Methods to Monitor Nighttime Visibility and Headlight Glare on the Road

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Framework

- **French project**
  - Participant: Lighting & Visibility research Team at LCPC
  - Sponsor: MEEDDAT (French DOT), T.O. #05MT6039
  - Objective: develop a nighttime visibility index for secondary roads

- **California project**
  - Participant: Visual Detection Lab at UC Berkeley School of Optometry
  - Sponsor: Caltrans (California DOT), T.O. #6603
  - Objective: develop a glare meter tool to rate headlight glare

- **Collaborative project**
  - CalFrance partnership
  - Share knowledge and leverage existing projects
Introduction

- Problem statement: nighttime driving safety
  - Fact: accident risk is higher at night than in daytime
  - Cause: low visibility
  - Solution: headlamps provide visibility, but cause glare
  - Assessment: addressed by manufacturers of lighting systems
  - Need: tools for road managers to assess the quality of service of the road

- Objectives
  - Visibility meter tool
  - Glare meter tool
Outline

- Introduction
  - Framework
  - Objective

- Nighttime Visibility Meter Tool
  - Approach
  - Implementation
  - Sample results

- Headlight Glare Meter Tool
  - Approach
  - Implementation
  - Experiments

- Integration
Visibility: Approach

- **Objective**
  - Assess the level of visibility offered to drivers at night on secondary roads (devoid of road lighting)

- **Approach**
  - Based on STV approach for road lighting
  - Can the driver detect an obstacle in time to avoid collision?
Visibility: Standard Scenario

- **Driver**
  - Eye height: 1.2 m
  - Age: 25 y

- **Headlamps**
  - Photometry: high-beam [UMTRI-2001-19]
  - Mounting height: 0.65 m
  - Separation: 1 m
  - Distance from driver: 1.8 m

- **Target (obstacle)**
  - Shape: square
  - Size: 0.18 m
  - Luminance factor: 8% (dark)
Visibility: Measurement System

- **Pavement retroreflectivity**
  - ECODYN (mlpc®)
  - On-board system to monitor the visibility of the markings along the road
  - Geometry based on EN1436
    - Vision at 30 m ⇒ 1.25° lighting angle,
      2.29° observation angle.
  - Retro-reflected luminance coefficient
    - \( R_L = \frac{L}{E_\perp} \)
    - Range: from a few mcd.m\(^{-2}\).lx\(^{-1}\) up to 2k mcd.m\(^{-2}\).lx\(^{-1}\)
Visibility: Computational Model

- **Target luminance**
  - \( L = \frac{\rho}{\pi} \cdot E \approx \frac{\rho}{\pi} \cdot (\frac{I_{\text{left}}}{d^2} + \frac{I_{\text{right}}}{d^2}) \)

- **Pavement luminance**
  - \( L_b = R_L \cdot E_\perp = R_L \cdot (\frac{I_{\text{left}}}{d^2} + \frac{I_{\text{right}}}{d^2}) \)

- **Visibility level**
  - \( VL = \frac{L - L_b}{\Delta L_{\text{th}}} = \frac{\Delta L}{\Delta L_{\text{th}}} \)
  - \( \Delta L_{\text{th}} = f(\Delta L, L_b, \alpha) \cdot \Pi F_i(\ldots) \)
    - \( F_i \): correction factors (contrast polarity, age, time, detection probability)
    - [Adrian, 1989]
Visibility: Implementation

- At every point along the road
  1. Get RL value from ECODYN measurements
  2. Set headlamps at 250 m
  3. Compute VL
  4. While VL < field factor
     set headlamps closer and go to 3
  5. Interpolate visibility distance
  6. Compare with « safety distance »

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Visibility: Implementation

Nighttime Visibility & Headlight Glare, Dumont et al

$$R_L = 15 \text{ mcd.m}^{-2}.\text{lx}^{-1} \Rightarrow 56 \text{ m visibility distance}$$
Visibility: Sample Results

Dark colored pavement $\Rightarrow$ better target visibility

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Visibility: Introducing Headlight Glare

- Modified scenario
  - Same driver, same car, same road
  - Opposing vehicle ⇒ everyone in low beam

- Modified computational model
  - Use CIE Glare Formula to compute disability glare equivalent veiling luminance $L_v$
  - Account for $L_v$ when computing VL

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Visibility: Introducing Headlight Glare

\[ \Delta L (\text{cd.m}^{-2}) \]

\[ \text{Threshold } \Delta L (VL=1) \]

\[ \text{Threshold } \Delta L (VL=7) \]

\[ R_L = 15 \text{ mcd.m}^{-2} \text{.lx}^{-1} \Rightarrow 36 \text{ m visibility distance} \]
Visibility: Sample Results

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  - Sample results

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- Integration
Glare: Approach

- **Objective**
  - Assess the level of glare from opposing vehicles in a variety of situations

- **Approach**
  - Capture the luminance distribution of the nighttime driving scene
  - Analyse image to locate glare sources and compute glare level
Glare: Measurement System

- Road scene luminance
  - CCD Photometer (Radiant Imaging PM-1613F-1)
  - 1020x1020 16-bit XYZ image
  - Optics $\Rightarrow$ 2.28’ per pixel
Glare: Discomfort Glare

- **Glare Index**
  \[ GI = \sum_{\text{sources}} L^a \cdot \Omega^b / L_b^c / \theta^d \]
  - \( L \): source luminance
  - \( \Omega \): solid angle subtended by the source
  - \( \theta \): eccentricity
  - \( L_b \): background luminance
  - \( a, b, c, d \): model parameters

- **Conversion to Glare Mark on De Boer scale**
  \[ GI = K \cdot 10^{-GM/4} \]
  - \( K \): model parameter
  [Vos, 2003]
Glare: Implementation

- Set model parameters
  - Method 1: use values proposed by Vos
  - Method 2: fit values with experimental data

- Find sources and get $L$, $\theta$ and $\Omega$
  from captured image
  - Method 1: brute force segmentation
  - Method 2: conspicuity-based segmentation
Glare: Lab Experiment

- **Modalities**
  - 3 types of road scenes (urban, residential, rural)
  - 3 glare source eccentricity values
  - 3 glare source intensity values

- **Subjects**
  - 16 observers

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Glare: Lab Experiment

Observed [blue] vs Predicted [pink] for Method 1

RMS for Method 1: 0.27
RMS for Method 2: 0.77
Glare: Field Test

<table>
<thead>
<tr>
<th>Scenario</th>
<th>glare source</th>
<th>mainline lighting</th>
<th>glare screen</th>
<th>windshield</th>
<th>De Boer ratings, two observers</th>
<th>De Boer rating predicted by Glare Meter Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>lo-beam</td>
<td>on</td>
<td>no</td>
<td>clean</td>
<td>5, 6</td>
<td>6.2</td>
</tr>
<tr>
<td>#2</td>
<td>hi-beam</td>
<td>on</td>
<td>no</td>
<td>clean</td>
<td>3, 3</td>
<td>3.4</td>
</tr>
<tr>
<td>#3</td>
<td>hi-beam</td>
<td>on</td>
<td>yes</td>
<td>clean</td>
<td>4 ½, 5</td>
<td>5.9</td>
</tr>
<tr>
<td>#4</td>
<td>lo-beam</td>
<td>off</td>
<td>no</td>
<td>clean</td>
<td>5, 6</td>
<td>6.2</td>
</tr>
<tr>
<td>#5</td>
<td>hi-beam</td>
<td>off</td>
<td>no</td>
<td>clean</td>
<td>2 ½, 3</td>
<td>3.4</td>
</tr>
<tr>
<td>#6</td>
<td>hi-beam</td>
<td>off</td>
<td>no</td>
<td>dirty</td>
<td>2, 2</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Glare: Disability Glare

- CIE Glare formula
  \[ \frac{L_v}{E_g} = \frac{10}{\theta^3} + \frac{5}{\theta^2} \cdot [1 + \left( \frac{A}{62.5}\right)^4] \]
  
  - \(L_v\): equivalent veiling luminance
  - \(E_g\): eye illuminance from glare source
  - \(\theta\): source eccentricity
  - \(A\): age

- Implementation
  - Detect glare source pixels \(\Rightarrow\) \(L\) and \(\theta\)
  - For every glare pixels
    - Get \(E_g\) from \(L\)
    - Add up to \(L_v\)
Glare: Lab Experiment

- **Modalities**
  - Increment grey level of disc on black background, in grey surround, until disc just detectable
  - 3 source eccentricities
  - 3 source intensities + no glare source

- **Subjects**
  - 16 observers
Glare: Lab Experiment

Log $L_v$ from subjects’ responses

Log $L_p$ from luminance image

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Conclusions

- **Nighttime Visibility Meter Tool**
  - Easily deployed
  - Needs to be calibrated
  - Can be improved
    - Introduce road geometry (curves, slopes)
    - Chose better contrast definition
    - Account for adaptation

- **Headlight Glare Meter Tool**
  - Calibrated
  - Needs stationary conditions

- **Integration: complementary use of both tools**
  - Locate low visibility road sections with the Visibility Meter Tool
  - Deploy the Glare Meter Tool on these sections
Nighttime Visibility & Headlight Glare

Thank you for your attention.