Research and Development of Airborne LiDAR Bathymetry localization technology in Korea

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Agenda:

• ALB deployments in Korea
• Applications of ALB data in Korea

• Development of Turbid Shallow Water (TSW) Algorithm
• Development of new ALB system – SEAHAWK – based on GTRI’s BRDL architecture

• Risk mitigation efforts for SEAHAWK using GTRI’s BRDL-1
Data Acquisition of ALB in Korea

Overview

East Coast

West Coast

Jeju Island

Dok Island

ABL Data Acquisition Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Area</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Ulleung and Dok Island</td>
<td>40km²</td>
<td>SHOALS 1000T</td>
</tr>
<tr>
<td>2011</td>
<td>West Coast (Biun Bay to Urchung Island)</td>
<td>190km²</td>
<td>HawkEye II</td>
</tr>
<tr>
<td>2013</td>
<td>Jeju Island and Dok Island</td>
<td>404km²</td>
<td>CZMIL</td>
</tr>
<tr>
<td>2014</td>
<td>West Coast (Tae An) and East Coast (Ulsan)</td>
<td>143km²</td>
<td>CZMIL</td>
</tr>
<tr>
<td>2015</td>
<td>West Coast and An Myun Island</td>
<td>221km²</td>
<td>CZMIL</td>
</tr>
<tr>
<td>2016</td>
<td>West Coast Biin Bay</td>
<td>158.74km²</td>
<td>CZMIL</td>
</tr>
<tr>
<td>2017</td>
<td>(on going) West Coast and Jeju Island</td>
<td>174km²</td>
<td>CZMIL</td>
</tr>
</tbody>
</table>
Dokdo Island

2006, SHOALS

2013, CZMIL
Applications of ABL in Korea

Tideland Flooding Simulation  Coastline Monitoring  Mud flat Map
Applications of ABL in Korea

Beach Erosion Monitoring

Coastline Change Monitoring

Profile

-8.194
Waveform Simulation of Turbid and Shallow Water

- Development of Waveform Simulator for (TSW: Turbid Shallow Water)
- Research for Ocean Optical Analysis of Water body in TSW
- Developing the Local Depth Measurement Algorithm for Korea West Coast

TSW model for Korea Western Sea:
Reflectance: 0.03 – 0.07
multi-layer backscatter model
## Development of a New ABL System – SEAHAWK

<table>
<thead>
<tr>
<th><strong>OBJECTIVES</strong></th>
<th><strong>CONSTRAINTS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Real-time coordinates and TPU</td>
<td>1 Circular scanner</td>
</tr>
<tr>
<td>2 1:1 product ratio</td>
<td>2 Co-aligned green/IR beams</td>
</tr>
<tr>
<td>3 KD Max (daytime) = 4.2</td>
<td>3 Integration into Geostory’s E-90</td>
</tr>
<tr>
<td>4 Depth range = 0 to 30m</td>
<td>4 Size : &lt; sensor 245k cc; rack &lt;283k cc</td>
</tr>
<tr>
<td>5 Bathymetric Spatial Density 1.5m</td>
<td>5 Weight: sensor &lt; 100kg; racks &lt; 115 kg</td>
</tr>
<tr>
<td>6 Bathymetric Accuracy</td>
<td>6 Power: &lt; 2.8kW from 4 plug configuration</td>
</tr>
<tr>
<td>(V) [0.3^2 + (0.013d)^2]^{1/2}m, 2\text{sigma.}</td>
<td>7 Laser : 30W, 10kHz, Bright Solutions</td>
</tr>
<tr>
<td>(H) ((3.5 + 0.05d)) m, 2 \text{sigma}</td>
<td>8 Navigation : Applanix POS-AV-510</td>
</tr>
<tr>
<td>7 Land/water discrimination 99%</td>
<td>9 Collaboration on telescope development</td>
</tr>
<tr>
<td>8 Topographic Spatial Density 0.5m</td>
<td>10 Budget</td>
</tr>
<tr>
<td>9 Topographic Accuracy</td>
<td>11 EAR99 compliant</td>
</tr>
<tr>
<td>(V): ±15 cm, 2 \text{sigma}</td>
<td></td>
</tr>
<tr>
<td>(H): ±1 m, 2 \text{sigma}</td>
<td></td>
</tr>
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</table>
Development of a New ABL System – SEAHAWK

**BRDL – 2015**
- Topo/bathy capable
- Real-time processing with TPU
- Green only
- Diffractive circular scanner
- 6” aperture
- Fiber-coupled detectors
- 2 kHz pulse frequency

**SEAHAWK – 2018**
- Topo/bathy capable
- Real-time processing with TPU
- IR+ green (co-located)
- Refractive/Diffractive circular scanner
- 12” aperture
- Directly-coupled detectors
- 10 kHz pulse frequency
Achieving co-aligned green/IR beams .... how?

SEAHAWK: co-located green and IR at sea surface
refractive/diffractive scanner (12” aperture)

- Compact Ritchey-Chretien telescope
- Diffractive/refractive scanner
- 532 nm Grating Ring: Equiv. Ø10” Area
- 1064 nm Grating Ring: Equiv. Ø4” Area
- Central Transmit Wedge: Achromatic

- 13 pounds (5.9kg)
- Startup = 48W
- Running = 2.4W

20°
Fabrication and testing of the SEAHAWK telescope

<table>
<thead>
<tr>
<th>No.</th>
<th>검사항목(Items)</th>
<th>검사방법(Test method)</th>
<th>규격(Specification)</th>
<th>결과(Results)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>조립정렬(Assembly alignment)</td>
<td>간섭계(Interferometer GPI XP/D)</td>
<td>3.5λ(WAVE)</td>
<td>1.435λ(WAVE)</td>
</tr>
</tbody>
</table>
Technology verification for SEAHAWK with GTRI’s BRDL-1 (co-aligned beams; directly-coupled detectors)
Deployment of BRDL-1 to Tampa, May 2017
Illustration of NRT TPU ...... Tampa, May 2017
Deployment of BRDL-1 to Tampa, May 2017
From random sample of 1600 waveforms:
1) IR Surface Peak Location leads Green Surface Peak Location by ~5 samples. Std dev = 2.08 samples

From sample of 10000 waveforms (not facing sun):
1) Background Noise Std Dev (PMT): 7.95 counts
2) Background Noise (APD): Mean = . StdDev = 16.51 counts
BRDL Second Flight – Green Waveforms (Tampa area, May 2017)

Depth:
<1 m

Depth:
6 m

2 m
7 m

3 m
8 m

4 m
9 m

5 m
Development of a New ABL System – Seahawk system

- High-performance, compact topo-bathy lidar
- Operates in high-power, linear-mode, waveform-resolved regime
- Custom water-cooled 30W 10kHz DPSS NdYAG frequency-doubled laser
- 3 channels: deep green; shallow green; IR
- First lidar with circular scanner having co-located green and IR beams
- First lidar with real-time TPU providing on-station accuracy assessment of bathymetry
- Telescope optics designed collaboratively with Myunji University
- Telescope mirrors fabricated in Korea
- Post-processing software developed in Korea
Seahawk system – operation and performance

- IHO-Order-1b (EAR99)
- Horizontal and vertical accuracy: 
  \[ V = \left[ 0.3^2 + (0.013d)^2 \right]^{\frac{1}{2}} \text{m}, \ 2\sigma, \ 0-30\text{m} \]
  \[ H = (3.5 + 0.05d) \text{m}, \ 2\sigma \]
- KDMax (daytime) = 3.7 or better
- Spatial resolution \( \sim 1.3\text{m} \) immediately fore and aft of aircraft (combining fore and aft scans).
- Operator may choose to visualize real-time point clouds colored by depth or TPU
- Raw data transferred via removable hard drives
- Data formats are fully-compatible with Geostory’s post-processing software
Seahawk system – physical design

- Design optimized for Beechcraft E90
- Modular 3-component design facilitates mobilization and maintenance
- System SWAP = 0.473m$^3$; 229 kg (installed); 2.2 kW (steady state)
- Novel telescope, scanner, laser, and electronics designs enable compact lidar head
- Robust TMU creates wide environmental operational windows: Temperature operational window 0°-50° C; Humidity operational window 0-95%, NC
- Camera rigidly attached to lidar frame facilitating sharing of trajectory
- Compact 20° circular scanner uses refractive transmitter and diffractive receiver.
Evolution of bathymetric lidar (pulse frequency -vs- time)
Following Feygels, et al. ..... 2014 JALBTCX

\[ C_{BL} = P_0 \cdot d_0 \cdot \sqrt{\frac{\eta}{\Delta\lambda}} \quad [kW \cdot m \cdot (nm)^{-1/2}] \]

where:

- \( P_0 \) is the transmitter (laser) pulse power;
- \( d_0 \) is the diameter of input receiver optics;
- \( \eta \) is the optical transparency of transmitter-receiver;
- \( \Delta\lambda \) is the bandwidth of receiver spectral selector

\[ (K_d D_{max})_X = (K_d D_{max})_{CZMIL} + \ln(C^X_{BL} / C^{CZMIL}_{BL}) / 2 \]

\[ C^{CZMIL}_{BL} = 232.4; \quad kW \cdot m \cdot (nm)^{-1/2} \]

SEAHAWK Predicted: \( C_{BL} = 299.56; \) KD Max = 4.12
Acknowledgements

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Questions?

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