WHITE PAPER

How to Use Imaging Colorimeters for FPD Automated Optical Inspection

Radiant Zemax

SEE THE DIFFERENCE

How to Use Imaging Colorimeters for FPD Automated Optical Inspection

There are three main approaches to optical inspection of Flat Panel Displays (FPDs) in high-speed production – whether in line, or at the end of the line in final inspection:

1) **Human inspection** – Easily handles moderately complex testing requirements. Relatively slow and variable when compared to electronic testing methods
2) **Machine vision based inspection** – Very fast for simple tests. Does not reflect human visual experience for many tests
3) **Imaging colorimeter based inspection** – Somewhere between the preceding two methods in speed. "Sees" like humans with a very high degree of reliability and repeatability

The use of imaging colorimeter systems and associated analytical software to assess FPD brightness and color uniformity, contrast, and to identify defects in FPDs is well established. A fundamental difference between imaging colorimetry and machine vision is imaging colorimetry's accuracy in matching human visual perception for light and color uniformity (and non-uniformity).

Testing using imaging colorimetry is faster, more flexible and more repeatable than human visual inspection, and more accurate in matching human visual perception than machine vision.

In this paper, we describe how imaging colorimetry can be used in a fully-automated testing system to identify and quantify defects in high-speed, high-volume production environments. We cover the test setup, and the range of tests that can be performed – spanning simple point defect detection through complex mura detection and evaluation.

Measurement Challenges

Imaging colorimetry systems are CCD-based imaging systems, calibrated to have the same response to light, brightness and color, as a standard human observer as defined by CIE models. They provide accurate, simultaneous measurements of brightness and color, and their spatial relationship. When used to image displays, data is generated that can be readily used to determine display uniformity and contrast performance. In addition, variations in uniformity can be analyzed to identify and locate potential display defects. Three important challenges for display measurement and analysis are:

Imaging colorimeters accurately capture the spatial relationships in the variation of light and color across an FPD, making this measurement method ideal for assessing visual performance.

(1) **identify** defects with a high correlation to human visual perception
(2) **quantify** the severity of the defects
(3) perform analysis **rapidly** and with high **repeatability**

The analysis and quantification of defects can form the basis for decisions relative to the display component that caused the defect and to determine next actions – for example to scrap the display or to return it for repair – increasing the effectiveness of quality testing and potentially reducing costs.

Measurement Components and Set-Up

By specifying an appropriate automated test sequence, an imaging colorimeter can be used to obtain extensive, accurate, high-resolution data to describe the performance of a particular display. This measurement data can often be obtained, depending on the display technology and resolution, in a few seconds to a minute for typical test sequences. By using new defect (mura) analysis techniques, these images can be used to determine fine-scale differences between defects that are directly related to their physical cause.

An FPD testing system consists of:

- *A measurement device*
- *Control software*
- *A set of tests*
- *Associated test criteria*
- *Interfaces to control test patterns on the display*
- *Interfaces to the production control system*

Automated measurement and analysis of displays with an imaging colorimeter requires combination measurement control and analysis software. The general structure of the system that we have developed for this application is shown in **Figure 1.** The key components of the system are: (1) a scientific-grade imaging colorimetry system; (2) PC-based measurement control software which both controls the imaging colorimeter and test image display on the device under test; and (3) a suite of image analysis functions that allow various tests to be run. The result is a system that can deliver quantitative, automated inspection for a variety display defects, such as point defects, line defects, and mura.

Figure 1. *FPD AOI test set-up with an imaging colorimeter under automated software control.*

The automated test software architecture used, Radiant Zemax TrueTest™, consists of a core set of measurement control modules that provide the interface with the imaging colorimeter and the display under test. A series of specific test functions is built on this base, using function calls to generate various measurements of white, red, blue, green display screens at various brightness settings for uniformity analysis, or of checkerboard patterns for contrast measurement. A partial list of tests implemented includes:

- ANSI brightness
- ANSI color uniformity
- Black Mura
- Blob Analysis
- Checkerboard contrast
- Chromaticity
- Color Mura
- Compare Points of Interest
- Diagonal Pattern Mura
- Line defects
- Mura defects
- Pixel defects
- Points of interest
- Uniformity

A user control interface allows tests to be selected and sequenced, and specification of test parameters and pass / fail criteria where relevant. For production applications, the user interface supports both an administrator mode with full control over test setup and an operator mode which only allows test execution.

*Basic AOI tests consist of **quality tests**, such as: brightness and color uniformity, chromaticity, and contrast.*

Application to Display Defect Detection

A broad range of display defects can be identified as pixel defects and line defects, physical imperfections in screen manufacture (such as delamination), damage to the screen (such as scratches), and imperfections in image uniformity (such as mura). Using recent work on visual perception, these defects can be numerically classified according to how noticeable they are (or are not) to human observers. This analysis process is fast and highly repeatable. It can be used with multiple display technologies including LCD, plasma, OLED and projection displays.

These defect detection and classification methods are demonstrated here through the analysis of a number of displays. In **Figure 2**, a photopic measurement of a display with a line defect is shown; the analysis software identifies this defect and indicates it on the display image as shown in **Figure 3**. Line defects are an example of a defect for which identifying a root cause is straightforward; the cause is LCD failure.

*A second category of AOI tests detect **display defects**. Some defects have well defined physical characteristics, such as point defects and line defects. Others are more random in structure, such as light leakage and mura.*

Figure 2. *Photopic measurement of a display screen with a line defect visible.*

Figure 3. *The line defect is identified by the imaging colorimeter AOI software; the location of the defect is identified on screen for the user.*

In **Figure 4**, a photopic measurement of a display with a point defect is shown; the analysis software identifies this defect and indicates it on the display image as shown in **Figure 5**. Point defects can be classified as a failed pixel if the analysis determines that the nature of the failure is that an LCD pixel is stuck on. However, direct viewing from a single angle cannot determine the difference between a dead pixel and a particle on the back surface of the display glass. In this case secondary examination is needed to discriminate and classify the cause.

Figure 4. *Photopic measurement of a display with a point defect – can you see it?*

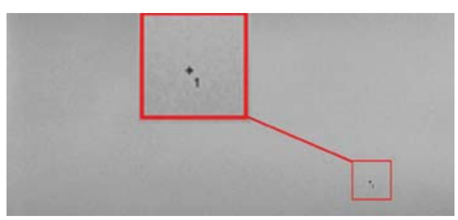

Figure 5. *The point defect is identified by the imaging colorimeter AOI software and marked on the display screen; we have zoomed in to make it more visible.*

For mura both detection and classification can be more complex. Mura are generally non-uniformities in luminance or color that cover an extended, irregular area. Mura are detected by identifying luminance or color contrast that exceed a perceivable threshold. However because human perception of these contrast is dependent on a number of factors including viewing distance, spatial frequency, and orientation, relevant mura cannot be identified by looking at simple, absolute values of contrast.

Recent advances in modeling human visual sensitivity to display defects allow the quantification of mura in terms of "just noticeable differences" (JND). Based on sampling of human observers, the JND scale is defined so that a JND difference of 1 would be statistically just noticeable; on an absolute scale, a JND value of 0 represents no visible spatial contrast and an absolute JND value of 1 represents the first noticeable spatial contrast – which for display technologies allows the grading of display defects. Thus an imaging colorimeter measurement of spatial distribution of luminance and color can be processed to create a JND map of the image where mura defects are graded with a direct correlation to human visual perception.

*Identifying **mura defects** is not a simple mathematical operation based on straightforward computation of contrast between regions. First, because the mura area can vary in size and shape and, second, because a human's ability to perceive the mura is a function of additional attributes – viewing distance, spatial frequency, and color.*

Figure 6 shows a display with a mura defect; after analysis, it is identified on the display image as shown in **Figure 7**.

Figure 6. *Imaging colorimeter measurement of a display with a mura defect; can you find it?*

Figure 7. *The mura defect is identified on the display by the imaging colorimeter AOI software. Its extent is shown, along with a JND value.*

In **Figure 8** and **Figure 9** processing steps in identifying the mura are shown. As an intermediate step, a difference image is generated that shows luminance deviations relative to a reference image. Then a JND map of the display is computed. Note that the mura test illustrated in **Figure 7** deliberately ignored edge effects that are readily apparent in the JND image. These effects are easily identified and classified separately.

Figure 8. *A difference image shows luminance deviations relative to a computed reference image. The location of the mura is highlighted.*

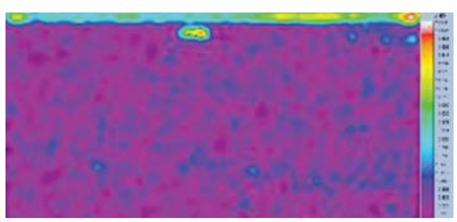

Figure 9. *A "false color" JND map of the display is shown. Both light leakage at the edge of the display and a significant mura defect are identified with larger JND values.*

Imaging colorimeter based AOI testing systems can quickly and reliably identify and quantify display defects. To determine or classify the root cause of the defect and therefore determine the disposition of the display, will sometimes require human inspection. In many cases, such as for the line defect shown in **Figure 3**, there is a 1-for-1 relationship between the identified defect and a cause. In these cases, classification is immediate and human inspection is not needed. In other cases, such as for some mura, there are multiple possible causes, so additional information is required to complete classification. An efficient method to perform this classification is to have the human operator make a determination of which of several causes is the correct one. To increase efficiency when human classification is needed, TrueTest indicates for the operator the exact location and details of the defect that needs further examination. By specifically targeting the defect that requires classification and by presenting appropriate detail, human judgment can be focused and accelerated.

Once a quality issue or a defect is identified by imaging colorimeter based AOI testing, some action will be taken, for instance: accept, reject and scrap, or reject and repair. This determination, or classification, will depend in part on distinguishing the cause of the quality issue or defect.

For the point defect shown in **Figure 4** and **Figure 5**, the operator is presented the exact location and information on the dark point, allowing them to quickly determine if this is a dead pixel or a particle on the backside of the display glass, etc.

Summary

The imaging colorimeter AOI testing methods described in this note can be applied to multiple display technologies and can be used for both FPD (LCD, plasma, OLED) and projection displays. By providing rapid, repeatable measurements that are correlated to human visual perception, and by being able to numerically characterize them, these methods allow display defects to not only be identified, but also classified by cause. This allows a consistent measurement of displays in manufacturing applications and allows automated determination of pass / fails in accordance with user defined criteria. More importantly, this also allows an automated determination of remedial action (e.g., rework or scrap).

*The tests described in this note were performed using a Radiant Zemax **TrueTest™ system**: TrueTest AOI testing software together with a ProMetric® imaging colorimeter.*

Additional References

1. "Methods for measuring display effect as correlated to human perception." For more on imaging colorimetry as applied to display defect detection, see: H. Kostal, G. Pedeville, and R. Rykowski, SPIE Electronic Imaging Conf., (2009).

2. "The Spatial Standard Observer: A new tool for display metrology." For more on JND analysis of display mura, see: A.B. Watson, Information Display, 23(1), (2007).

3. "Imaging Colorimetry: Accuracy in Display and Light Source Metrology." For more on basic imaging colorimetry, see: R. Rykowski and H. Kostal, Photonics Handbook, (2008).

Radiant Zemax TrueTest system is currently deployed in a wide range of engineering, QA, and production testing environments. The system provides highly accurate and repeatable defect detection, and the overall speed and accuracy is a significant improvement over human only quality assessment. Contact us to find out more.

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