc is heated, and then a vacuum is applied that pushes the plunger against the disc forming the plastic to the contours of the plunger. Two plunger shapes are used. One is a narrow cone to produce the main narrow frustum with apex angle of 30°. The other shape is a cone with 90° apex angle and cylindrical sides to fit within the body of the SLET—shown in Fig. 3. The shaping of the apex hole of the frustum is performed under a low-magnification microscope using a small razor knife after it has been gently drilled. A wooden toothpick can be used as a file to remove any burrs and finally shape the aperture of the frustum. The frustum is cleaned off with a blast of air and painted with thinned gloss-black paint on the interior and exterior surfaces. In addition to assuring opacity of the now thinned plastic material, the paint also serves to smooth out small imperfections in the edges of the shaped hole, making it a better reflector.

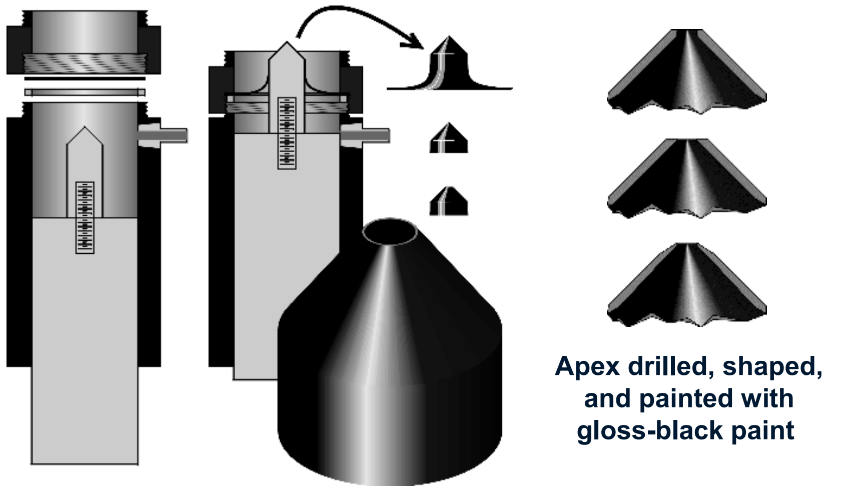


Fig.3. *The frustums are vacuum-formed from gloss-black vinyl plastic discs originally approximately 0.25 mm thick. After formation the resulting material is from 0.12 mm to 0.05 mm thick and needs to be painted with gloss-black paint to assure its opacity.*

3. RESULTS

We first determine the performance of the display and the camera under extreme conditions, and we compare the performance of the camera using both NFSs. A laptop computer FPD is used that has an active-matrix liquid-crystal display. Two types of patterns are used: black boxes on white backgrounds, and white boxes on black backgrounds. Figure 4 shows the sizes of the boxes used: V/n for $n = 5, 15, 30, 45, 90$ relative to the screen vertical size V. By convention, $n = 0$ refers to a full screen.

In Fig. 5 we see the corruption of the measurement of the luminance of the black box on a white screen as the size of the box is reduced. The open CCD camera (without the NFSs) shows many hundreds of percent corruption of the measured black. The lower curves are made using the NFSs. Only when the size of the square is smaller than the aperture in NFS#1 (for box size $V/90$) does the performance between NFS#1 and NFS#2 differ appreciably. This shows that the FPD is functioning rather well in that its black luminance doesn't change appreciably for all the displayed box sizes.

In Fig. 6 we show the same kind of measurements using a white square on a black screen. The effects of veiling glare are much less, but are not entirely eliminated. A small error, increasing as the size of the box gets larger, is most pronounced at the full screen. Again, the data obtained from the NFSs agree well and show that the FPD is functioning as desired in that the luminance of the central white area does not change appreciably with box size. There is a continual drift over time in white luminance on the order of a few percent that can be observed in these data. However, the upturn in the CCD open data for larger box size is a manifestation of veiling glare in the optical system.

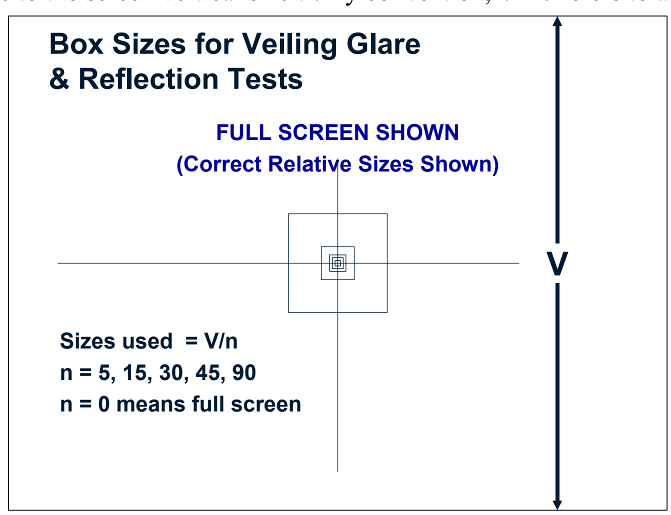


Fig. 4. *Box sizes used to test the overall performance of the camera and NFSs.*

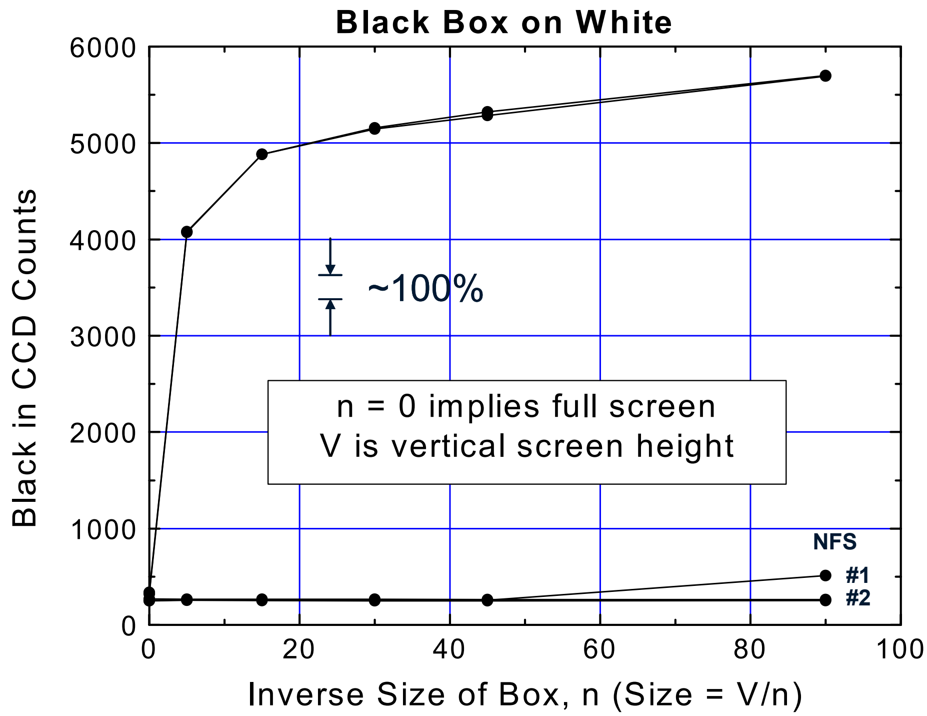


Fig. 5. *Veiling glare in the camera system and the FPD is revealed by measuring the black luminance (in CCD counts) of different sized boxes on a white screen. The upper data is the open CCD camera without the NSFs.*

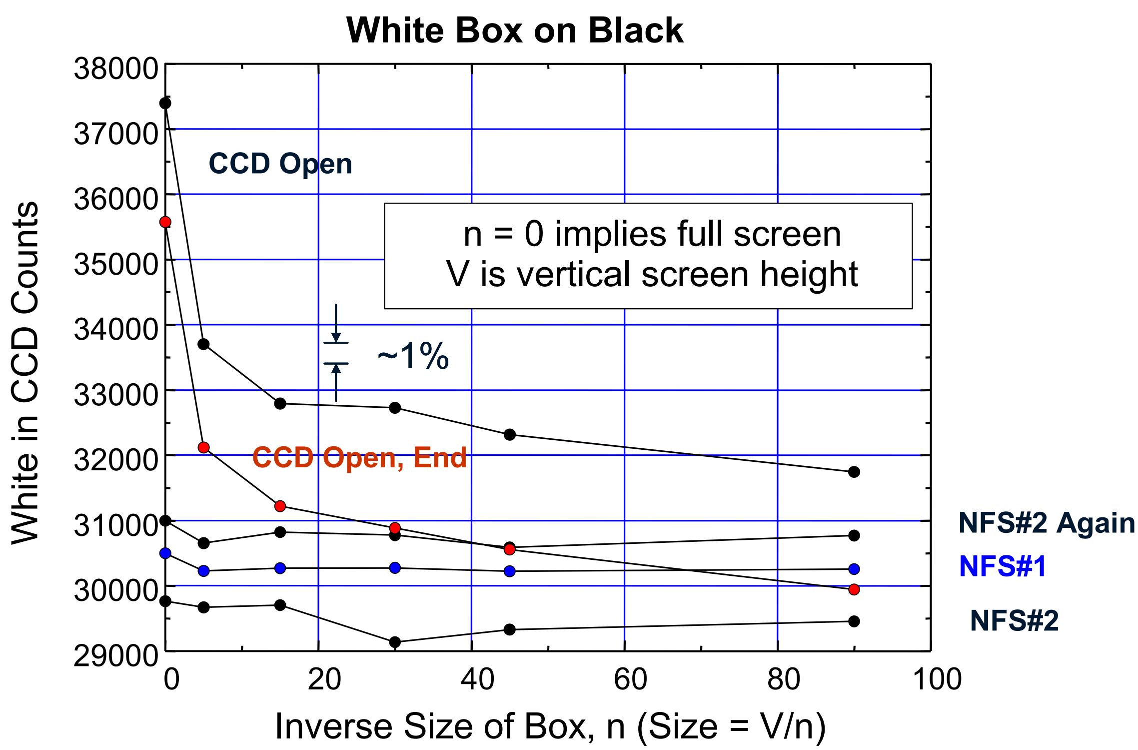
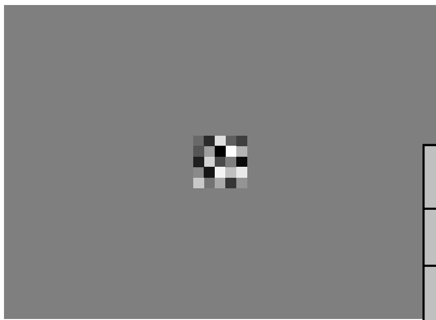


Fig. 6. *CCD camera and FPD performance for a white box on a black background. Two measurements were made with NFS#2 to indicate the extent of the slow drift in overall screen luminance with time.*



106	42	223	95	63
85	159	0	255	180
31	212	74	127	10
138	21	244	191	233
201	116	170	53	148

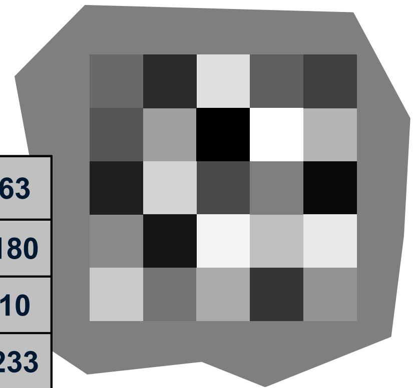


Fig. 7. *Simulated noise patch on a gray background. The numbers in the table are the bit levels used to create the patch. A magnified view of the noise patch is presented at the right. Box size is V/30.*

Figure 7 shows a simulated noise patch used as a test pattern, with the gray-level values (out of 255) for each square in the patch. Test patches are designed to be more easily measured than the typical small features of image noise, but to have enough similarity to actual noise that the measurement performance with the open CCD and with the NFSs can be compared. NFS#1 is employed for these measurements and the size of the boxes are selected at $n = 30$ so that they are larger than the front aperture of NFS#1. NFS#1 is expected to provide a better measurement of luminance in general offering less of a perturbation on the screen characteristics and being able to better eliminate any stray light.

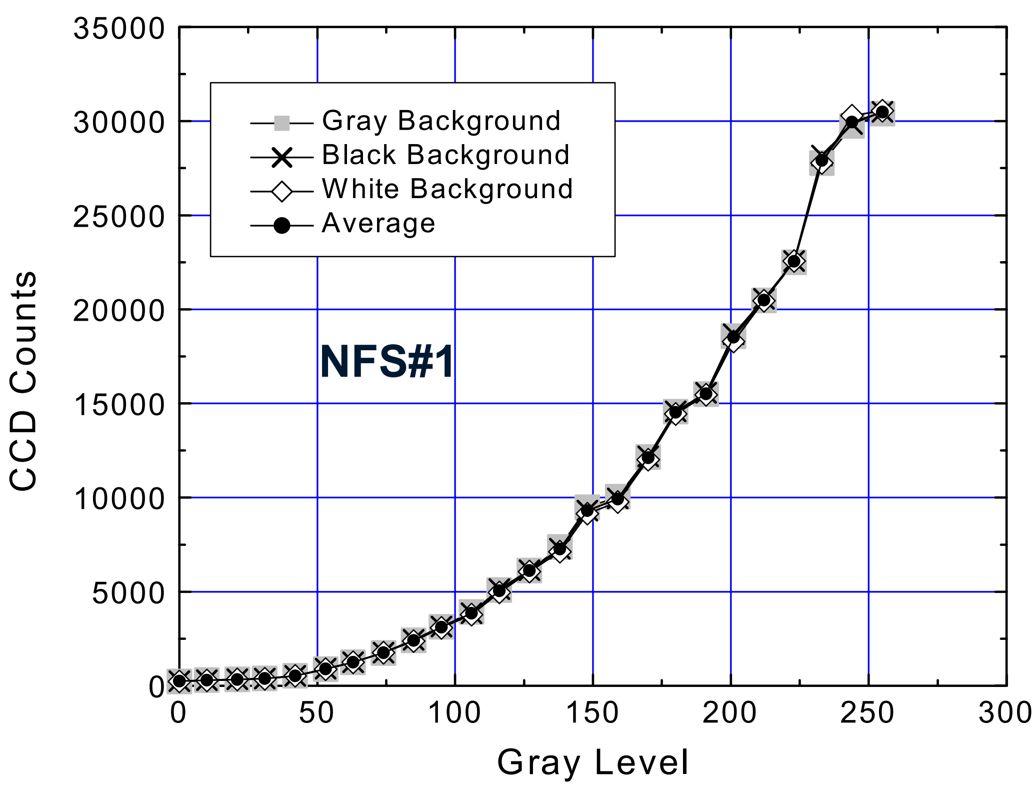


Fig. 8. *The electro-optical transfer showing the luminance in CCD counts vs. the selected gray level for the noise patch as measured by NFS#1 with three backgrounds (gray, black, and white).*

Figure 8 shows the measurement results for the test pattern in Fig. 7, using NFS#1, with the gray level and CCD counts for all 25 squares in the test patch normalized to the average of the three series of measurements. The test patch is measured with a gray background (127/255, as shown in Fig. 7), with a black background, and with a white background. At the scale of the graph in Fig. 8, the three sets of measurements appear to overlay one another, indicating that NFS#1 is doing a very good job of eliminating the effects of veiling glare in the measurements. Figure 9, in which is graphed the deviation from average for the same measurements, shows that the measurements are in fact very close for the different backgrounds. These tests show both that NFS#1 is working well on features of the size of the squares in the test patch, and that the display being measured is consistently producing grayscales in features of this size independent of what is being shown on the rest of the display.

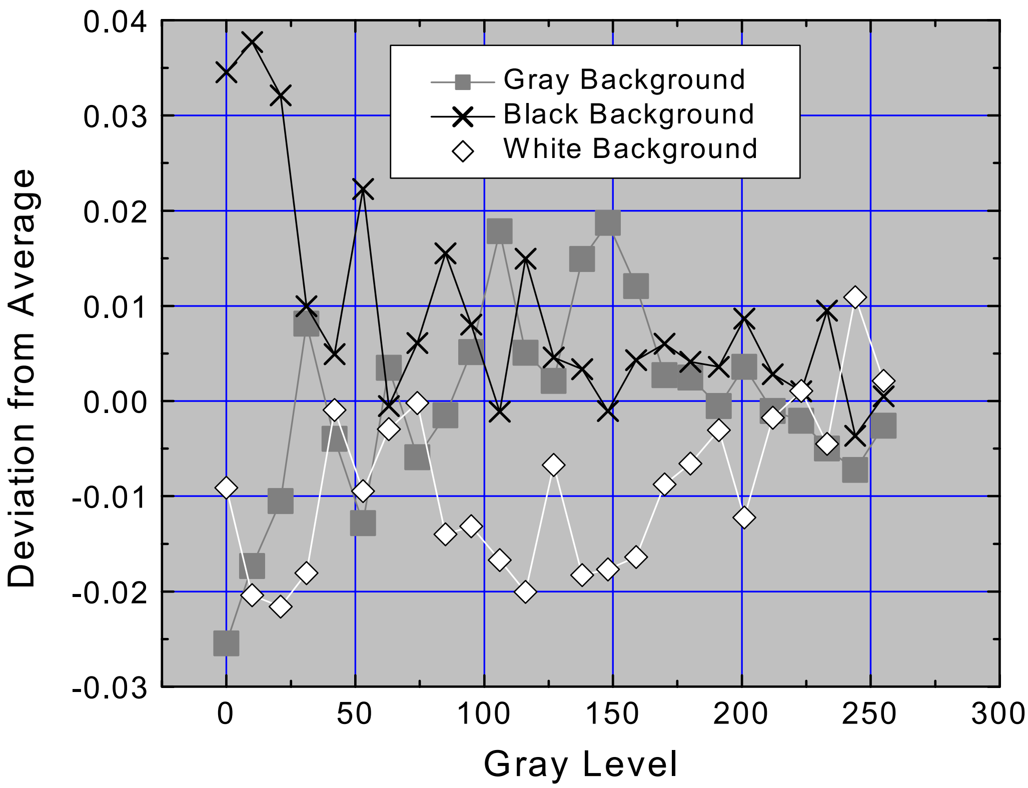


Fig. 9. *The deviation from average of measurements made using NFS#1 on the noise patch for a medium gray (127/255), black, and white background surrounding the noise patch. This demonstrates that the FPD is working well with no profound cross-coupling or shadowing through the entire noise block and for all the selected gray levels.*

Figure 10 shows the open CCD measurements (white, gray, and black backgrounds) of the same test pattern, compared to the average NFS#1 data. The NFS#1 measurements are taken before the open CCD measurements, and then again afterward, to verify the repeatability of the experiment. It can be seen that the open CCD measurements differ significantly from the NFS#1 measurements, especially for the white and gray backgrounds. This result is consistent with contamination of the open CCD measurements with veiling glare from the background. The open CCD measurements also exhibit several inversions (of two squares with similar grayscales, the square intended to have the brighter grayscale has a lower measured CCD count). Contamination of the measurements by light from adjacent squares in the pattern (where the two squares in question are surrounded by different local patterns) could be a contributing factor to the inversions. Figure 11 shows the same data normalized to the NFS#1 average. It can be seen that the darker grayscale squares are the ones with the most serious measurement errors, and that the white background tests have the most serious errors.

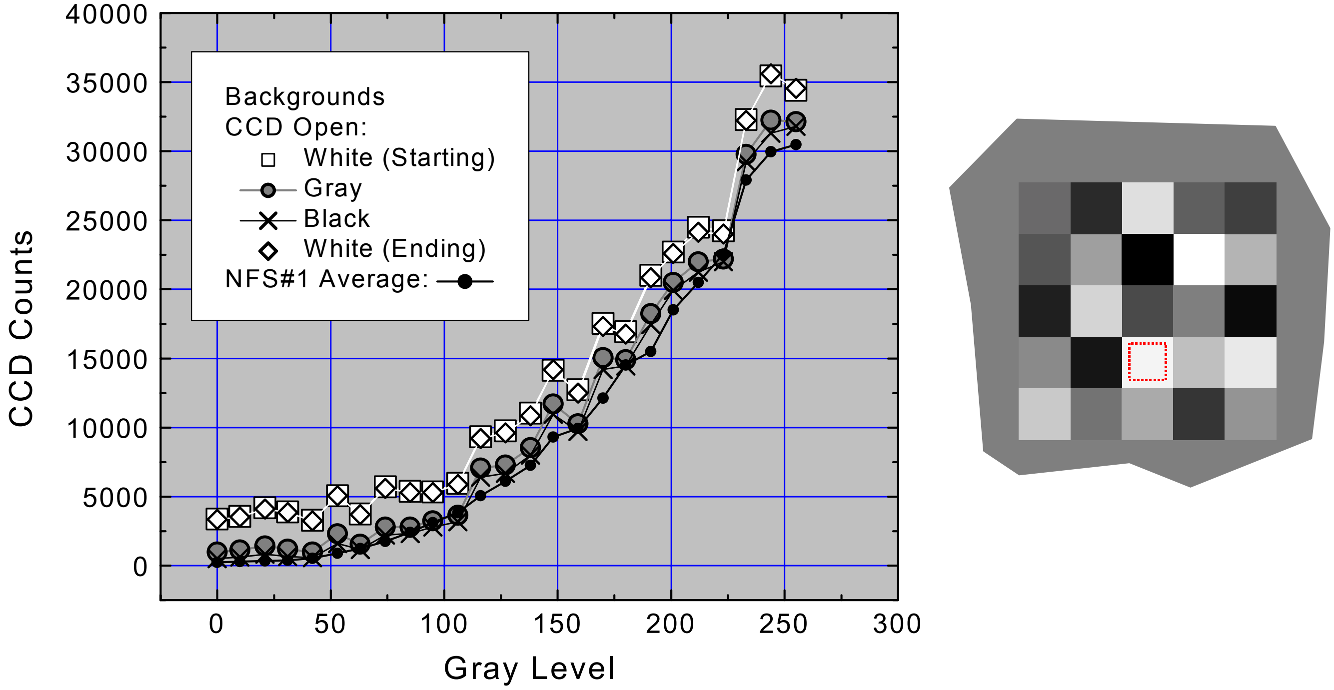


Fig. 10. CCD measurements without the NFSs compared the average of the previous NFS#1 data. The CCD open data for a white background were taken at the first and then again after all the rest of these data were taken. The CCD open data for the white background essentially lie on top of each other indicating the repeatability of the measurement. Note the inversions especially in the white-background data. The typical measurement area is indicated in the enlargement at the right.

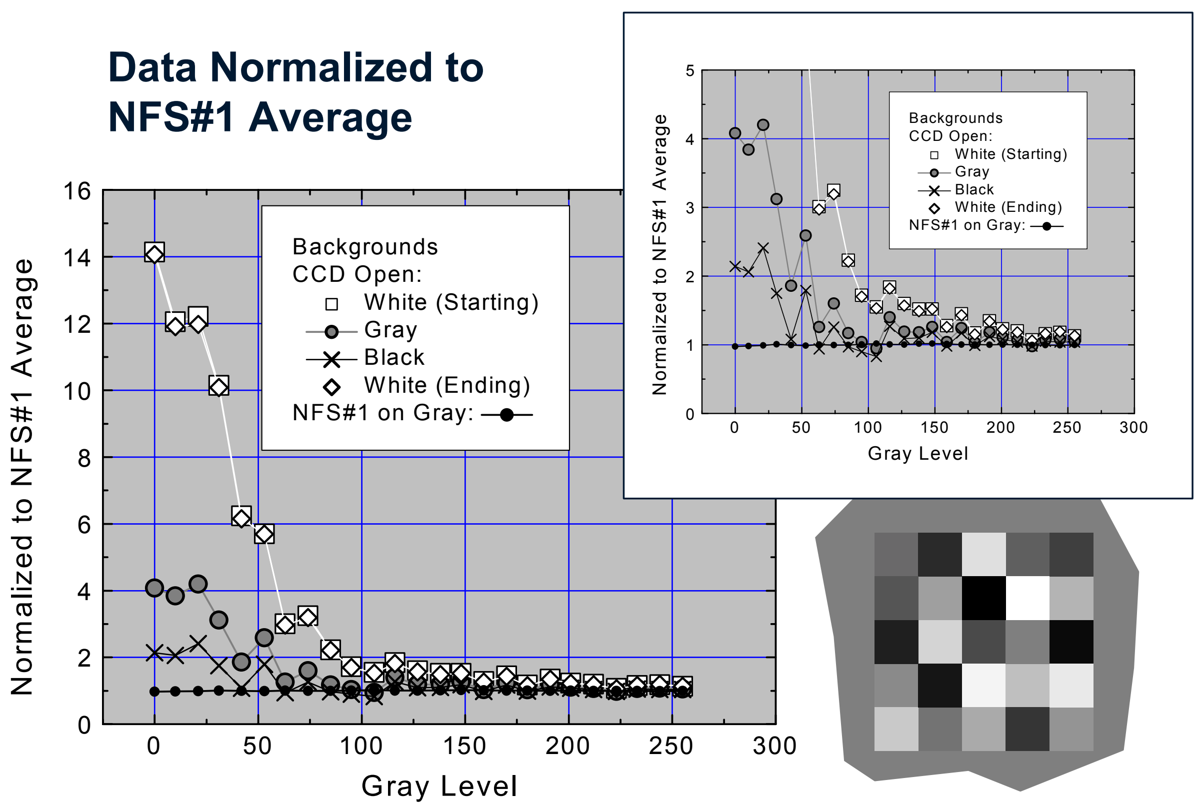


Fig. 11. CCD open data normalized to the NFS#1 average compared to the NFS#1 data on a gray background. Serious errors are encountered for darker boxes in the noise patch. For the black box, this ranges up to a 1400 % error.

In all these measurements we refer to luminance measurements in terms of CCD counts. The conversion is approximately 511 counts/(cd/m^2) for an open CCD measurement on full-screen white without the presence of a SLET. The combined standard uncertainty of this is approximately 3 % based upon the calibration of the luminance meter employed (2 %) to measure the luminance in cd/m^2, and the uncertainty in the CCD measurement (1 % for white measurements). The comparison of the two white-background measurements in each of Fig. 10 and Fig. 11 shows that the repeatability of the measurement is much lower than the errors in the CCD measurements. Based on the data in Fig. 9 and Fig. 6, we would claim a relative expanded uncertainty with a coverage factor of two to be approximately 5 % for an absolute luminance measurement using the CCD camera. However, most of the measurement results are reported relative to measurements made with the NFS, whereby an absolute calibration of the instrumentation is not required. For such relative measurement results, Fig. 9 best indicates the combined standard uncertainties encountered as a function of screen luminance (4 % for black measurements down to 1 % for white measurements). Additional factors contributing to the uncertainty of the results are in the overall drift in the FPD output that are a few percent (see Fig. 6). These data should be regarded as phenomenological indications of potential problems rather than an absolute characterization of either the FPD or CCD camera.

4. CONCLUSION

The measurements taken using NFSs can do two things for us. (1) They can indicate how well the display is working under a variety of conditions and prove whether or not the display performance varies with image content or not. (2) They can provide accurate luminance measurements of feature sizes down to small groups of pixels. In comparison to the SLET-based images, the regular CCD imaging system measurements showed significant errors that became very large with small dark features on a bright background. The characteristics of the measurement errors were consistent with light scattering and reflections in the camera optics producing a general veiling glare in the resulting image. (Additional problems can arise from reflection of light back from the apparatus that were not detailed in this report.)

This study has confirmed that CCD-camera-based measurements might produce significant errors when looking at small features such as image noise in high-contrast scenes with significant bright areas being displayed in the image. Those who are using these devices for this type of measurement should be aware of the potential sources of error and know how to take steps to minimize the effects of these errors. Such cameras may well provide accurate measurements of uniformity of full screens of color, but caution must be exercised if accurate measurements of scenic details are intended—particularly when bright areas are nearby the measurement region or cover a large portion of the screen. The main message here is that the user of an instrument should be aware of the possible limitations of the apparatus and to know how to diagnose the performance of the instrument when it is used in less than ideal situations. The problem might be that too much is being expected from the apparatus, not that the apparatus is in any way deficient. The use of SLETs and NFSs are particularly helpful in revealing accurate luminance and color measurements that are to be compared with the open camera performance without SLETs. Alternative methods are under investigation to eliminate the veiling glare characteristics of the cameras through the use of point-spread-function-deconvolution techniques and similar image-analysis methods. However, before any such methods can be trusted, it is clear that the use of a SLET (or NFS) to accurately measure the target source luminances and colors is warranted. Another type of camera is also under investigation to dramatically reduce the veiling glare in the camera system by using a liquid or solid fill similar to the eye [3].

5. REFERENCES

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