# Development and Validation of a Luminance Camera

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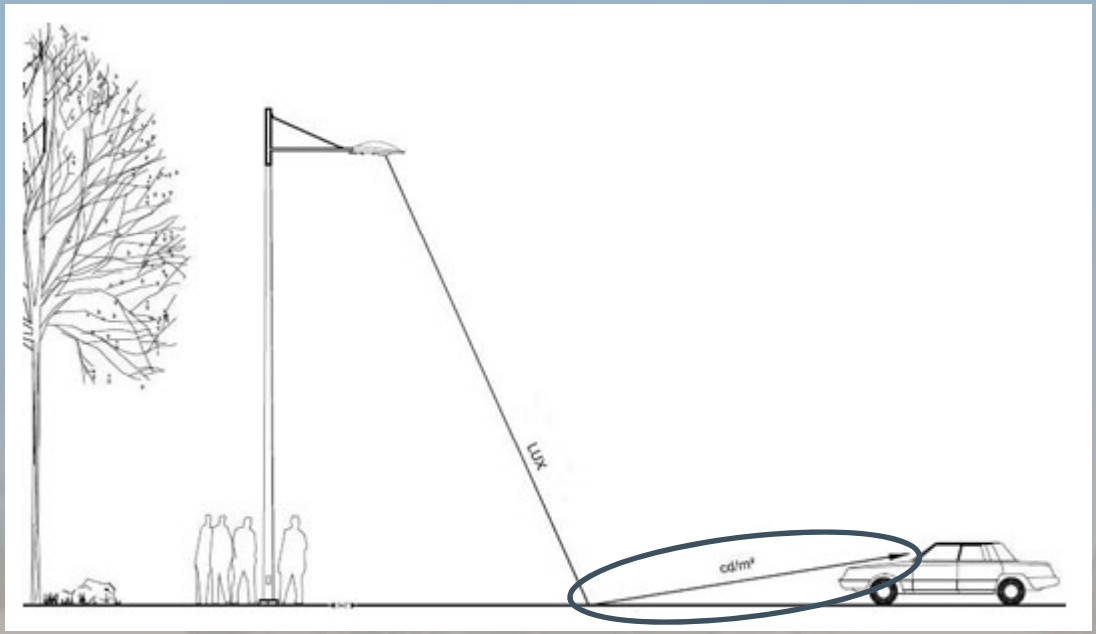
Driving Transportation with Technology

Virginia Tech Transportation Institute

# Background

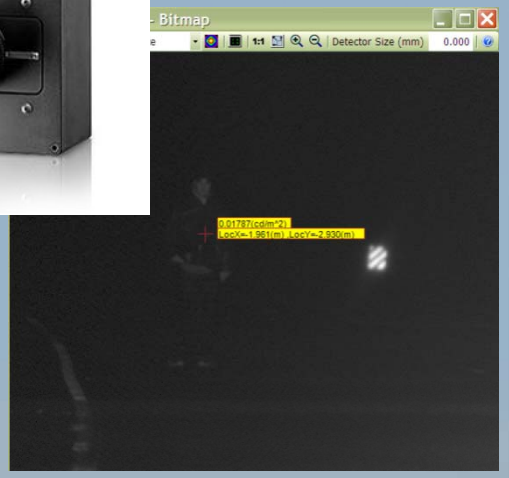
Luminance - amount of visible light leaving a point on a surface in a given direction




From: Schréder

# Background

- Static Photometers
  - PRO:
    - Capture luminance data for entire scene in image
    - Fan to decrease temp. → decrease image noise
  - CON:
    - Unable to capture dynamic data in rapid succession


- Hand-held luminance meters
  - PRO:
    - Capture luminance data for specific points of interest
  - CON:
    - Time-consuming for multiple points of interest
    - Unable to conduct future analysis since no image is recorded

# Goals

1. Calibrate a digital video camera to a photometer
   - Develop rapid method of image capture for calibration
2. Develop working system for dynamic video capture
   - Determine optimal manual camera settings or allow automatic, camera-determined settings
3. Determine the level of repeatability and reproducibility (R&R) of the working system
4. Compare results of the working system in a dynamic environment

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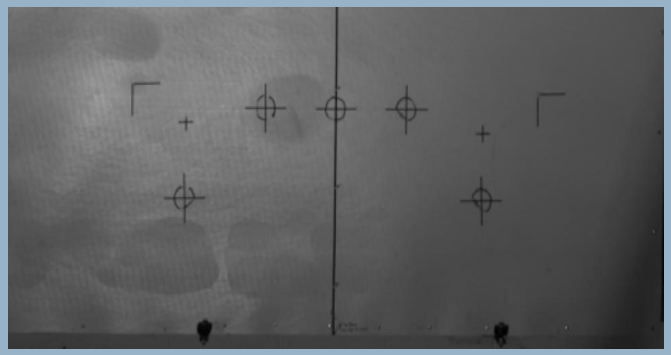
# Calibration - Equipment

- Radiant Imaging ProMetric still photometer
- Point Grey Grasshopper FireWire digital cameras ("Luminance Cameras")
- MATLAB Image Acquisition and Processing Toolboxes
- Incandescent 200-watt light bulb
- High-Pressure Sodium (HPS) 400-watt street luminaire



# Calibration - Procedure

- Controlled environment
- Simultaneous image capture with ProMetric photometer and Luminance Cameras
  - Software automatically adjusts Luminance Camera variables



| | |
|---|---|
| **Light Level (cd/m2)** | 24.1, 15.6, 7.99, 1.87 |
| **Camera Gain (dB)** | 24, 21, 18, 15, 12, 9, 6, 3, 0, -2.25 |
| **Camera Shutter (ms)** | 267, 213, 159, 105, 51, 41, 36, 31, 26, 21, 16, 11, 6, 1 |

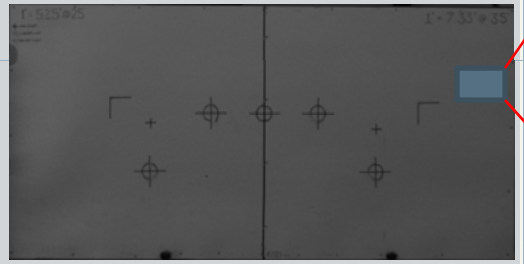
4 Light levels
10 Gain values chosen
x 14 Shutter values chosen
560 images captured by Luminance Camera

# Calibration - Procedure

Overlay of images completed automatically through software

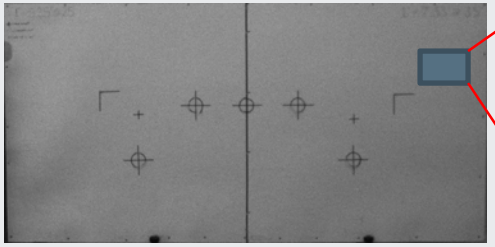

**Pixel Value**

Luminance (cd/m²)



| | | |
|---|---|---|
| 2.13 | 2.13 | 2.10 |
| 2.13 | 2.13 | 2.10 |
| 2.08 | 2.08 | 2.13 |

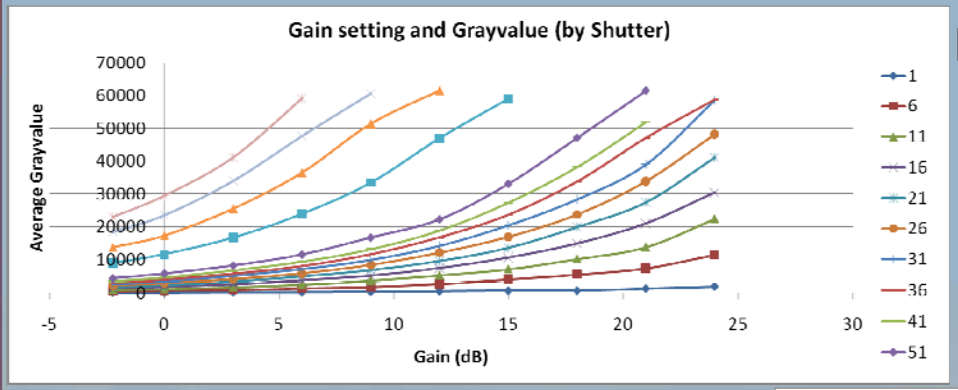
grayvalues



| | | |
|---|---|---|
| 2608 | 2704 | 2816 |
| 2704 | 2928 | 2624 |
| 3152 | 2848 | 2656 |

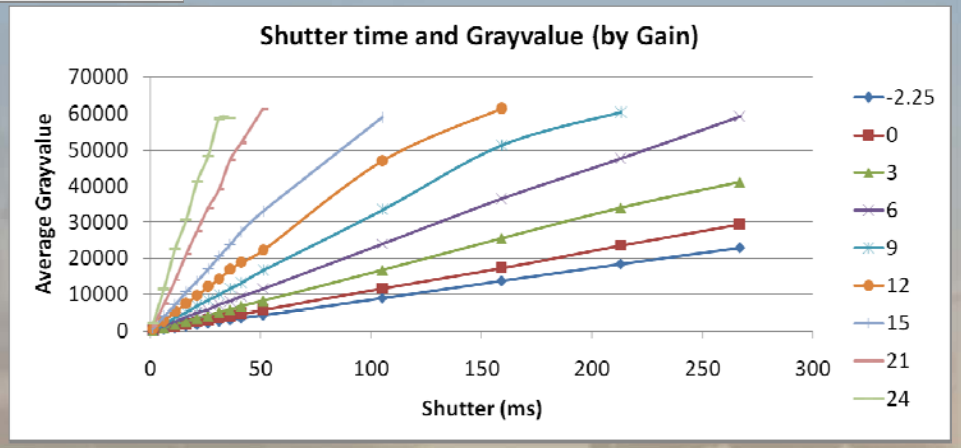
# Calibration - Results

## Pixel analysis



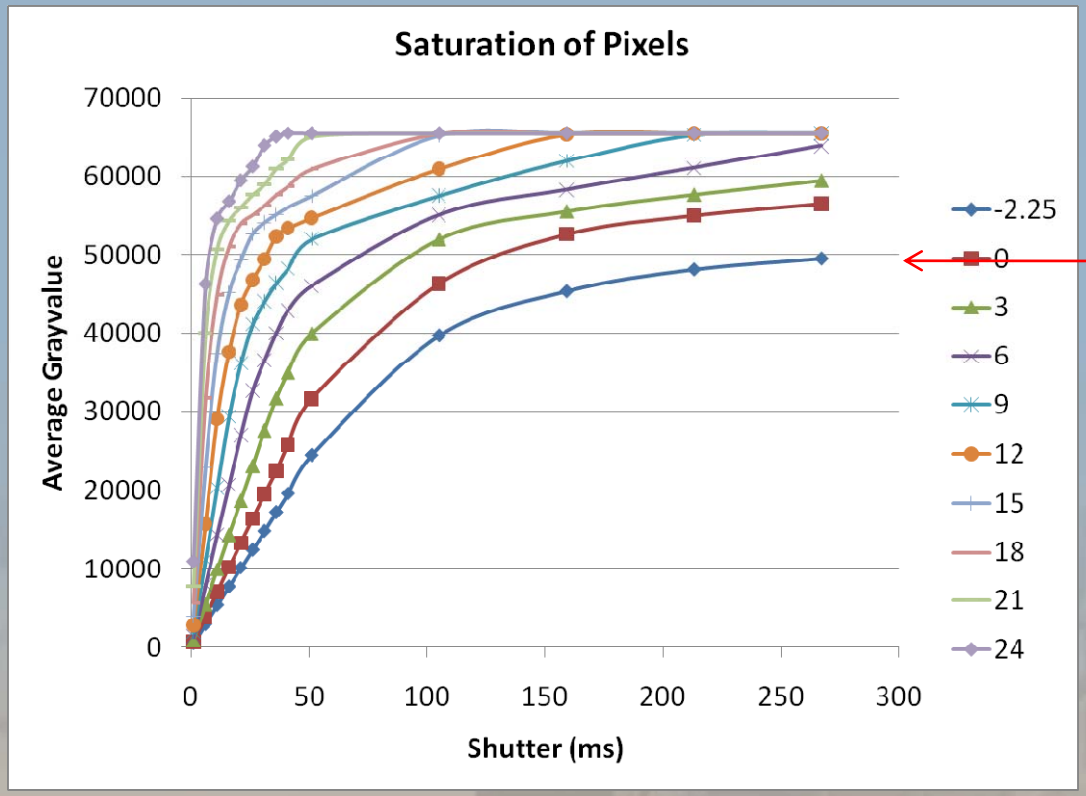

Positive relationship of Luminance Camera grayvalue and gain

Positive relationship of Luminance Camera grayvalue and shutter



# Calibration - Results

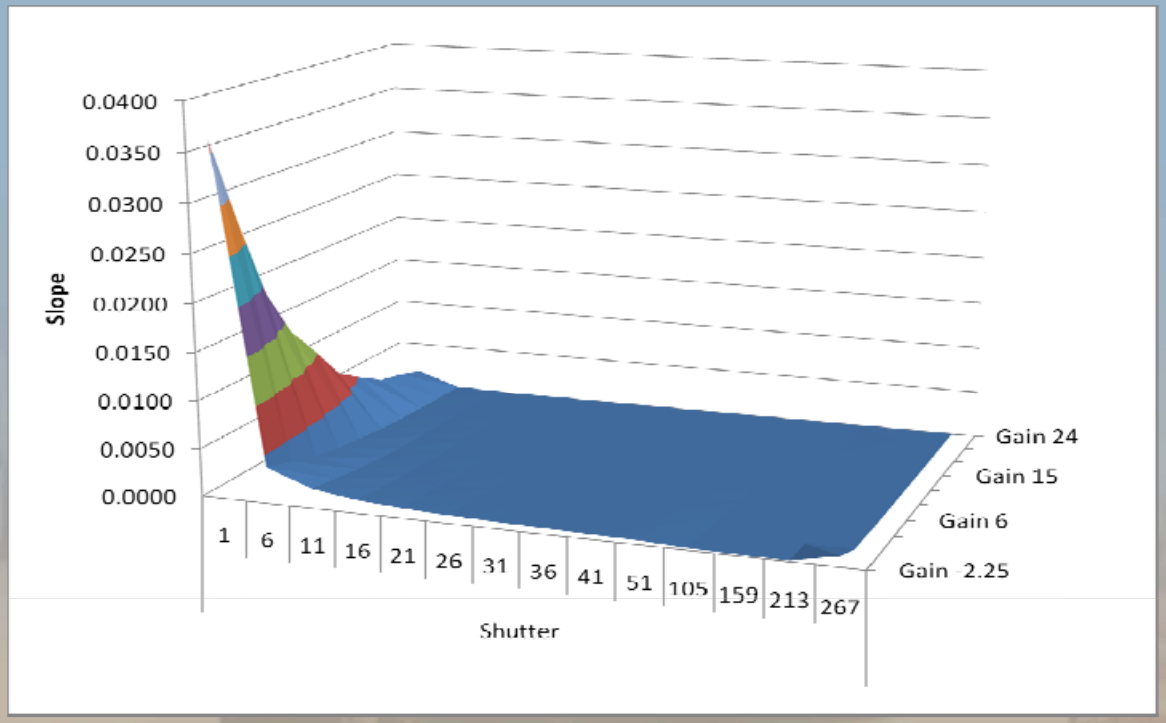
- Level of pixel saturation (by gain)




Grayvalues > 50,000 taken out of analysis

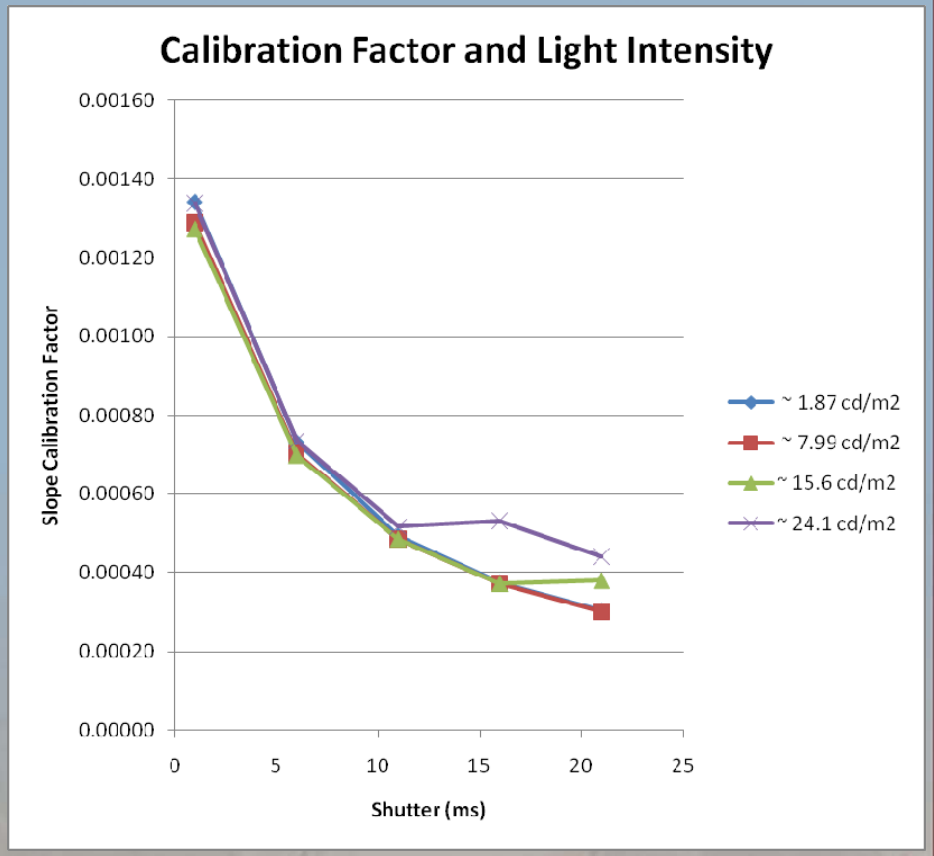
# Calibration - Results

Calibration Slope for each gain and shutter combination = $\frac{\text{Photometer Luminance}}{\text{Luminance Camera grayvalue}}$



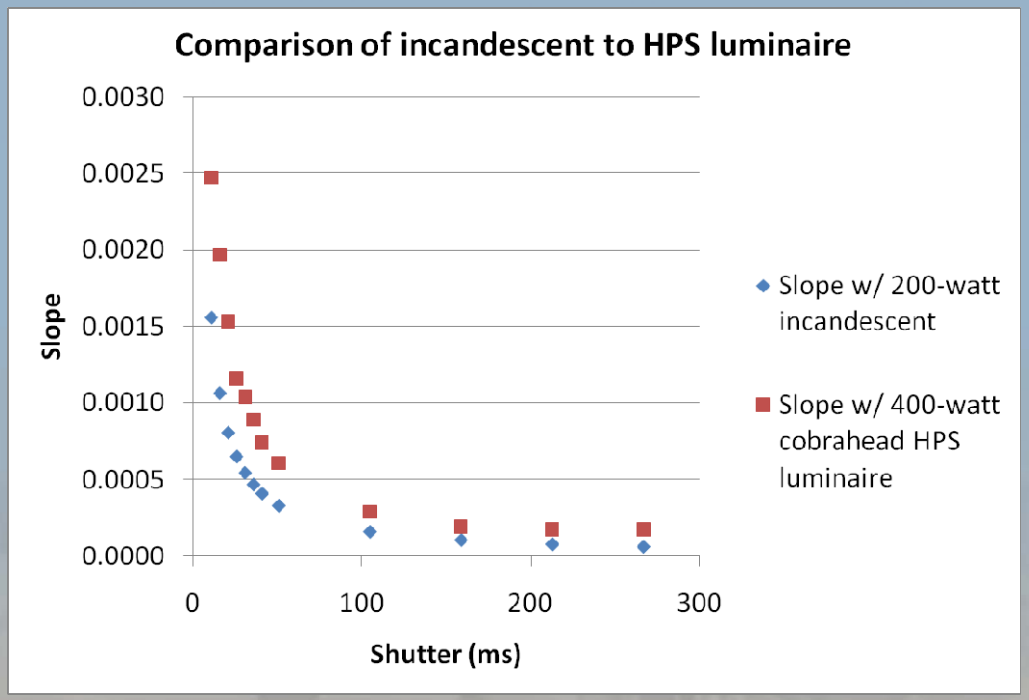
# Calibration - Results

Calibration factor similar across light intensities



# Calibration - Results

Impact of spectral distribution of luminaire

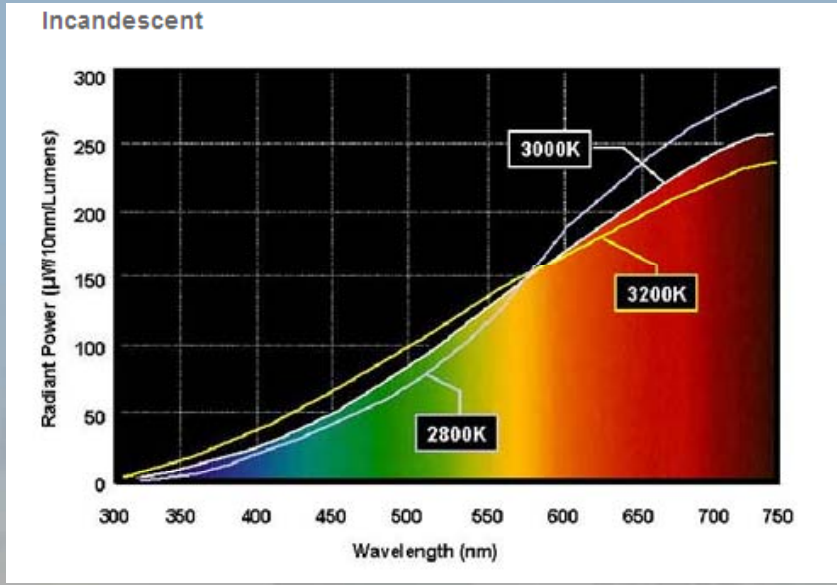



- Different calibration factor needed for different lighting
- Larger value needed for HPS lighting than incandescent lighting

# Calibration - Results

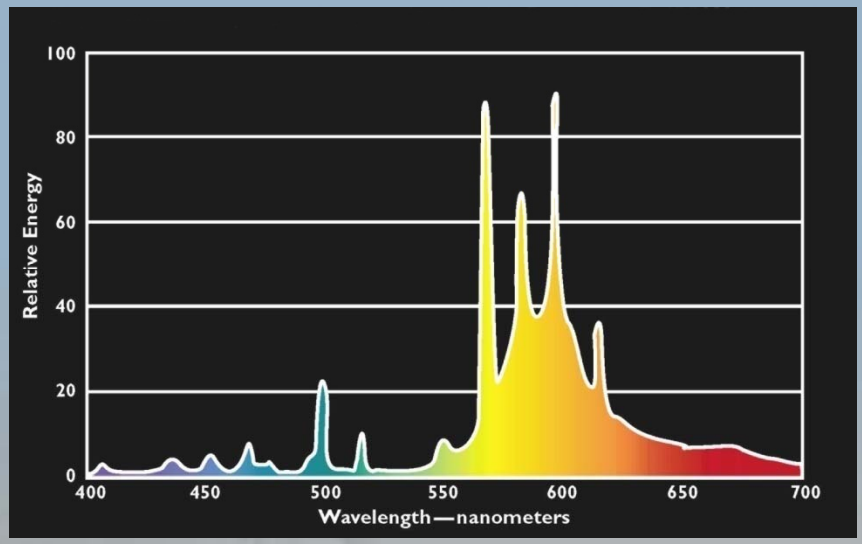
## Spectral distributions

Incandescent




From: GE Lighting

High-pressure sodium




From: University of Chicago

# Calibration - Discussion

- Multiple cameras calibrated to photometer
- Rapid method developed
  - Automated
    - Image capture
    - Overlay of images
    - Calculation of calibration factors for multiple gain and shutter combinations
- Spectral distribution of light source impact on calibration process

# Goals

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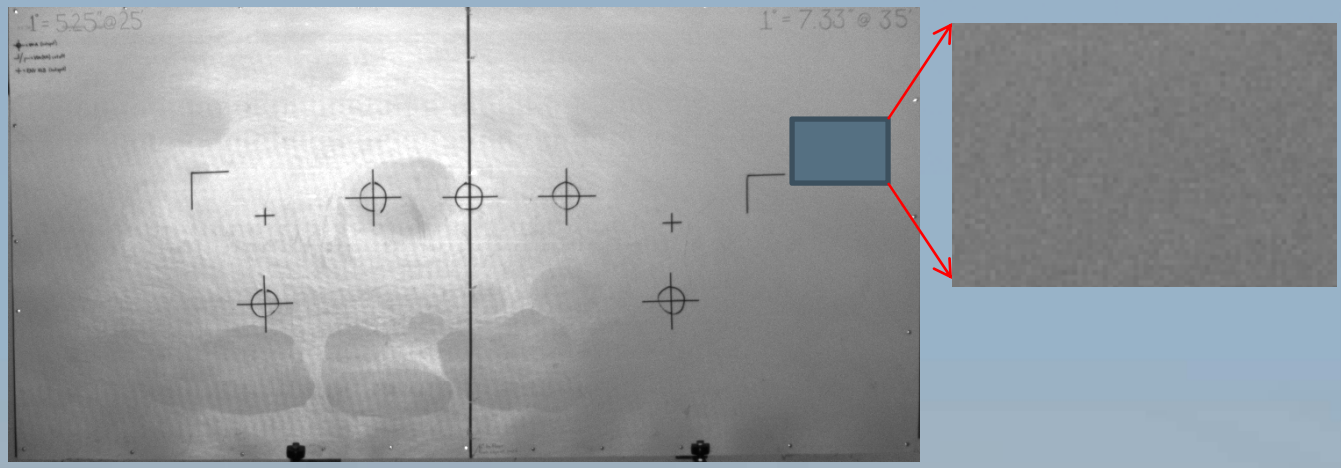
# Dynamic Evaluation - Procedure

- Vehicle equipped with 2 Luminance Cameras manually & auto-configured
- Highway, rural, and downtown areas driven
- Capture images simultaneously at ~4fps
- Select gain and shutter settings for manual camera

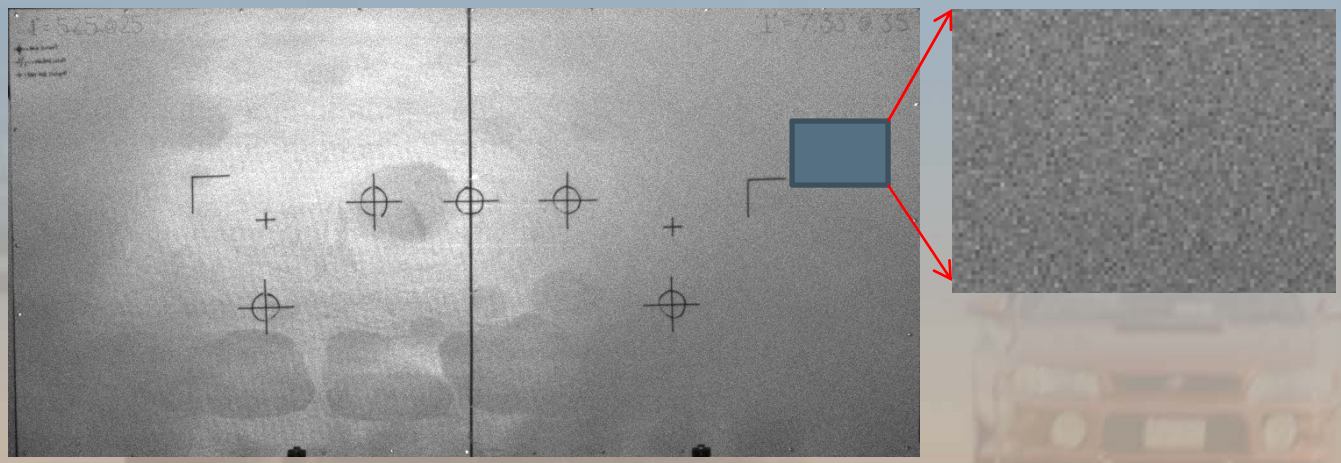
# Dynamic Evaluation – Procedure
# Camera Setting Selection

Impact of gain on image noise level

Gain = 0dB



Gain = 24dB



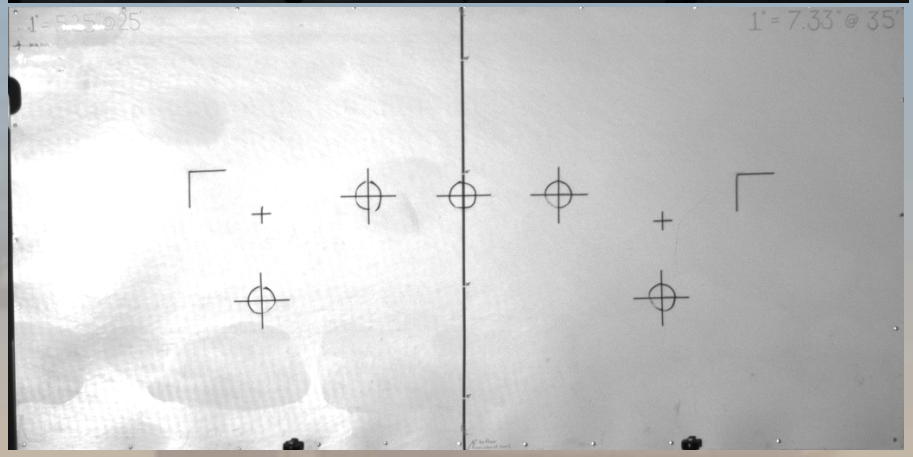
# Dynamic Evaluation – Procedure
# Camera Setting Selection

Impact of shutter on image

Shutter = 6ms

- Dark quality
- Difficulty distinguishing targets or objects of interest

Shutter = 51ms



- Reach pixel saturation quickly with glare

# Dynamic Evaluation – Procedure
# Camera Setting Selection

## Estimation of maximum luminance

Darkened image → High pixel saturation

Increase in image noise ↓

| | SHUTTER (ms) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GAIN (dB)** | **1** | **6** | **11** | **16** | **21** | **26** | **31** | **36** | **41** | **51** | **105** | **159** | **213** | **267** |
| **-2.25** | 899.4 | 172.6 | 96.2 | 66.6 | 48.4 | 40.6 | 34.7 | 30.1 | 26.5 | 21.7 | 10.8 | 14.0 | 6.8 | 7.3 |
| **0** | 732.1 | 120.8 | 69.1 | 47.2 | 39.3 | **32.2** | 25.9 | 23.2 | 20.7 | 15.8 | 7.8 | 5.4 | 3.6 | 3.0 |
| **3** | 477.8 | 89.3 | 49.2 | 34.9 | 26.8 | 21.7 | 19.3 | 15.0 | 14.0 | 12.5 | 5.5 | 3.5 | 2.7 | 2.2 |
| **6** | 332.8 | 64.0 | 35.1 | 24.5 | 19.4 | 15.2 | 13.3 | 12.6 | 9.9 | 7.7 | 3.7 | 2.5 | 1.9 | 1.6 |
| **9** | 214.1 | 40.6 | 23.4 | 17.6 | 12.6 | 10.0 | 9.6 | 7.7 | 6.1 | 5.5 | 2.8 | 1.7 | | |
| **12** | 165.4 | 33.6 | 18.6 | 12.0 | 9.7 | 7.5 | 6.1 | 5.6 | 5.2 | 3.9 | 2.0 | | | |
| **15** | 107.3 | 22.9 | 12.7 | 9.8 | 6.8 | 5.4 | 4.4 | 3.7 | 3.2 | 2.7 | 1.7 | | | |
| **18** | 81.2 | 14.8 | 8.2 | 6.2 | 3.9 | 3.2 | 2.5 | 2.4 | 2.0 | 1.8 | | | | |
| **21** | 56.1 | 12.1 | 6.9 | 3.8 | 3.3 | 2.6 | 2.2 | 1.8 | 1.8 | | | | | |
| **24** | 41.8 | 7.0 | 5.2 | 2.4 | 2.0 | 1.8 | 1.8 | 1.7 | | | | | | |

# Dynamic Evaluation - Results

Manual


Automatic

High presence of blurring and saturation with auto configuration

# Dynamic Evaluation - Discussion

- Auto-enabled
  - Blur
  - Oversaturation
- Manually enabled gain and shutter
  - Appropriate combinations found for multiple road settings
    - Ex. Downtown area → low shutter

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# R & R Evaluation

- Repeatability – level of data consistency over time
- Reproducibility – level of data consistency among different users

1. Perform multiple trials of data collection
2. Measure variance in data
3. Where is variance found?
   - In device/camera = repeatability
   - In user of device/camera = reproducibility
     - < 10% → "acceptable" variance
     - 10-30% → "may be acceptable"
     - > 30% → "unacceptable"

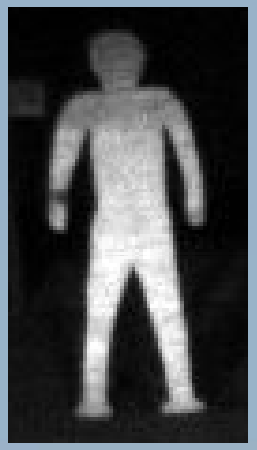
Automotive Industry Action Group (AIAG). (2002). *Measurement systems analysis (3rd ed.)*

# R & R Evaluation - Procedure

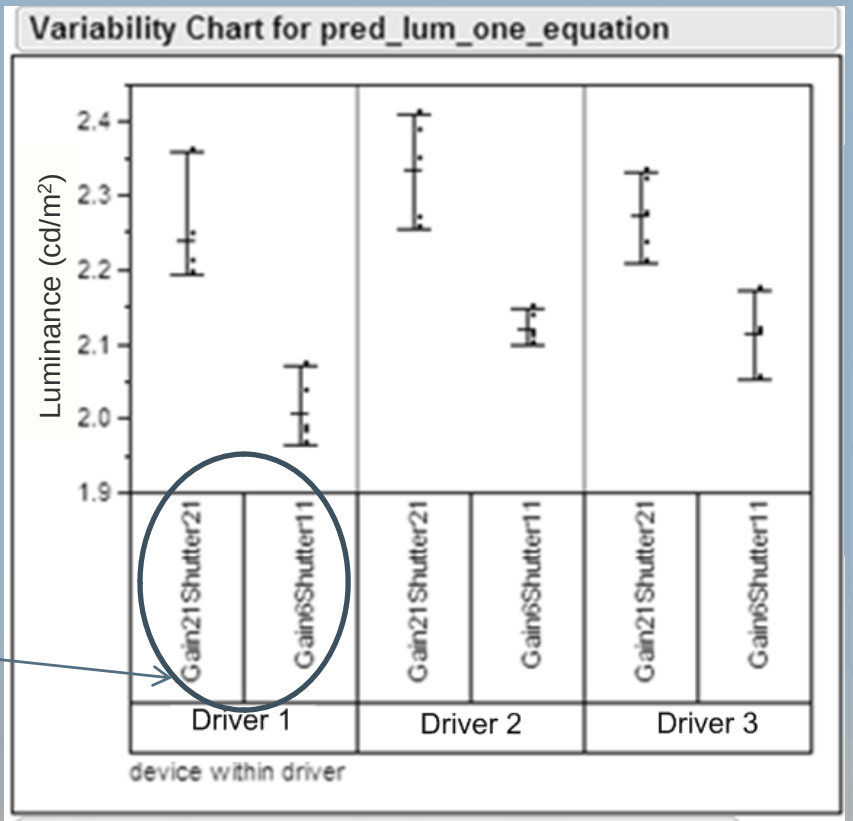
- Environment without overhead lighting selected
- Targets/objects of interest displayed for measurements
- Luminance Cameras equipped in vehicle
- Reproducibility
  - 3 drivers/users parking car, illuminating environment
- Repeatability
  - 2 cameras, manually set
  - Multiple images taken
- Calculated mean luminance of selected targets

# R & R Evaluation - Results

"Pedestrian"



2 cameras, manually set gain and shutter

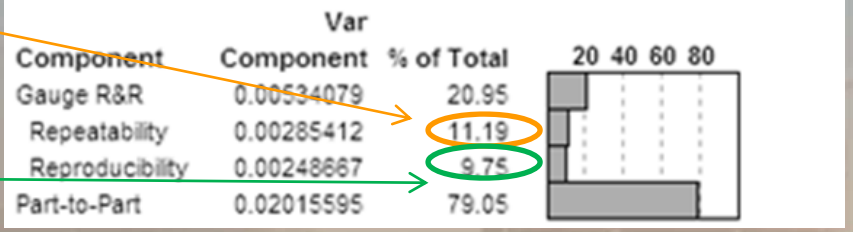



Camera variance

10-30% "may be acceptable"

Variance among users

< 10% "acceptable"



# R & R Evaluation - Results

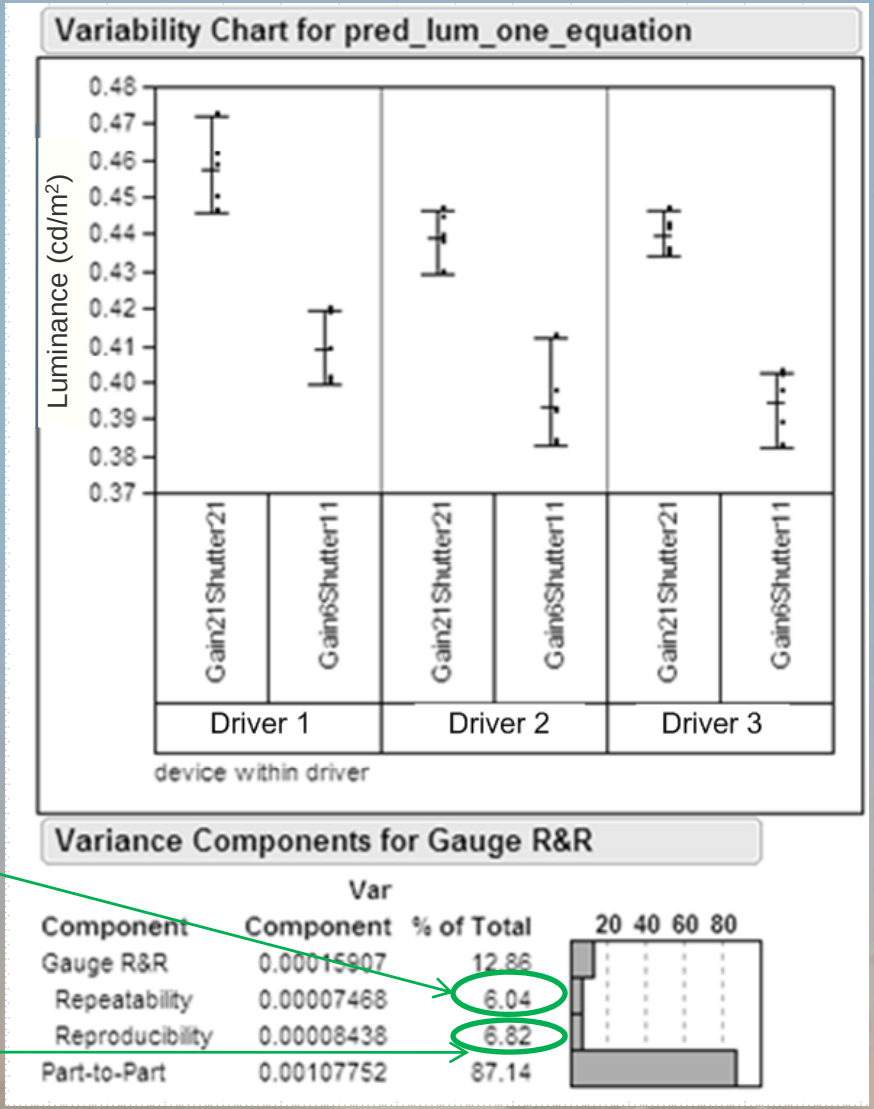
Selected area of pavement

Camera variance

< 10% “acceptable”

Variance among users

< 10% “acceptable”



# R & R Evaluation - Discussion

- Luminance Camera performance
  - Reliable across time
  - Reproducible among users
- Considerations to prevent oversaturation
  - Targets/objects of interest
  - Camera settings

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# Dynamic Roadway Comparison - Procedure

- Vehicle equipped with photometer & Luminance Camera
- Drive public roads
  - Luminance Camera - Continually capture video
  - Photometer - Stop vehicle, capture image of scene
- Corresponding images later matched
  - Targets/objects of interest selected (pavement markings)
  - Mean luminance of targets calculated

# Dynamic Roadway Comparison - Results

Photometer image

Mean value = 2.508 cd/m$^2$

Luminance Camera image (Gain = 0dB, Shutter = 26ms) →

Mean grayvalue = 2331.0

Calibration factors
- HPS = 0.0011
- Incandescent = 0.00065

2331.0 x 0.0011 = 2.5641 cd/m$^2$

2331.0 x 0.00065 = 1.5152 cd/m$^2$

# Dynamic Roadway Comparison - Discussion

- Successful comparison of photometer to Luminance Camera
- Spectral distribution issues are evident

# Conclusions

- Rapid method of camera calibration developed
- Cameras calibrated to multiple settings (to allow for different environments)
- Repeatability and Reproducibility of the camera system evaluated
- System evaluated in dynamic environment

# Future Steps/Limitations

- Calibration improvements
  - Diffuse calibration surface
  - Photopic filter
    - Decrease spectral impact
    - Better indication of what human eye sees
- Dual camera approach in order to capture wide range of luminance in environment
- Methods to reduce camera temperature/decrease image noise