Detection and Estimation of Wake Vortex on Ultra Fast-Scanning Pulsed-Doppler Lidar

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Outline

1. Introduction
   - Narita Observation Campaign
   - Motivation
   - Lidar and Scanning Strategy

2. Examples of Estimated Results
   - Simulation
   - Application to Real Data

3. Conclusion
Introduction

◆ Narita Observation Campaign
   (see details in the PPT file by N. Matayoshi)

 ➢ Development of WV database in Narita Airport, Japan
   ✓ Large number of samples with high-quality estimation by using a fast-scanning Doppler lidar
   ✓ Update of safe separation in RECAT-3
   ✓ Traffic optimization

 ➢ Real-time detection, and estimation
   ✓ Provide WV information in (quasi) real time
Introduction

◆ Motivation

➢ Lidar – *Practical simpleness for observation*
  ✓ Single-lidar observation
  ✓ High scan rate

Windcube200S, Leosphere

➢ Algorithm – *High accuracy and robustness for low CNR*
  ✓ Pulsed-Doppler lidar has low range resolution (tens of meters) with current technology
  ✓ Need to extract small structure of a WV (< 15 m) from low range resolution (tens of meters) measurements.
  ✓ Low-order moments of Doppler spectrum are not good enough because min and max velocities of a WV are not considered.
  ✓ Detection of min and Max velocities in a Doppler spectrum is valid. But not robust for a low CNR condition

Proposal of a method with high estimation accuracy and robustness for a low CNR condition
Introduction

◆ Lidar and Scanning Strategy

 Lidar
  ✓ Windcube200S, Leosphere
  ✓ Pulsed-Doppler Type
  ✓ Wavelength: 1543 nm
  ✓ Max power: 5 mW
  ✓ Pulse Repetition: 20 kHz
  ✓ Digital Sampling rate: 250 MHz

 Scanning Strategy
  ✓ RHI: 0 – 40 deg for landing aircrafts
  ✓ 20 – 60 deg for take-off aircrafts
  ✓ Scan duration: 6 sec (+ 2 sec to reset)
  ✓ Range sampling: Every 5 m; 100 – 885 m
    (physical range resolution: 48 m)
  ✓ Elevation sampling: Every 0.2 deg
  ✓ Velocity sampling: Every 3 m/sec; -30 – 30 m/sec
Methodology

Traditional Methods

- Measurement

  ✓ Pulsed-Doppler lidar has low range resolution of tens of meters (much larger than core size of WV).
  ✓ Based on 1st moment: Min and max velocities of a WV are NOT considered.
  ✓ Addition of 2nd moment: Doppler spectrum is approximated by a (symmetry) Gaussian distribution. But Gaussian is NOT suitable for a WV case.
  ✓ Based on min and max velocities in a Doppler spectrum: Can provide high estimation accuracy. But not robust for low CNR. (In general, fast-scanning links to low CNR)

- Deterministic Calculation

  ✓ Measurement always includes fluctuation.
  ✓ Need to consider measurement error especially in a low CNR condition
Example of Estimation Results

- Simulation Case 1/4
  - Large cores (left: 6.0 m, right: 6.5 m)
  - No background wind

<table>
<thead>
<tr>
<th>Parameters</th>
<th>1st moment based method</th>
<th>Proposed method</th>
<th>Simulation Truth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left</strong></td>
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<tr>
<td>y (m)</td>
<td>279.7</td>
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<td>z (m)</td>
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<td>( \Gamma_{5-15} ) (m²/sec)</td>
<td>-183.6</td>
<td>-318.2</td>
<td>-281.0</td>
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<td>y (m)</td>
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<td>z (m)</td>
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<tr>
<td>( \Gamma_{5-15} ) (m²/sec)</td>
<td>205.1</td>
<td>347.5</td>
<td>301.9</td>
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</table>

Both methods show excellent agreements in estimated location.

For circulation, errors are reduced roughly from 65% to 10%.
Example of Estimation Results

**Simulation Case 2/4**

- Large cores  
  (left: 6.0 m, right: 6.5 m)
- With background wind

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Even with background wind, accuracy is almost equivalent.
Example of Estimation Results

◆ Simulation Case 3/4
  ➢ Small cores
    (left: 3.0 m, right: 2.0 m)
  ➢ No background wind

### Simulated Radial Wind Field

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<td>$\Gamma_{5-15}$ (m²/sec)</td>
<td>$-213.1$</td>
<td>$-397.6$</td>
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<tr>
<td>$\Gamma_{5-15}$ (m²/sec)</td>
<td>265.5</td>
<td>471.1</td>
<td>427.7</td>
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</table>

Small WVs (cores < range gate, 5 m) are also estimated with equivalent accuracy.
Example of Estimation Results

Simulation Case 4/4

- Small cores (left: 3.0 m, right: 2.0 m)
- With background wind

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<tr>
<td>$\Gamma_{5-15}$ (m(^2)/sec)</td>
<td>$-245.9$</td>
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Even with background wind, accuracy is almost equivalent.
Example of Estimation Results

- Application to Real Data 1/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)

![Measured Radial Wind Field](image)
Example of Estimation Results

Application to Real Data 2/6
Temporal progress of WVVs (8 sec interval between adjacent RHIs)

Measured Radial Wind Field

- range (m)
- height (m)
- radial wind velocity (m/sec)
Example of Estimation Results

Application to Real Data 3/6
Temporal progress of WVs (8 sec interval between adjacent RHIs)
Example of Estimation Results

- Application to Real Data 4/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)
Example of Estimation Results

- Application to Real Data 5/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)
Example of Estimation Results

- Application to Real Data 6/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)
Conclusion

- An algorithm to detect a WV and estimate WV parameters is developed.
- Motivation is to achieve high estimation accuracy even in a low CNR condition to obtain knowledge of WV characteristics with a large number of observations and to use it in real-time operations.
- Simulation results show a good estimation accuracy (location error is less than 1 m, circulation error is about 10 %)
- The application to real data resulted in a reasonable estimation.

- Statistical evaluation will be carried out with fresh (just-generated) WVs (comparing estimation with theoretical values derived from QAR data)