Flat Panel Inspection

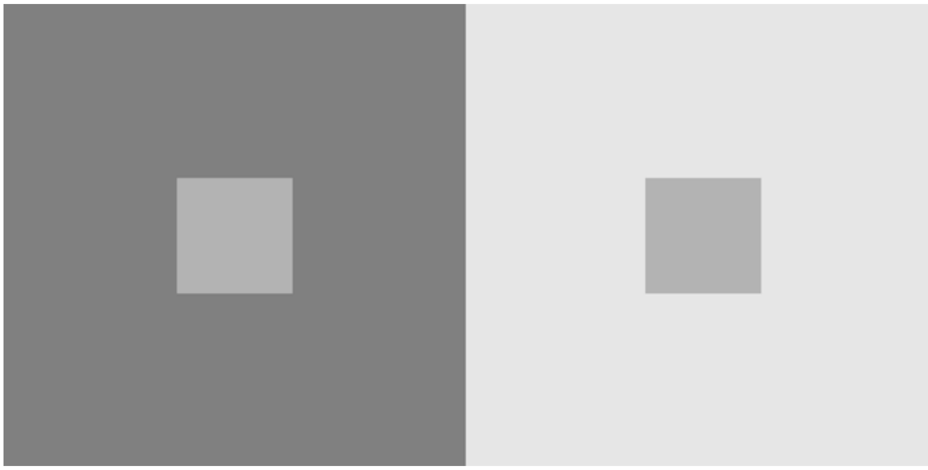
Learn what makes a camera suitable for flat panel display inspection

INTRODUCTION

Machine vision is being used more and more within the manufacturing industry for quality assurance and inspection purposes. It provides an objective visual verification to ensure quality standards are met and that defects are not present in the finished product or at any point during the assembly process. A good example of the necessity of machine vision within the manufacturing process is the production of flat panel displays, as they can have a number of defects that are too small for the human eye to spot rapidly or identify objectively.

FLAT PANEL DISPLAYS

Flat panel displays (FPD) can now be found in a wide range of consumer electronics, from smart phones and tablets to high resolution computer monitors and televisions. Ensuring that these displays reproduce images accurately is heavily reliant on their inspection process. The human eye is far too subjective when it comes to evaluating the brightness and color of a display. The process, therefore, requires a form of machine vision to perform objective analysis on each display. This analysis consists of quantitative measurements of luminance uniformity across the display.



Optical illusion illustrating squares of the same luminance appearing differently due to contrast with the background.

In this context, luminance is the amount of light emanating in a particular direction weighted by the luminous efficiency function. This function models the brightness sensation of human vision at different wavelengths.

MEASURING LUMINANCE

When evaluating the luminance consistency of a panel, the approach of just-noticeable difference (JND), is used. The JND is a quantitative measurement of the minimum change between intensities required to be perceivable to a general human observer. Defined by Weber's Law, the JND is expressed as the maximum ratio between two measured intensity levels that cannot be perceived by a human observer, illustrated by the following equation:

$$\frac{\Delta I}{I} = k$$

Where I is the initial intensity, ΔI is the variation of intensity for which the human observer perceives no difference, and k is a constant illustrating the JND threshold. For instance, if an observer is presented with two lights where each is set to an intensity of 100 units, and they had to change the intensity of one light until they noticed a difference in intensity, for example to 105 units, the JND would be:

$$\frac{105\text{-}100}{100} = 0.05$$

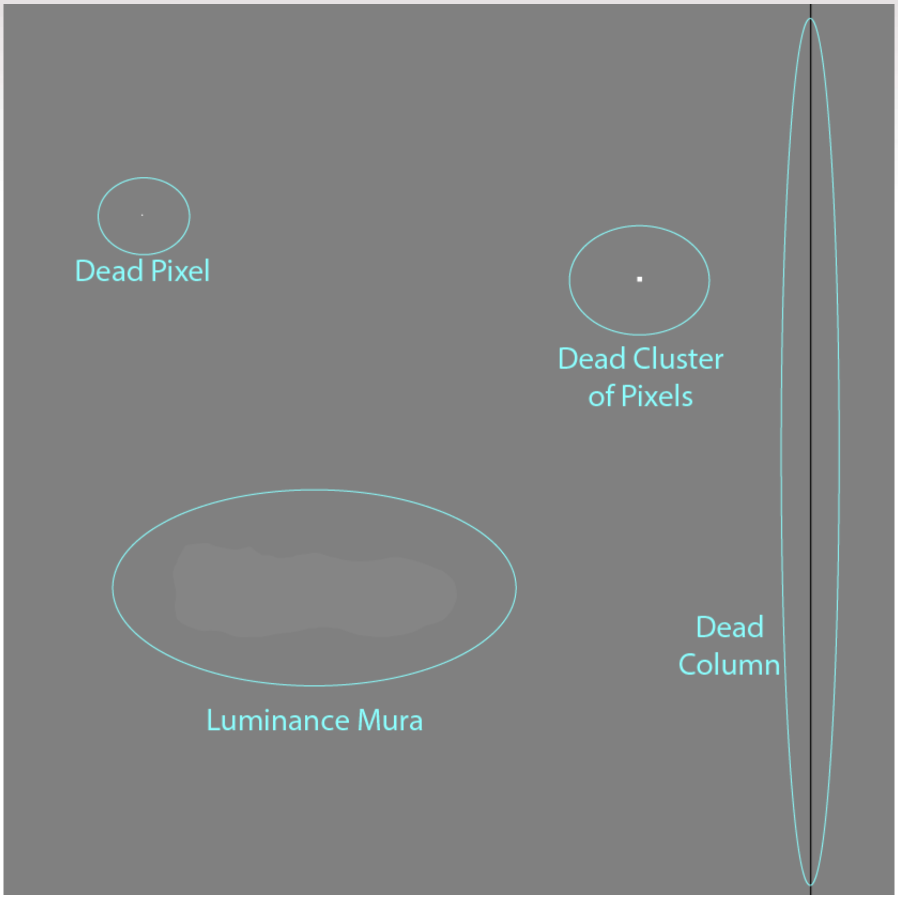
If this JND were applied to a light of the same wavelength with an intensity of 1,000 units, it could be varied between 950 and 1050 units of intensity before a perceivable change is seen.

MURA

Mura is a Japanese term that signifies non-uniformity or distortion, and when it is applied to FPD inspection, it relates to areas of noticeable changes in luminance. There are a number of factors that influence mura in relation to a human observer, such as viewing distance, spatial frequency, and color. Common types of mura include dead pixels, dead rows or columns of pixels, and uneven luminance patterns. Any form of dead pixel is a critical defect as they are often uncorrectable. However, variances of luminance, specifically in organic LED (OLED) displays, are expected based on the nature of the OLED itself.

Organic LED displays do not possess a backlight as the OLED emits its own light for each pixel. OLED pixels are made up of three sub pixels of red, green, and blue to create a number of colors using the additive properties of colored light. The organic nature of the LED causes a unique level of light intensity produced by a given input voltage. These variations in luminance can be visible to the human eye, introducing intensity values beyond the JND threshold. By inspecting the display, the areas of mura can be detected, and the sub pixels can be given a voltage offset to produce an image of uniform luminance.

Since mura is dependent on color and spatial frequency, a variety of colors are evaluated where the entire FPD is displaying a single color, removing the spatial frequency variable. The machine vision camera is positioned at a set working distance to eliminate the viewing distance variable, allowing the inspection to focus only on color dependant mura. A matching color filter and monochrome camera are used to enhance and capture the areas of non-uniformity in the panel.



Simulation of Mura and Other Display Imperfections

Using a monochrome camera and varying color filters allows for all of the camera's pixels to be simultaneously sensitive to a specific wavelength. In contrast, a color camera would not work as effectively in this scenario since each pixel has a red, green, or blue filter covering the pixel, making each sub-group of pixels react differently to a specific wavelength.

SMALL DEFECT DETECTION

FPD inspection is also capable of pinpointing issues with specific pixels or sub pixels, as well as scratches or chips in the panel. To accomplish this in a single frame, the inspection camera requires a resolution of at least four times that of the display. This is due to the Nyquist limit, which states that the minimum sampling frequency should be at least double the signal frequency. Since this principle needs to be applied both horizontally and vertically, the minimum resolution of the camera must be quadrupled, not doubled. By illuminating the sub-pixels of one color at a time, the imaging system has enough resolution to see each sub-pixel and any defect they may have.

FROM A CAMERA PERSPECTIVE

Given the example of a standard 1080P high definition display, measuring 1920 x 1080 pixels, a resolution of at least 3840 x 2160, or over 8 megapixels, is needed. This is the minimum required resolution for sub pixel defect detection, generating a 2:1 pixel mapping from camera to display. It would however be ideal to have a camera with a higher resolution than this to allow for a buffer zone around the display as well as an increased pixel density in the region of interest. A more ideal pixel mapping ratio would 3:1 and above to get further from the Nyquist limit.

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SUITABLE CAMERAS

While lower resolution cameras are capable of performing consistent luminance inspection, detecting small defects in a panel requires a significant increase in pixel density. Lumenera has a variety of cameras with high resolution that are suitable for FPD inspection. The Lt1265R camera, which satisfies the Nyquist limit for a HD panel, has a resolution of 4240 x 2832 pixels, just over 12 megapixels. It has a dynamic range of 59 dB, allowing it to detect dead or underperforming pixels among brightly lit areas.

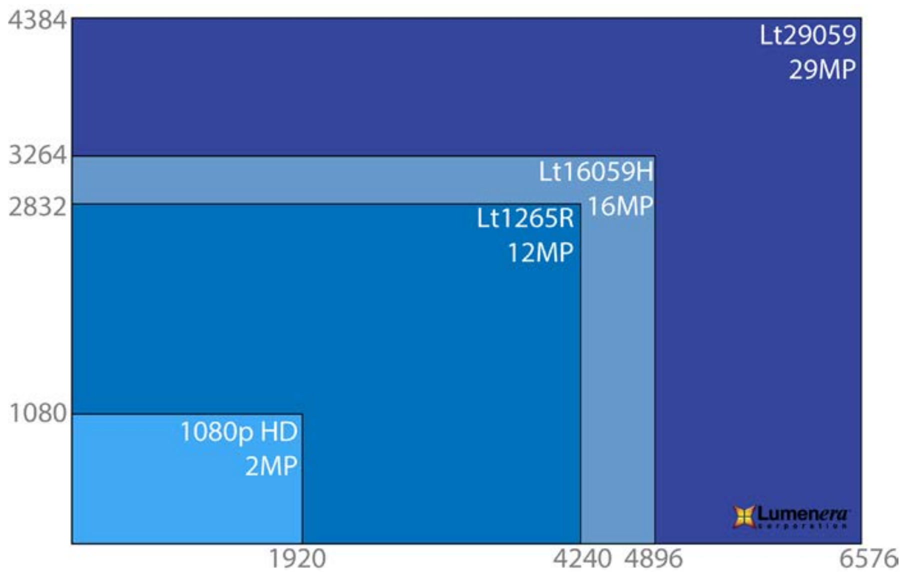
The 16 megapixel Lt16059H camera offers even more resolution and dynamic range (66.7 dB) and is the ideal candidate for detecting spatial variations in the FPD illumination over a wide range of values. The boost of resolution to 4864 x 3264 approaches the 3:1 pixel ratio for 1080p HD, allowing clearer detection of small defects in the panel. When using lenses designed to effectively resolve much higher resolutions, costs will also be need to be evaluated for the system design.

The Lt29059 is currently Lumenera's highest resolution camera at 29 megapixels, which surpasses a 3:1 pixel mapping for 1080p HD displays, offering clear detail for each pixel in the display. The camera's ON Semiconductor (Truesense) KAI-29059 CCD sensor has a 6576 x 4384 pixel resolution -- nearly 14 times that of 1080p. The Lt29059 is also capable of performing inspections of 4K displays by capturing 2 sections of the panel in 2 separate images.

The camera's high dynamic range also allows it to detect issues with pixels among brightly lit areas without getting washed out by the neighboring picture elements.

In addition to small defect detection, these cameras are all capable of performing mura analysis as they are available in monochrome, allowing them to operate with a color wheel or different color filters. The cameras' general purpose I/O ports allow them to be triggered externally by the system's color filter wheel or any other external trigger with highly deterministic results. They are also capable of seeing brightness variations with more detail than the human eye, capturing images at a bit depth of 14-bits. This will allow the system to fine-tune individual sub-pixel voltage levels with more precision, targeting a variance as close to zero as possible.

Furthermore, Lumenera's robust drivers, API, and SDK allow for easy and reliable customization and integration. Using USB 3.0 to transfer the large file sizes that 14-bit images generate, especially from the Lt29059, ensures high throughput speeds and will not be the bottleneck of the system.



Pixel to pixel comparison between Lt29059, Lt16059H, Lt1265R, and 1080p HD

FEATURED CAMERAS

Lt1265R Highlights

High resolution, low noise, 12 megapixel CCD USB 3.0 camera with Sony ICX834 sensor

Resolution: 4240 x 2832
Dynamic Range: 59 dB
Frame Rate: 15 fps
Optical Format: 1 inch

Lt16059H Highlights

High performance, 16 megapixel 35 mm CCD USB 3.0 camera with ON Semi-conductor KAI-16070 sensor

Resolution: 4896 x 3264
Dynamic Range: 66.7 dB
Frame Rate: 12 fps
Optical Format: 35 mm

Lt29059 Highlights*

High resolution, 29 megapixel CCD USB 3.0 camera with ON Semiconductor KAI-29050 sensor

Resolution: 6576 x 4384
Dynamic Range: 64 dB
Frame Rate: 6 fps
Optical Format: 35 mm

**Preliminary specs, subject to change*

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