OUTLINE

• FPD quality now critical to model purchase and referral
• Automated Test Methods for illuminated FPDs are well-established
  ▪ quantitative, objective, repeatable
  ▪ can point to root causes, quality improvement
• Automated testing is now extended to cover non-lit or cosmetic defects
• Together, these methods can improve quality and reduce the negative impacts of “escapes”
DISPLAY QUALITY DRIVES THE SALE

- For modern buyers, functionality of electronics may surpass the appearance, NVH and performance of the car
- Display readability, clarity, brightness, color and contrast will be judged against the latest phablets, laptops and TVs
- High resolution and a wide range of color/contrast make display defects harder to detect
PROPER TESTING PRECLUDES “ESCAPES”

• An “escape” is a defective product that has found its way to the consumer
• The negative consequences of an escape include:
  • On the showroom floor, a discovered defect can de-rail a sale
  • After the sale, replacing a display can be time consuming and expensive
  • That repair may spoil the owner’s experience with your brand
  • That owner, through the miracle of the www, can put others off your brand
• Just as easily, a perfect display can result in a satisfied customer and endorsement of your brand.
# Testing High-Resolution Displays

<table>
<thead>
<tr>
<th>Human Inspectors</th>
<th>Imaging Colorimeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective, qualitative</td>
<td>Objective, quantitative</td>
</tr>
<tr>
<td>May be ambiguous and inconsistent</td>
<td>Documented pass-fail standards for key factors: brightness, color, clarity, contrast</td>
</tr>
<tr>
<td>Poor repeatability makes it difficult to determine defect source</td>
<td>Traceable and repeatable measurements can drive to root cause, meet quality standards</td>
</tr>
<tr>
<td>Marginally scalable</td>
<td>Highly scalable, with faster takt times and reduced operating costs</td>
</tr>
</tbody>
</table>

SEE THE DIFFERENCE
• Mura is Japanese word for “Blemish”
• Found in all types of FPDs
• Usually detected at low gray and black levels when driven with a solid-color input
MURA DETECTION

• Multiple methods have been used to detect Mura in Flat Panel Displays:
  • edge detection
  • calculating gradients in the image
  • contrasts against a background luminance
  • color / brightness differences from nearby locations / averages

• This presentation will discuss two techniques:
  • Spatial Standard Observer
  • SEMU
SPATIAL STANDARD OBSERVER

• A model of human contrast sensitivity with respect to spatial frequencies
• Describes systems and techniques for processing visual information
• Matches human visual perception
• Produces a numerical value, Just Noticeable Difference, as a visibility metric
• Embodied in U.S. Patent 7,783,130, derived from research at N.A.S.A.
• Makes possible the accuracy and repeatability of an automated system
• Offers a powerful weapon for identifying and quantifying perceptible Mura
The difference between test image and reference image is filtered by a constant sensitivity function, windowed by an aperture function, and pooled non-linearly over space to yield Just Noticeable Difference (JND) metrics.

CONTRAST, FILTER AND WINDOW

• Local Contrast image 3 establishes the difference between the test 1 and reference 2 images
• The Local Contrast image 3 is subsequently modified by the Contrast Sensitivity Function (left) 4 ...
• ...and windowed by an aperture function (right) that models human vision 5
SSO DEMONSTRATED ON BLACK MURA

Black Mura test image 1 captured with an imaging colorimeter

Defect identified in software, displayed in Local Contrast view 3

Just Noticeable Defects 7 quantified, compared with pass / fail criteria
LED MURA (EDGE LIGHT)

- Light from the display’s backlight may leak around the edges of displays when measuring on a dark screen.
BUTTERFLY MURA

• A mirror pattern, edges brighter than corners, while measuring display in the black state

1 Image

7 Final analysis
JND SEMU

- SEMI = Semiconductors and Materials International
- SEMU = SEMI Mura
- Traditional measure of JND based on contrast

\[ JNDSEMU = \frac{|c|}{1.97/A^2 + 0.72} \]

where \( c \) is average contrast of mura being measured (% relative to background)

and \( A \) is area of contrast being measured (mm\(^2\))
PARTICLE DEFECTS

- Particle Defects are very small blemishes on the display. These can be the result of dust or defective pixels present in the display.
DETECTION OF COSMETIC (NON-LIT) DEFECTS

- Advances in technology now allow Imaging Colorimeters to be applied to the detection of both illuminated and cosmetic (non-lit) defects.
- Using contrast detection, spatial measurement, Mura detection, pattern matching, and optical character recognition (OCR), the following cosmetic defects may be detected and quantified.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface attributes</td>
<td>• Surface Color&lt;br&gt;• Finish uniformity</td>
</tr>
<tr>
<td>Surface Defects</td>
<td>• Scratches, dents, dings&lt;br&gt;• Surface particles, foreign material&lt;br&gt;• Logo defects</td>
</tr>
<tr>
<td>Features</td>
<td>• Connector, camera or button existence / positioning&lt;br&gt;• Key position / cosmetics</td>
</tr>
<tr>
<td>Gaps</td>
<td>• Fit of component surfaces.&lt;br&gt;• Seams</td>
</tr>
<tr>
<td>Patterns</td>
<td>• Text (Part #, SN, SKU) readability and correctness via OCR&lt;br&gt;• Label positioning&lt;br&gt;• Label correctness via pattern matching and/or OCR</td>
</tr>
</tbody>
</table>
SURFACE DEFECTS: SCRATCH

• Scratches (and dents, particles, inclusions) are identified based on their contrast. The values shown are contrast ratios relative to a background level.
SURFACE DEFECTS: DENT

- The defect’s intensity, length and width can be measured and used to determine whether a product passes or fails.
FEATURES: POSITIONING

- Graphical symbols can be inspected.
- High resolution is required
GAPS

- Distances between high contrast areas are measured as gaps.
- Physical gaps are important to discover and quantify on the production line.

<table>
<thead>
<tr>
<th>inches</th>
<th>Pass</th>
<th>Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. gap</td>
<td>.053</td>
<td>.050</td>
</tr>
<tr>
<td>Min. gap</td>
<td>.044</td>
<td>.024</td>
</tr>
<tr>
<td>Avg. gap</td>
<td>.047</td>
<td>.039</td>
</tr>
<tr>
<td>Uniformity</td>
<td>83%</td>
<td>47%</td>
</tr>
</tbody>
</table>
PATTERNS

- Text printed on the unit under test or on a label can be read by the camera and OCR software.
- Serial numbers can be read from printed text or from a barcode.
DISPLAY STACK-UP ISSUES

• A typical FPD is a vertical stack of Backlight Unit, LED and various touch-sense / cover films.

• A defect in any element of the stack can result in a failure
  ▪ A particle in a cover film may appear in final display as a dead pixel
  ▪ A defect in a Backlight Unit may reveal itself as color non-uniformity
  ▪ A cosmetic gap in a stack-up layer might cause Mura or prevent assembly

• Sunk costs grow as stack assembly proceeds. Performing cosmetic inspections of layers as a prerequisite to final assembly can prevent shipping a defective display or rejecting an expensive, completed display
PROCESS / HANDLING IMPROVEMENTS

- Cosmetic inspection can detect flaws or defects consistently introduced by prior manufacturing and handling steps.
- Over time, trends and patterns in the image analyses can be used to adjust processes to remedy recurring quality issues.

Pareto of DUT Defects

- Uniformity, top
- Scratch, right edge
- Dent, bottom
- Logo defect, top
- Wide seam, left edge
- Incorrect label
CONCLUSIONS

• To make the sale and build the brand, perfect displays are required. “Escapes” must be avoided.
• New technology is available to support automated display testing for both illuminated and cosmetic (non-lit) defects.
• The resulting quantifiable test processes can drive process improvements, ensure display quality and deliver a favorable customer experience.
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