Validating LiDAR sensor surveillance systems for airport operations

LiDAR versus conventional out-the-window view for safety critical airport operations

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Agenda

Background
Introduction to LiDAR sensing for Apron Surveillance
Experimental Design
Experimental Setup
Experimental Results
Conclusion & Outlook
Background
Fatal Accidents | Worldwide Commercial Jet Fleet | 2008 through 2017

Source: BOEING Statsum 2017
Background
Accidents and Incidents on Apron

- Wind Shear or Thunderstorm/Icing
- System/Component Failure or Malfunction/Fire/Smoke
- Other
- Loss of Control – Ground
- Ground Handling
- Ground Collision
- External Load Related Occurrences
- Cabin Safety Events
- Bird
- ATM/CNS
- Aerodrome
- Abrupt Maneuver

Visually recognizable  Not visually recognizable
Introduction to LiDAR sensing
Advantages

- Non-cooperative environmental scanning
- Large angles of detection
- Accuracy of position and pose at millimeter range level (?)
- Independent from light conditions (?)
- Less sensitive to weather conditions (?)
Introduction to LiDAR sensing
Temporal resolution

- LiDAR Field of View
- Human Binocular Vision
- Human Symbol Recognition
Lidar Equation

\[ P_{\text{return}}(r, \lambda) = P_0 \times A \eta \times \frac{c \times \tau}{2} \times \frac{O(r)}{\pi \times r^2} \times \beta(\theta, \lambda) \times \exp\left(-2 \int_0^r \alpha(r, \lambda)dr\right) \]

LiDAR system: const.  Backscatter coefficient
Measurement geometry  Transmission term
### Reflection values for different surfaces

<table>
<thead>
<tr>
<th>Description</th>
<th>Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare aluminum metal that is weathered and scratched/scored</td>
<td>81.21%</td>
</tr>
<tr>
<td>Galvanized steel from roof and vent covers</td>
<td>47.37%</td>
</tr>
<tr>
<td>Gray and white weathered runway concrete</td>
<td>38.52%</td>
</tr>
<tr>
<td>Approximately 30-year-old runway construction concrete with (mostly granite) aggregate showing</td>
<td>37.84%</td>
</tr>
<tr>
<td>Weathered, galvanized bare steel from roof and vent covers</td>
<td>27.27%</td>
</tr>
<tr>
<td>Frost. (Particle size 10 μm)</td>
<td>22.52%</td>
</tr>
<tr>
<td>Weathered, galvanized steel from roof and vent covers</td>
<td>16.52%</td>
</tr>
<tr>
<td>Fine snow (Particle size 24 μm)</td>
<td>9.99%</td>
</tr>
<tr>
<td>Unweathered, transparent construction plate window glass</td>
<td>8.65%</td>
</tr>
<tr>
<td>Medium granular snow (Particle size 82 μm)</td>
<td>2.03%</td>
</tr>
<tr>
<td>Tap water</td>
<td>2.00%</td>
</tr>
<tr>
<td>Ice</td>
<td>1.61%</td>
</tr>
<tr>
<td>Coarse snow (particle size 178 μm)</td>
<td>0.63%</td>
</tr>
</tbody>
</table>

Source: NASA spectral library for 1540 nm
Lidar Equation

\[ P_{\text{return}}(r, \lambda) = P_0 \times A \eta \times \frac{c \times \tau}{2} \times \frac{O(r)}{\pi \times r^2} \times \beta(\theta, \lambda) \times \exp \left( -2 \int_0^r \alpha(r, \lambda) \, dr \right) \]

LiDAR system: const.  Backscatter coefficient
Measurement geometry  Transmission term

C - atmospheric composition
Introduction to LiDAR sensing
Transmission term/Absorption term

Weather condition | Transmission term for $r = 500m$
--- | ---
Mean Latitude | Winter | 263.15 K | $1 - 0.0017 = 0.9983$
Mean Latitude | Summer | 303.15 K | $1 - 0.0017 = 0.9983$
Tropics | Summer | 313.15 K | $1 - 0.0019 = 0.9981$

Source: simulated spectra from HITRAN data
Video available on www.linkedin.com/in/hannesbrassel
Experimental Design

\[ \alpha = 2 \arctan \left( \frac{g}{2r} \right) \cdot 60'[. \]

\( \alpha: \) Angular diameter

\( r: \) Distance to object

\( g: \) Object size

1° = 60 arcmin ['']
# Experimental Design

<table>
<thead>
<tr>
<th>Visibility Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear/Day:</td>
<td>Clouds and visibility okay (CAVOK) according to Meteorological Terminal Air Report (METAR) during daytime.</td>
</tr>
<tr>
<td>Clear/Night:</td>
<td>CAVOK during nighttime.</td>
</tr>
<tr>
<td>Rain/Day:</td>
<td>“Precipitation in the form of liquid water drops, varying in size from 0.5 to a maximum of 6 mm in diameter […]” during daytime.</td>
</tr>
<tr>
<td>Rain/Night</td>
<td>Rain during nighttime.</td>
</tr>
</tbody>
</table>
Experimental Design

Detection (‘is there an object?’)
Recognition (‘is the detected object an aircraft?’)
Identification (‘is the recognized aircraft an A320?’)
Size Estimation (‘how large is a detected object?’)
Experimental Setup
Recognition by components
Experimental Results
Experimental Results
Experimental Results

Influence of **illumination** on object detection/size estimation/recognition/identification:
Validating LiDAR sensor surveillance systems for airport operations
Institute of Air Transportation and Logistics/ Hannes Brassel
9th SESAR Innovation Days // 2-6 December 2019, Athens, Greece
Experimental Results

Influence of **rain** on object detection/size estimation/recognition/identification:
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Outlook

LiDAR 3D Point cloud

Processing
- Identification
- Recognition
- Detection
- Tracking
- Probabilistic movement estimation
  - Physics-based
  - Maneuver-based
  - Interaction-aware

Automatic hazard detection and estimation

Visualization
- Automatic hazard detection and estimation
- Automatic hazard detection and estimation
- Automatic hazard detection and estimation

Airport Surveillance
- e.g. B747 on unsuitable Taxiway!
- e.g. Aircraft-Aircraft conflict risk!

Controller HMI
- e.g. Object on Taxiway!

Controller

OTWV

Camera

Weather dependent processing

Controller

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Thank you for your attention.

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