Electronic Display Metrology—Not a Simple Matter

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Abstract: *Most would assume that the characterization of electronic display quality would be a straightforward process offering few complications. However, what the eye sees can be very difficult to capture accurately and quickly in a meaningful way. With the advent of many new display technologies, there is a need for a level playing field so that different technologies can be compared on an equivalent basis. Orchestrating display metrology to accomplish this is wrought with several difficulties that will be reviewed especially in the areas of stray light management/measurement and meaningful reflection characterization.*

Keywords: display metrology, haze, NIST, reflection measurements, stray light, veiling glare

INTRODUCTION

When we look at electronic displays, such as when we see a number of laptop computers presented in a store, we subjectively evaluate each display's performance within a few seconds. We quickly establish what we like or dislike in an electronic display just by looking at it. (We will refer to an electronic display simply as a display from here on.) Many think that it would be a simple matter to measure that display's performance and characterize its suitability for a given task. Perhaps this simplistic viewpoint is understandable because when we use our eyes we are making our evaluation using the most sophisticated detector and image processing system imaginable, in fact, it is unimaginable for its complexity. Thus, we are faced with using vastly inferior equipment to characterize displays—relatively simple equipment that we have invented, equipment that pales in comparison with the human eye system. However, we don't have a mechanism to extract numerical results from the eye's subjective evaluation, and we are therefore forced to use measurement apparatus to supply us with a parameterized characterization of display performance. To properly use such apparatus, we need to know how that apparatus works so that we don't expect too much from it. We also need to understand the parameter that we are attempting to measure so we are not fooled into misusing our apparatus in an inappropriate way. It is the purpose of this paper to illustrate these kinds of problems and show how such a metrology effort fits the role of national metrology institutes.

IMPORTANCE OF GOOD DISPLAY METROLOGY

Given that display measurements may be not as easy as we expect, why is display metrology important? The answer lies in why standards are important. There are two kinds of standards. We create performance or compliance standards that manufactured items should meet—criteria that need to be achieved so that we can adequately, properly, and safely use such items. There is another type of standard that details *how* to make good measurements: Measurement standards allow us obtain accurate measurement results of display characteristics. This second type of standard has been the focus of the NIST Flat Panel Display Laboratory—the development of good display metrology and the distribution of that metrology in measurement standards.

NEED FOR GOOD DISPLAY METROLOGY: Why are accurate measurements of display characteristics so important? Several reasons can be cited that underscore the need for a solid bedrock of good display metrology:

1. **Specification language:** We want to be able to speak intelligently and accurately about display characteristics. The language used to specify display characteristics needs to be determined and correlated with good metrology for measuring those characteristics. This eliminates confusion and enables clear statements of expectations, achievements, and results of measurements. Procurement of displays requires a clear specification language

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upon which all can agree as to what is required. Legal protection of both the buyer and seller at all levels of manufacturing and implementation of the display demands a clear and unambiguous specification language tied to good metrology.

2. **Level playing field:** There are many different technologies available today, especially for flat panel displays (FPDs), and more technologies are constantly being developed. Even within a single technology there can be a number of different implementations. All these displays, as much as is possible, need a way of being evaluated with a metrology that allows them to be accurately compared. We may want to be able to compare the quality of a head-mounted display (HMD) that fits on glasses with a laptop display or a head-up display (HUD). There may even be different playing fields for effective comparisons depending upon the task for which the display is to be used and the associated environment. For example, a digital cinema projector cannot be compared to a sunlight-readable reflective display because the displays will be used in entirely different environments, but we need good display metrology to capture the quality of these displays within their intended environments.
3. **Human response characterization:** Vision science and ergonomics need good metrology to provide a solid basis for their characterization of vision performance in order to establish the requisite performance levels appropriate for the task to which a display will be applied. For example, how much contrast is needed to quickly and reliably read text on a display in an emergency situation? Readability tests would be performed to determine the minimum character contrast needed. The readability would then be correlated with the measured character contrasts. A minimum required display character contrast level would be established from such an experiment. Suppose the experimenters were not familiar with what a difficult measurement character contrast can be, and they trusted their instrumentation without performing any diagnostics. They would measure a lower contrast than what the eye actually appreciated and needed. Suppose the actual contrast seen by the eye was 10:1 but they measured it to be 3:1. In their ignorance, they would write the lower 3:1 contrast in a standard, and people would start using that requirement of a 3:1 contrast. Now suppose somebody makes a new kind of display that is just able to obtain the 3:1 character contrast specified in the standard. However, they properly establish the character contrast of their display using good measurement methods that accurately obtain the correct character contrast that the eye appreciates. Because the 3:1 contrast level was ignorantly set too low in the standard, their display would not have sufficient contrast as determined by the original experiment to be 10:1. As a result, there could be severe consequences if the mistake is not caught and if the display is used in a critical application.
4. **Global commerce and e-commerce:** Now that the Internet has shrunk the world and electronic commerce opportunities abound, proper representation of products has become important. Color transportability, appearance, etc., all depend upon the display device being measured properly. Many people think that all we need do is purchase a hand-held colorimeter, point it at whatever display we desire, and read off the values of the luminance and color coordinates. It is not always that easy, and serious errors can be caused if we are not careful and don't understand the limitation of our equipment. To prove that the fabric viewed on the display looks the way the clothes designer intended it to appear or as it will appear after somebody buys it is a non-trivial problem.
5. **Safety:** Displays need to be measured so that their performance in critical situations can be determined. Being able to read a display in sunlight or in high-ambient light conditions is an example of requiring a careful characterization of reflection. Suppose we were designing a new rescue helicopter and wanted to use a new light-weight FPD. We need to be able to adequately characterize the reflection properties of candidate displays in a laboratory to select the best display for this purpose. If the reflection metrology is not adequate to the task, displays could be approved that will not perform adequately. The alternative to laboratory testing would be to place any candidate display in a test helicopter, and that could be prohibitively expensive. The requirements imposed by safety are generally more restrictive than the requirements for, say, entertainment. Qualifying displays for important applications requires good metrology.
6. **Specialized displays and usage:** There are a number of specialty displays used for very demanding applications that need critical metrology associated with them for evaluation and procurement purposes: medical displays, automotive displays, avionic displays, and others. For example, the medical radiological community requires a display that will provide them with the contrast and resolution that faithfully duplicates their experience with x-ray film. Proper diagnoses depend upon it. The consequences of failure can be immense.

GOALS OF GOOD DISPLAY METROLOGY: What kind of metrology is acceptable? We might list several goals that good metrology and meaningful measurements should consider having. The items in this list are not necessarily complete, nor are they entirely independent:

1. **Robust:** Robustness is achieved in a measurement method if the methods and apparatus used are insensitive to small changes in the apparatus. If there are two different ways to measure a display characteristic and each method gives the same result with the same uncertainty, how do the methods compare if their apparatus is modified slightly or inadvertently? If one method permits larger perturbations yet provides the same results, that method is preferred over one that requires careful attention to many details. Robustness is not always attainable, but being aware of robustness can sometimes help us select measurement methods that will cause less aggravation and suffer fewer problems.
2. **Reproducible:** Reproducibility is the ultimate achievement of a measurement method. Basically a measurement method is reproducible if people will get the same measurement result using the same method with appropriate instrumentation measuring an identical display (an ideal device) within the requisite uncertainty.
3. **Relevant:** Here we will adopt an existing definition promoted by Wright and Handschy: [1] "By 'relevant,' we mean that the measurements must predict some aspect of user experience, guide product improvement, or provide a basis for comparing one display product with competitive display products." Depending upon the goal, what can be relevant for one task may not be relevant for another task. For example, luminous efficacy is the flux output of a display in all directions divided by the electrical power supplied to the display. The frontal luminance efficiency is the luminance of the display as observed from its normal divided by the electrical power supplied to the display. Both are "bang-for-the-buck" measurements. One is appropriate for displays that might be viewed from many different directions, and the other can be more appropriate for displays that are normally used by one person such as laptop displays.
4. **Unambiguous:** The measurement method must be clear to the user. What can and can't be done should be clear. The apparatus used and any possible modifications of that apparatus need to be identified (obviously, diagrams are especially helpful). The possible problems with the measurement need to be clearly indicated, and any warnings should be clearly stated so that people are not tempted to use their apparatus inappropriately. A related quality is that the specification of the measurement method should be complete and self-contained so that the user doesn't need to look for the requirements scattered all over a document.
5. **Extensible:** Measurement methods that can straightforwardly be applied to a variety of display technologies are preferable. For example, with cathode-ray tubes (CRTs) a determination of the electron beam profile can be useful. The measurement is certainly applicable to CRTs, yet the manifestation of a problem in a beam profile might be color fringing around a white pixel or convergence of the colors. Thus, a color fringing or misconvergence measurement would be the preferred measurement for extensibility purposes.
6. **Accessible:** To the extent possible we want to design measurement methods that can be performed by as many people as possible with a variety of apparatus. Requiring the use of expensive or unique apparatus when it is not necessary should be avoided; yet at the same time, warnings here are appropriate should it be anticipated that people will want to use inadequate instrumentation. For example, requiring the use of a luminance meter with a 0.1° or smaller measurement field will exclude instrumentation with a 0.125° measurement field. If both types of instruments are made, then, if possible, we would want to accommodate the widest range of instrumentation that we can. We wouldn't want to exclude instrumentation unless there were a valid and important reason for doing so. Perhaps the measurement method can be modified in some way to accommodate a wider range of instrumentation.
7. **Simple:** The measurement method should avoid unnecessary complications. If the measurement method is not easy to perform and even quick to perform, then people may have less of a desire to use that method. Some measurement methods are difficult and complicated, and there is no way to change them (bidirectional reflectance distribution measurements are an example). However, it is important to keep in mind how the measurements might be used and by whom. If we anticipate that production-line measurements will be made, then we will want to provide the simplest possible measurement method to achieve the goal so that the measurement can be performed quickly in an industrial setting. For example, sometimes it is possible to anticipate the industrial production environment and provide a means of correcting the measurement for non-darkroom conditions.

8. **Selectable:** Provided each measurement method and associated measurement result has a specific name that is not used by any other method, then the user can select what measurements will best characterize the display under consideration. It is the idea of a buffet. We take what we want (or need) from a larger selection of possibilities. Those measurements that make the most sense for the product or application considered will be selected, and those that do not apply are ignored. Making a darkroom contrast measurement on a reflective display is meaningless and need not be performed, but an ambient contrast measurement would be useful. However, in comparing a reflective display to a direct-view emissive display, we would not want to compare the darkroom contrast of the emissive display with the ambient contrast of the reflective display. Rather, the level playing field would be to compare ambient contrast performance. Display manufacturers need the freedom to select the appropriate method to document their success, and users need to be made aware of the differences in the various metrics. All this can be successful provided each type of contrast measurement has a specific and unique name that is employed in the description of the measurement result.

Such a buffet of measurement methods that attempts to meet the above goals has been published by the Video Electronics Standards Association (VESA) through the efforts of their Display Metrology Committee: Flat Panel Display Measurements Standard (FPDM).[2] The FPDM not only contains measurement procedures (69 total in version 2), but also contains full discussions of measurement problems and diagnostics in its Metrology Section as well as tutorial information in the Technical Discussions Section. Having well over 300 pages, it is intended to be a complete manual for display metrology.

INVOLVEMENT OF NIST: Some have wondered why national metrology institutes have become involved. In particular, why has NIST taken an active role in researching, creating, and disseminating display metrology?

1. **Devoted to good metrology:** National metrology institutes are generally devoted to making good measurements. Often there are numerous checks and diagnostics performed so that mistakes are not make. Such a passion for good metrology requires an investment of time that cannot be afforded by many manufacturers and implementers of displays.
2. **Unbiased, impartial, and trusted:** Conflict of interest is always avoided. Since their funding comes from the people, they are disposed to serve the best interests of the public as well as the industry. The focus can be on measurement methods and results without being coerced to developing methods that preferentially treat one technology over another.
3. **Internal resources for careful measurement:** The Optical Technology Division at NIST maintains calibration facilities for photometric and radiometric quantities. Access to such facilities provides the FPD Laboratory with state-of-the-art calibrations and other services. To assist industry with color measurements, they maintain a display and detector radiometric calibration facility so that, for example, corrections can be determined that allow colorimeters to be used with accuracy in measuring the chromaticity coordinates of a particular display type.[3]
4. **Support of users and manufacturers:** Although the United States is not a dominant manufacturer of displays at the present time, it is a significant user of displays. The interests of the manufacturers, the OEMs (original equipment manufacturers) and individual users can be served as needs arise. Manufacturers may shy away from a certain measurement method if it casts their display in a less than favorable light. Users may shy away from certain measurement methods that don't provide an indication of how the display will work in their ambient environments. Both types of measurements are important.
5. **Focused resources of manufacturers and taxes:** Because metrology research is time-consuming and equipment-intensive, many companies are reluctant to devote resources to metrology research. Especially in a competitive market, companies prefer to devote resources to researching new ideas and to production. A number of companies have stated that having national metrology institutes like NIST pursue display metrology is a good investment of taxes because it spreads the burden around to all those who benefit.
6. **Flexibility:** Adding to the cost of metrology research is the need to maintain flexible laboratories. We need to be able to meet the rapidly changing needs of the display industry. Rather than creating an apparatus that can be used for only one type of measurement, the apparatus is created to permit a rapid reconfiguration to accommodate new measurement research. As we participate in conferences, standards organizations, and interactions with members of the display industry, we constantly try to anticipate current and future needs, always being mindful of how we can reconfigure the laboratories to meet those needs.

7. **Assessment:** In addition to the calibration services NIST offers for photometry, radiometry, and colorimetry via the Optical Technology Division of NIST, a means of assessing the light-measurement needs and capabilities of the display industry is useful. To determine the state of the art in display measurements, NIST has started an internal cooperative project between the Flat Panel Display Laboratory and the Optical Technology Division referred to as the Display Measurement Assessment Transfer Standard (DMATS, pronounced "dee–mats").[4] The purpose of DMATS is to simulate a very stable display that has a wide color gamut as well as other display characteristics that are encountered in practice such as luminance range (four orders of magnitude), polarization, small grilles, etc.; see Fig. 1. A star comparison program is anticipated: NIST will measure the targets; ship it to the participating laboratory that will then measure the targets they wish; it will then be returned to NIST and remeasured. The comparison results will be shared with the participant. After a number of laboratories have participated, anonymous results will be published to reveal the uncertainties that might be anticipated in making display measurements. The purpose is to determine how well laboratories are prepared to measure colors, luminances, and other display artifacts, as well as to test their measurement procedures and practices. If successful, this program will be maintained and enhanced to serve the display industry.

Fig. 1. *DMATS with 36 targets.*

Similar remarks can be made for all national metrology institutes. They are in an excellent position to offer metrology support to a very competitive display industry.

SEEMINGLY SIMPLE MEASUREMENTS CAN OFFER SURPRISES

STRAY LIGHT PROBLEMS: One of the most ubiquitous problems in making display measurements is stray light. The reason it is a problem is that many are not aware of its presence. One of the most basic measurements of a display is the luminance of full-screen white. One of the most difficult measurements is to determine the luminance of a black character on a white screen. Both of these measurements are affected by stray light. The full-screen white measurement is illustrated in Fig. 2. Many do not understand that their luminance meters were probably calibrated using a relatively small source of light. The source of light represented by the screen introduces light extending far beyond the measured area, and, depending upon the stray-light rejection characteristics of their instrument, they can obtain a rather surprising range of luminance measurements. The situation can be much worse when we attempt to measure a black rectangle on a

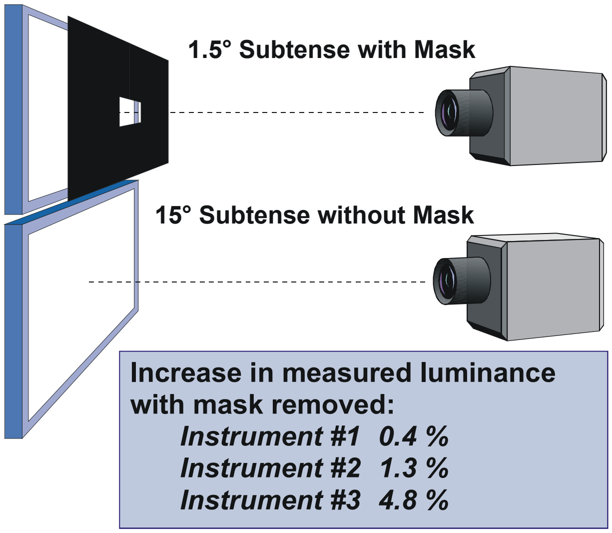

Fig. 2. *Full-screen white luminance measurement with and without a flat mask.*

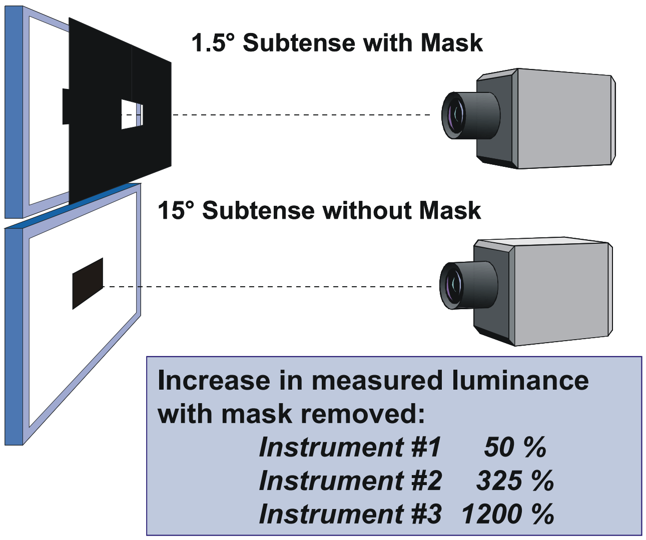

Fig.3. *Luminance of black rectangle on white screen with and without a flat mask.*

white screen. In Fig. 3 we show the surprising range of errors because stray light from the surrounding white area contaminates the black area. The stray light contamination comes from reflections between the lens elements and components within the luminance meter. The general term for such stray light is veiling glare. When the stray light becomes clearly visible in the form of geometrical patterns contaminating the image (as seen in photography and videography with bright sources present), it is often called lens flare. The problem is that many don't understand the possible existence of the stray-light contamination. They often accept what the meter says without questioning the measurement. It is not that their instrument is necessarily bad or inappropriate for the measurement; it is that they expected too much from their instrument.

The use of a flat mask may also present problems. All such flat masks reflect some of the light back onto the screen, often on the order of a few percent. When measuring black areas on a white screen for high-contrast displays, the reflection of the light from the mask can be a serious source of error. NIST has developed the gloss-black frustum mask to better eliminate the light contamination from the mask; see Fig. 4. A comparison between the frustum and flat masks reveals that the flat mask outperforms the frustum mask *only* if the flat mask is placed on the surface of the display and that surface is near the pixel surface (as in laptop computer displays).[5] However, it may not be possible to place the flat mask on the surface of the screen for several reasons: heating effects could change the screen characteristics, the surface of the screen could be damaged from accidental mishandling, and the manufacturer may not permit the surface to be touched as when offering a new prototype display for evaluation.

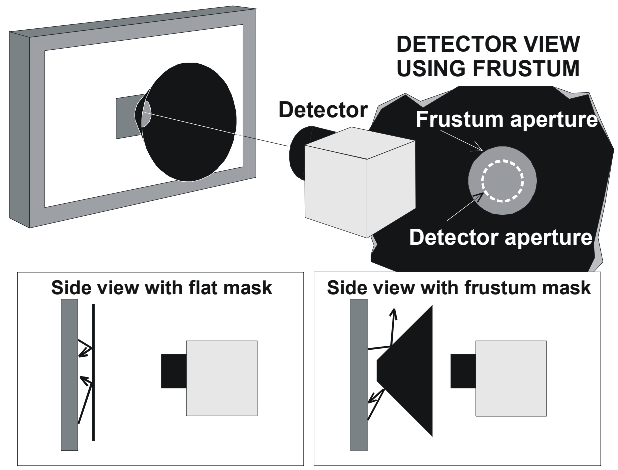

Fig. 4. *Gloss-black frustum mask compared to the flat mask.*

When there is a need to measure very small dark areas on a screen with bright areas present, the problem of veiling glare is exacerbated. Such measurements can be made using replica masks[6] or narrow-frustum masks.[7] Work is underway to determine how well point-spread-function information and deconvolution techniques can be used to successfully account for the effects of veiling glare. Regardless of the existence of software solutions, it will be necessary to provide measurement methods to evaluate the image-processing corrections.

Related to veiling-glare corruption of luminance measurements is the stray-light contribution to front-projection measurements. In front-projection situations there are several sources of stray light; see Fig. 5. Whenever the intrinsic performance of the projector is desired to be measured, it is necessary to properly account for stray light or eliminate it. One method to eliminate most of the stray light is shown in Fig. 6. It employs a stray-light elimination tube (SLET) composed of gloss-black frustums and a gloss-black tube. The idea of the SLET is not to attempt to absorb light by hitting a single matte-black

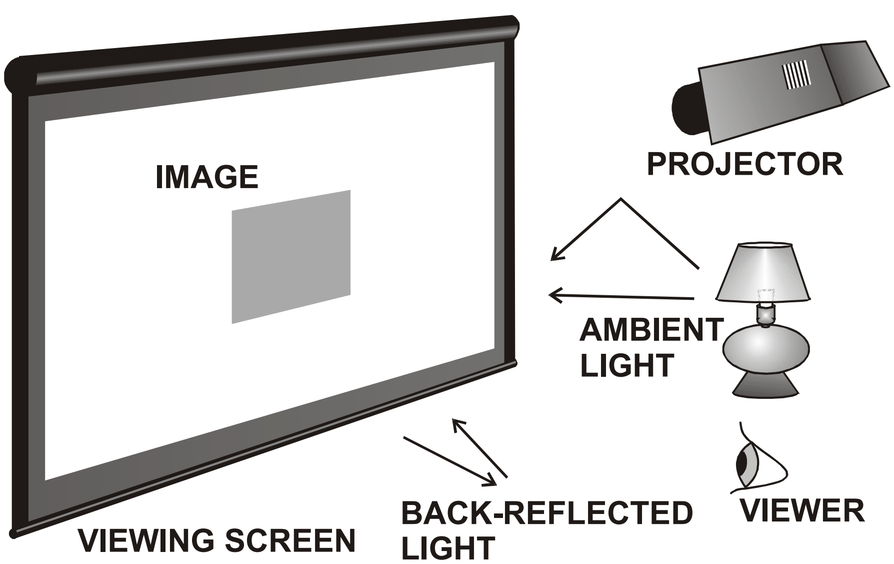

Fig. 5. *Sources of stray light in projection measurements. Dark areas in the image are especially vulnerable to stray-light contamination.*

surface, but to direct the stray light rays into traps where through multiple reflections they are extinguished. Another method to account for stray-light contributions is shown in Fig. 7. It employs a projection mask to obscure the direct rays from the projector so that the stray-light illuminance can be measured and subtracted from the direct measured illuminance of the projector.[8] Because of its small size, it offers a minimum perturbation on the entire system. The projection mask is useful for darkened rooms, but the SLET can render accurate measurements of the projector even in high-ambient-light environments. Some have suggested that accurate projection measurements (as with measuring the contrast of a checkerboard pattern) can be made in black rooms using black screens for which illuminance measurements

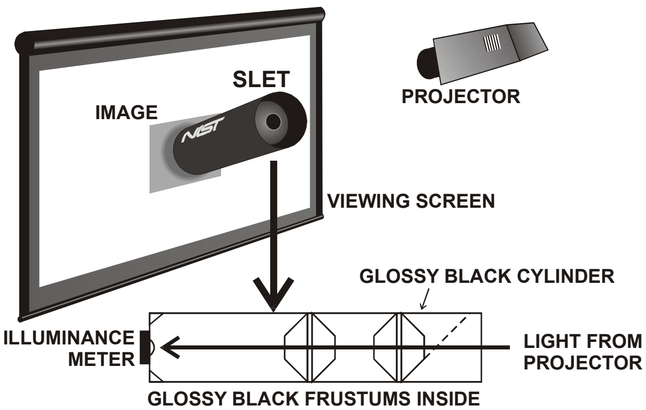

Fig. 6. *The use of a SLET in projector measurements.*

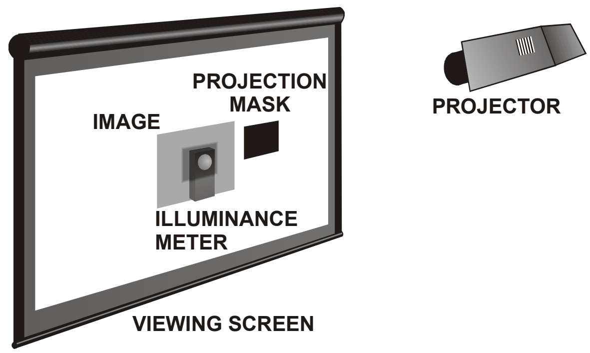

Fig. 7. *The use of a projection mask in making projector measurements in darkened rooms.*

are made on the light from the projector. Even in such laboratory conditions, reflections from the black walls can contribute as much as a 30 % error or more in making the black measurement of a checkerboard. Thus, even for laboratory measurements in very controlled environments, consideration must be given to the possible influence of, and accounting for, stray light. Diagnostics must be performed to assure ourselves that we are measuring what we think we are measuring.

To address these problems in greater detail, a new laboratory has been created at NIST, the Microdisplay and Projection Laboratory. In addition to working with completed projectors, the measurement of the raw microdisplay used in projectors and various other display types has become a major concern of industry.[1] Additionally, work is underway to investigate the performance of a simulated eye-design (SED) camera that may have very low veiling-glare attributes.[9]

REFLECTION CHARACTERIZATION PROBLEMS: Reflection measurements have been made on displays for a number of years. However, many of those measurement methods were developed for CRT display technologies. The newer FPDs can have reflection properties that are very different from older CRT displays, and new measurement techniques must be developed to adequately characterize all types of display reflection. The two main categories of reflection are specular and diffuse. Unfortunately, these terms have not always been completely understood. When we speak of specular reflection, we mean the type of reflection that produces a distinct virtual image of the source just as a mirror does where the observed luminance L of the distinct virtual image is proportional to the luminance of the source L_s where the constant of proportionality is the specular reflectance σ:

$$L = \sigma L_s. \qquad \text{(specular reflection)} \qquad (1)$$

Diffuse reflection means simply to scatter light out of the specular direction. Many have confused diffuse reflection with Lambertian reflection. A Lambertian surface is one that exhibits the same luminance independent of the direction from which the surface is observed. Such a luminance L is proportional to the illuminance E falling upon the surface,

$$L = q\,E, \qquad \text{(Lambertian reflection)} \qquad (2)$$

where q is the luminance coefficient and is related to the diffuse reflectance ρ by $q = \rho/\pi$. Some have restricted their understanding of reflection to these two simple models without realizing that diffuse reflection is usually not Lambertian. In fact, it is difficult to find any material that is perfectly Lambertian.

The Flat Panel Display Laboratory of NIST promotes[10] a three-component model where the diffuse reflection is separated into two terms: diffuse Lambertian (or simply Lambertian) and diffuse haze (or simply haze). Haze is the closest term that people could find that would permit us to identify and distinguish it from other types of reflection.[11] In Fig. 8 we illustrate these three components as would be observed on a black screen using a small point source of light as obtained from a small flashlight with its head screwed off. The Lambertian component is the general gray background that is observed much like what we would observe from dark-gray matte paint. The specular component is the distinct virtual image of the bright bulb seen in the screen. The haze component is the fuzzy ball of light that surrounds the specular image. A display can exhibit any one of the three components or any combination of the three components. Haze is an intermediate state of reflection between specular and Lambertian. The haze fuzzy ball is seen to follow the specular direction but its luminance is proportional to the illuminance from the source (not the luminance of the source like specular reflection).

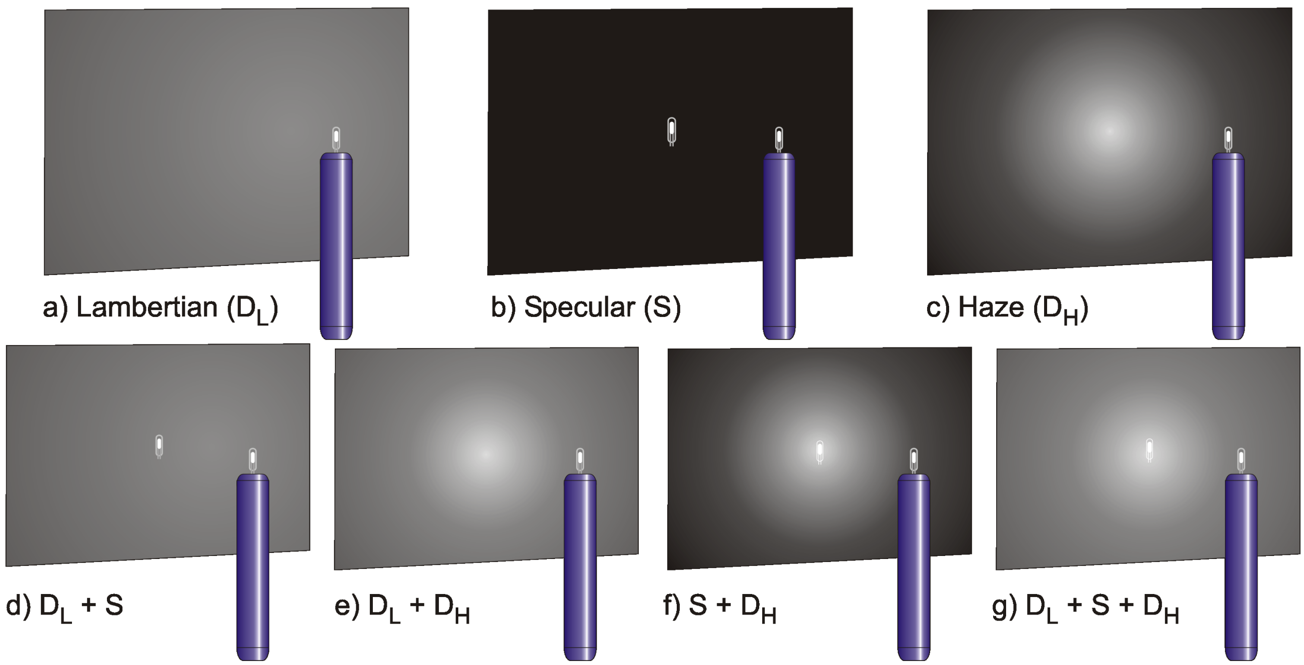

Fig. 8. *Three distinct types of reflection encountered in displays: Lambertian, specular, and haze.*

If we examine a number of different displays, we will see how nicely the reflection properties divide into these three categories. The three component model is needed to properly describe display reflection properties using a simple language. A piece of copy paper is a display with primarily a Lambertian component. A mirror is a display with primarily a specular component. If only a Lambertian component and/or a specular component is present, then the display characteristics can be easily measured via the two component model that everybody likes as expressed in Eqs. (1) and (2). However, whenever a non-trivial haze component is present, a reproducible measurement of reflection becomes very difficult and better reflection measurement techniques are needed. Bidirectional reflectance distribution function (BRDF) methods are capable of providing measurements of these components, but many are not in a position to make or afford such detailed and complicated measurements. Alternatives are under investigation at the FPDL of NIST to permit the extraction of parameters associated with these three components using simple methods.

Because space constraints for this paper do not permit a full description of these reflection properties, especially as they relate to the bidirectional reflectance distribution function, please refer to reference 10 for more details. However, it is possible to illustrate why haze causes such measurement problems. Figure 9 illustrates a ray of light originating at a light source and reflecting off a display into a simple luminance meter and the human eye. The lens of the luminance meter has a larger diameter than the eye (the eye is usually considered to have an aperture of from 3 mm to 5 mm). The gray lines depict the detector subtense associated with different lens sizes. The line traveling from where the ray hits the screen to the center of the detector is the specular component. The round distribution of light from the display surface represents the Lambertian component, and the gray lobe represents the distribution of light associated with the haze. Notice that the detector, presumed to be a luminance meter, is generally calibrated anticipating a Lambertian type of luminous intensity distribution. When haze is present, the amount of light measured depends very much upon the diameter of the lens and its distance from the display because of the elongated lobe structure of the reflected light. The meter expects a Lambertian-like experience, and we are trying to use it to measure a very nonuniform distribution making the measurement very sensitive to the geometry of the apparatus. Thus, whenever there is a significant amount of haze reflection, the measurement becomes very dependent upon the geometrical configuration of the apparatus that can include the source size and distance as well as the detector size and distance.[12] It is because of this geometrical sensitivity that conventional reflection measurements based upon Lambertian and specular models invented for old display technologies will no longer work in reproducible ways whenever haze is a non-trivial component of reflection.

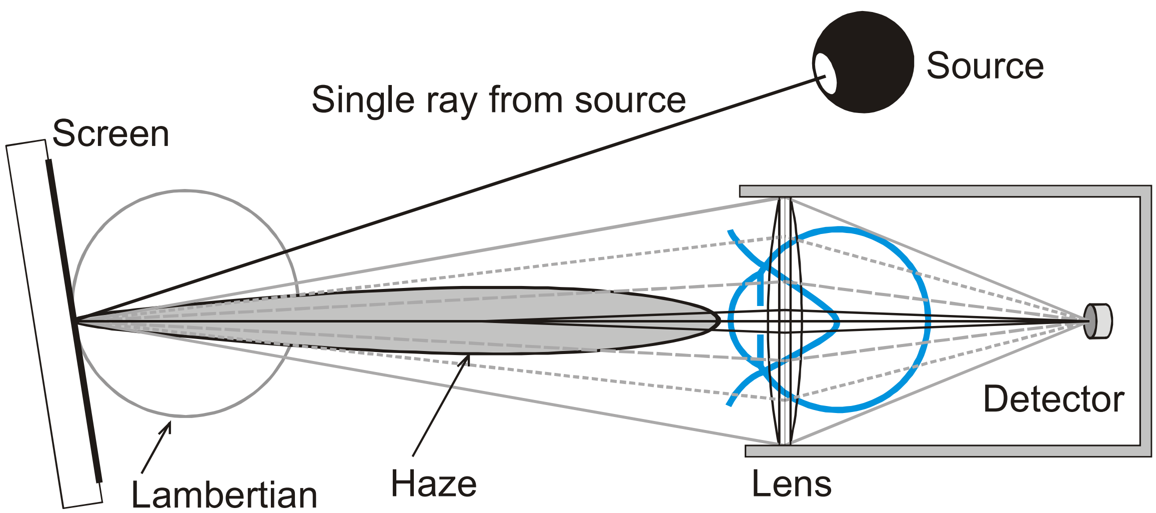

Fig. 9. *Single ray from light source is shown reflecting into an eye compared with a detector having a lens. The straight lines on each side of the center reflected ray represent different possible lens sizes.*

CONCLUSION

The contribution provided by national metrology institutes like NIST to the display industry can be found in the development of good display metrology, in its dissemination, and in contributing to the education of the industry about problems with measurement methods, instrumentation, and apparatus. We've seen that even apparently simple measurements must be made carefully with a cognizance of the limitations and performance of the measurement instrumentation. Taking things for granted can lead to disappointing errors, particularly when making luminance measurements of dark areas whenever bright areas are present on the screen.

Because the front surfaces of many FPDs can now be placed very close to the pixel surface, strong diffusing surface treatments can be used on FPDs. These diffusing surfaces can have reflection properties that make their reproducible measurement very difficult. A three-component reflection model has been developed to provide a suitable reflection language to enable adequate description of display reflection for communication purposes. The separation of the diffusing reflection into diffuse Lambertian and diffuse haze assists in the careful identification of important reflection properties of modern displays. NIST is in the process of developing measurement methods that are sufficiently simple to make them attractive for general use.

NIST will continue to support the display industry in collaborating with standards organizations and others in developing display metrology that meets the needs of the display industry. Creating a public awareness of the problems associated with display metrology as well as their solutions will be a focus of our activities.

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