Fast Reactive Illumination through Rain and Snow

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Sponsors: ONR, NSF, Intel, Samsung
Driving in Snow at Night
### How many Rainy/Snowy Nights in a Year?

<table>
<thead>
<tr>
<th>City</th>
<th>Nights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berlin, Germany</td>
<td>55</td>
</tr>
<tr>
<td>Brussels, Belgium</td>
<td>65</td>
</tr>
<tr>
<td>Cape Town, SA</td>
<td>52</td>
</tr>
<tr>
<td>Chicago, USA</td>
<td>48</td>
</tr>
<tr>
<td>Kuala Lumpur, Malaysia</td>
<td>79</td>
</tr>
<tr>
<td>Paris, France</td>
<td>56</td>
</tr>
<tr>
<td>Pittsburgh, USA</td>
<td>59</td>
</tr>
<tr>
<td>Seattle, USA</td>
<td>62</td>
</tr>
<tr>
<td>Tokyo, Japan</td>
<td>50</td>
</tr>
<tr>
<td>Zurich, Switzerland</td>
<td>64</td>
</tr>
</tbody>
</table>

[World Meteorological Organization, 30 year average]
Post-processing: De-raining and De-snowing

Rain frequencies

Scene frequencies

[Barnum et al, 07]
Headlight that sees through Rain and Snow

Goal: High Light Throughput and Accuracy

[Similar in spirit to “Lighting up dust”, Ken Perlin]
... a detour

[ Barnum, Narasimhan, Kanade, 10 ]
Rain Streaks versus Rain Drops

Long Exposure Time (12 ms)

Short Exposure Time (1 ms)

Rain streaks appear dense but drops are sparse
Operating Range: Visibility of Rain Streaks

Not visible beyond 5-6 meters from the source
Reactive Illumination

- projector
- beam splitter
- camera
- operating range
- capture system latency
- reactive control
# System Pipeline

<table>
<thead>
<tr>
<th>Frame #</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capture</td>
<td>TX</td>
<td>Process</td>
</tr>
<tr>
<td>Frame 1</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Frame 2</td>
<td></td>
<td></td>
<td>Capture</td>
</tr>
<tr>
<td>Frame 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame 4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Time (ms) | 5 | 9 | 14 | 18 | 27 | 36 |

| Latency |
Simulated Rain

- System latency 13ms
- Camera/Projector 1024x1024
- Detection error 2 pixels
- Tracking latency 3 frames
Detecting, Tracking and Predicting Drops

View from the system camera
Performance under Detection Errors

- **Light throughput (%)**
- **Detection error (pixel)**

Lines represent:
- **Rain (5mm/h)**
- **Snow (1mm/h)**
Slow Capture and Projection

Standard daylight  Not so Smart daylight

Projecting black streaks instead of white streaks 😞
High Speed Bit-Plane Projection

What we see….or don’t see
(30 Hz)

What a high-speed camera sees
(2000 Hz)

[ Temporal integration ]

[Raskar et al, Narasimhan et al, Debevec et al]
Making Rain Disappear (90 mm/h)

System Latency

Standard headlight

Smart headlight
Making Rain Disappear (90 mm/h)

Standard headlight

Smart headlight
Performance of our system

System Latency: 13 ms
Imaging exposure: 5ms
Tracking latency: 1 frames
Resolution: 1024 x 1024
Car motion: 30 kph
Projection rate: 120 Hz

Light throughput (%)

Fallrate (mm/h)

Snow (accuracy = 63.4%)
Rain (accuracy = 68.9%)
Performance of an Ideal system

System Latency: 0 ms
Imaging exposure: 1 ms
Tracking latency: 0 frames

Resolution: 1024 x 1024
Car motion: 30 kph
Projection rate: 10000 Hz
Embedded Design for Imaging and Illumination

Projector and camera in one device?

High-speed computations
Rain Rain Go Away…

• Improves driver visibility directly
• Simulations suggest that the idea is feasible
• Initial lab prototype is encouraging

• Still a long way to go:
  • Wind, turbulence, vibrations
  • Making the device compact, fast moving car