MEASURING HEAD-UP DISPLAYS FROM 2D TO AR: SYSTEM BENEFITS & DEMONSTRATION

Presented By Matt Scholz  |  November 28, 2018
TODAY’S AGENDA

- **The State of Head-Up Displays**
  - 2D, 3D, and Augmented Reality HUD

- **Simplifying HUD Testing**
  - Single-Camera Measurement System
  - Electronically-Controlled Lenses
  - Resolution and Depth of Field

- **Software Demonstration**
  - Measuring Contrast
  - Characterizing Distortion
  - Testing for Ghosting Effects
THE STATE OF HEAD-UP DISPLAYS
OVERVIEW OF HUD TECHNOLOGY & THE ROAD AHEAD
HEAD-UP DISPLAY OBJECTIVES

1. Project information in view of the driver to improve safety
2. Ensure visibility of information in all ambient conditions
3. Allow driver to remain focused on the road while viewing information
THE PATH FORWARD
THE HUD HIERARCHY

Dimensionality of Projection
- Traditional (Fixed-XYZ)
- Augmented Reality (Variable-XYZ)

Dimensionality of Image
- 2D (Flat Image)
- 3D (3D Image)

Projector Technology
- Laser
- Display (TFT, Thin-Film Transistor)
- Projector (DLP, Digital Light Processor)
### TYPES OF OPTICAL HUD PROJECTIONS

<table>
<thead>
<tr>
<th></th>
<th>2D</th>
<th>3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td><img src="image1.png" alt="2D Fixed Example" /></td>
<td><img src="image2.png" alt="3D Fixed Example" /></td>
</tr>
<tr>
<td>AR</td>
<td><img src="image3.png" alt="2D AR Example" /></td>
<td><img src="image4.png" alt="3D AR Example" /></td>
</tr>
</tbody>
</table>
TRADITIONAL HEAD-UP DISPLAYS

Multi-color head-up display in 2019 Yukon Denali. Source: www.GMC.com

Hudway Drive aftermarket head-up display. Source: PRWeb.com
PROBLEMS WITH TRADITIONAL HUDS

Because images are at a fixed distance...

- Requires shifting visual focus from HUD images to objects at variable distances
AUGMENTED REALITY HUDS

AR-HUD concept from Continental AG. 
Source: continental-head-up-display.com

3D HUD concept from Toyota. 
Source: www.autoevolution.com
BENEFITS OF AR-HUDS

Seamless integration with objects at every line of sight.
LASER-BASED PROJECTIONS

LASER STRUCTURE

VIRTUAL IMAGE

Laser and Beam Splitter

Picture Generating Unit (PGU)

Rotating Mirror

Projected Image

Windshield/Combiner

HUD
LASER-BASED PROJECTIONS

Benefits:

• Small components
• Low energy usage
• High luminance (very bright)
• Large FOV
• Can be used in *windscreen applications* (FOV takes up a much larger area of the windshield)

Laser-based HUD in Jaguar XE sedan. Source: www.jaguarusa.com
LASER-BASED PROJECTIONS

Challenges:

• Limited to 2D, fixed projections
• Resolution
  • “Fuzzy” images, low sharpness
    • Effect of single beam refracting from mirror/beam splitter
    • Causes ghost-like effect
• Speckle
  • Random granular pattern occurring when laser beam is diffusely reflected
TFT DISPLAY-BASED PROJECTIONS

VIRTUAL IMAGE

TFT STRUCTURE

HUD

Projected Image

Mirror (flat or convex)

Rotating Mirror (concave)

TFT Display

Picture Generating Unit (PGU)

Windshield/Combiner
TFT DISPLAY-BASED PROJECTIONS

Benefits:

• Easily used for 3D, AR
• Display-based
  • Well-understood technology, regulations in place
• Long lifecycle
• Reliable color
  • Control by display calibration

TFT display HUD from DENSO. Source: www.denso.com

Display-based combiner HUD from Continental. Source: continental-head-up-display.com
TFT DISPLAY-BASED PROJECTIONS

Challenges:

• Limits to max luminance
  • Driving up luminance output can cause shifts in color accuracy and expected distribution

• Limited FOV
  • Limited by source display
DLP PROJECTOR-BASED PROJECTIONS

DLP STRUCTURE

VIRTUAL IMAGE

Source Image

Picture Generating Unit (PGU)

HUD Optics

DLP Optics

Projected Image

HUD Box

Windshield/Combiner

HUD Electronics

© Radiant Vision Systems, LLC.

Radiant Vision Systems | A Konica Minolta Company
DLP PROJECTOR-BASED PROJECTIONS

DMD

Micro-mirror array
DLP PROJECTOR-BASED PROJECTIONS

Benefits:

- Easily used for 3D, AR
- Small, powerful
  - Enables space & cost savings
- Large FOV
- Same chipset as cinema projection technology
  - Luminance output (bright)
  - More saturated colors
  - Best contrast
DLP PROJECTOR-BASED PROJECTIONS

Benefits:
- Easily used for 3D, AR
- Small, powerful
  - Enables space & cost savings
- Large FOV
- Same chipset as cinema projection technology
  - Luminance output (bright)
  - More saturated colors
  - Best contrast

DLP HUD concept from Continental AG. Source: continental-head-up-display.com
DLP PROJECTOR-BASED PROJECTIONS

Challenges:

• Image alignment
  • Clarity, Sharpness
  • Ghosting
  • Distortion
OPTICAL MEASUREMENT
SIMILARITIES & DIFFERENCES FROM 2D TO AR
OPTICAL MEASUREMENT REQUIREMENTS

Tests to ensure virtual image quality:

- Luminance
- Chromaticity
- Uniformity
- Contrast
- Defects (Pixels/Lines)

- Modulation Transfer Function (MTF)
- Ghosting
- Distortion
- Warping
- Eyebox Limit

COMMON TESTS PERFORMED ACROSS ALL HUD SYSTEMS
OPTICAL MEASUREMENT REQUIREMENTS

20m

10m

4m

2.5m

AR-HUD

Trad. HUD

5° FOV

10° FOV

20° FOV
# MEASUREMENT CHALLENGES

<table>
<thead>
<tr>
<th>Projected Image</th>
<th>Traditional HUD</th>
<th>AR HUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminance</td>
<td>8-10,000 cd/m²</td>
<td>15-30,000 cd/m²</td>
</tr>
<tr>
<td>Display Size</td>
<td>125-180 mm H</td>
<td>&gt;635 mm H</td>
</tr>
<tr>
<td>Field of View</td>
<td>5-10° H (2-4° V)</td>
<td>&gt;10° H (&gt;4° V)</td>
</tr>
<tr>
<td>Image Distance</td>
<td>2-4 meters</td>
<td>7-20 meters</td>
</tr>
<tr>
<td>Display Resolution</td>
<td>≤800 x 480 pixels</td>
<td>&gt;800 x 480 pixels</td>
</tr>
</tbody>
</table>

SAME CHALLENGES, INCREASING DEMAND ON TEST SYSTEM
DEMANDS ON MEASUREMENT SYSTEM

Regardless of HUD type (2D, AR, 3D)...

• Increasing *display size* and *field of view*:
  • Requires improved spatial measurement

• Increasing *image distance*:
  • Requires extended focus flexibility

• Increasing *display resolution*:
  • Requires higher-resolution measurement
SIMPLIFYING HUD TESTING
SOLVING CHALLENGES ACROSS HUD SYSTEMS
PROBLEM 1: COMPONENT REQUIREMENTS

1. Metrology
2. Gauging
3. Full FOV
METROLOGY

• Obtaining absolute light & color data for:
  • Luminance
  • Chromaticity

• HUD test system must have a component for:
  • Photopic metrological solution
GAUGING

• Obtaining **dimensional measurements** for:
  • Distortion
  • Warping
  • Ghosting

• HUD test system must have a component for:
  • **Human Inspection or Imaging**
FULL FIELD OF VIEW

- Obtaining **contextual information** for:
  - **Contrast**
  - **Uniformity**
  - **Mura (blobs)**
  - **Pixel/line defects**
- HUD test system must have a component for:
  - **Imaging or Positioning (Robotics)**
OPTION 1: HARDWARE COMBINATION
SIMPLIFYING COMPONENTS
OPTION 2: SINGLE PHOTOMETRIC IMAGER
SINGLE-CAMERA MEASUREMENT SYSTEM

CIE-matched optical filter wheel (photopic/color)

Built-in neutral density filters

Electronically-controlled Lens

Scientific-grade CCD (2-29 MP)

Metrology + Gauging + Full FOV Imaging — All in One System
WHAT ABOUT AR? 3D?

• Does the same camera meet all requirements?

√ YES

• The key is bringing everything into focus...
  • A greater number of calibrated F-Stops
  • High-resolution CCD (for accuracy at any depth)
    • For example: Performing MTF measurement at 20m distance for AR
PROBLEM 2: VIRTUAL IMAGE DISTANCE

Traditional Head-up Display

ARS Head-up Display
SIMPLIFYING FOCAL DISTANCE
ELECTRONICALLY-CONTROLLED LENSES

- Electronic lenses focus on any projected image plane (depth)
  - Infinite focus flexibility
  - Remove human calculation, error
  - Reduce time between measurements
ELECTRONICALLY-CONTROLLED LENSES

Quickly adjust focus if camera or image location varies.
How do you acquire the same amount of visual information at all depths?
SIMPLIFYING DEPTH OF FIELD
HIGH-RESOLUTION IMAGING

- Eliminates resolution effects of the measurement camera
  - Isolates resolution of HUD images for accurate testing
- A 16MP+ resolution optimizes performance
  - Available systems to 29MP
HIGH-RESOLUTION IMAGING

• Eliminates resolution effects of the measurement camera
  • Isolates resolution of HUD images for accurate testing
• A 16MP+ resolution optimizes performance
  • Available systems to 29MP

Images captured with a 1MP resolution camera (left) as compared to a 29MP camera (right).
SOFTWARE DEMONSTRATION
EXAMPLES FROM RADIANT TrueTest™ HUD SOFTWARE MODULE
SOFTWARE BENEFITS

• Packaged HUD test suite
• Characterize HUD defects using HUD test images
  • Understand & document the severity of defects
• Customizable parameters
  • Pass/fail displays based on defect severity
  • Quality control in production

Radiant TrueTest™ Software: TT-HUD Module
CONTRAST

Crisp edges, brighter brights, darker darks.
MEASURING CONTRAST

• **TT-HUD Benefits:**
  • Supports many methods:
    • *Checkerboard Contrast*
    • *Diamond Contrast*
    • *Sequential Contrast*
    • *Inverse Checkerboard Contrast*
  • Stray light correction algorithm
  • High-dynamic-range imaging achieves accurate contrast levels
DISTORTION

Are symbol dimensions & locations accurate?
MEASURING DISTORTION

- **TT-HUD Benefits:**
  - Provides users with:
    - *Raw data for centroid X,Y locations*
    - *Measured deviation from point to point on all vertices*
    - *Pass/fail criteria for different levels of accessibility*
  - Identify if any area of FOV is missing from measurement
  - Dot or Line Grid test patterns
GHOSTING

• Achieve a single, clear projection
MEASURING GHOSTING EFFECTS

• TT-HUD Benefits:
  • Only solution with diverse ghosting algorithms based on photometric images
  • Measure multiple ghosts simultaneously
  • Output luminance of ghost
  • Output distance from primary image to ghost
COMPLETE HUD MEASUREMENT SYSTEM

Up to 29MP

ProMetric® I Imaging Colorimeter

ProMetric® Y Imaging Photometer

TrueTest™ TT-HUD Software Module
SUMMARY

✓ Regardless of 2D, 3D, or AR-HUD measurement can be simplified using:

✓ Photometric imagers to capture complete visual data using a single camera

✓ Electronically-controlled lenses for image location regardless of focal distance

✓ From traditional HUD (2-4m) to AR HUD (up to 20m distance)

✓ Resolution for precision depth-of-field measurement at any focal distance

✓ Software tests specific to HUD testing

✓ Characterize defects and enable pass/fail using custom parameters & tolerances