New Topographic-Bathymetric Lidar Technology for Post-Sandy Mapping

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Remote Sensing Division
NOAA’s National Geodetic Survey
Canadian Hydrographic Conference
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Background

• U.S. Department of Commerce
  • National Oceanic Atmospheric Administration (NOAA)
    • National Ocean Service
      • National Geodetic Survey
        • Remote Sensing Division
  • Primary programs
    • Coastal Mapping Program
    • Aeronautical Survey Program
  • Emergency Response
Hurricane Sandy

- Landfall: October 29, 2012
- Cost: est. $50B in damages
- Damage extends over significant portion of U.S. East Coast and on both sides of the land-water interface
  - Innovative remote sensing tools & techniques needed
**Topo-Bathy Lidar**

- Emerging class of lidar system: occupies middle ground between conventional topographic and bathymetric systems:
  - Shallow water
  - Narrow beam, low power, very high measurement rates

- Why of interest to NOAA?
  - Uniquely suited for shoreline mapping
    - Seamless, high-resolution data across backshore, intertidal, and nearshore marine zones
  - Fill in shallow water gap (shoreward of NALL line)
  - SLR analysis, inundation modeling
  - Habitat mapping
  - Riverine mapping
  - Coastal zone management, coastal science => **IOCM!**
Design considerations for topo-bathy lidar:
Effect of pulse power and width on determining shallow submerged topography

Traditional bathymetric Lidar

Topo-bathy Lidar

“long”, “wide”, high-power pulse: cannot (easily) differentiate between surface and bottom return

“short” pulse: surface and bottom return is separate or convolved

Slide courtesy of Amar Nayegandhi, Dewberry
<table>
<thead>
<tr>
<th>Manufacturer / Owner</th>
<th>CZMIL</th>
<th>LADS Mk3</th>
<th>Hawkeye III</th>
<th>SHOALS 3000</th>
<th>Chiroptera</th>
<th>VQ-820-G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mapping Environment</td>
<td>Topo-Bathy</td>
<td>Bathy</td>
<td>Topo-Bathy</td>
<td>Bathy</td>
<td>Topo-Bathy</td>
<td>Topo-Bathy</td>
</tr>
<tr>
<td>Country of origin</td>
<td>USA</td>
<td>Australia</td>
<td>Sweden</td>
<td>Canada</td>
<td>Sweden</td>
<td>Austria</td>
</tr>
<tr>
<td>Released / First known survey</td>
<td>2012</td>
<td>2011</td>
<td>2013</td>
<td>2010</td>
<td>2011</td>
<td>2011</td>
</tr>
<tr>
<td>Number of Lasers</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Laser wavelength</td>
<td>532 nm (green) and 1064nm (IR)</td>
<td>532 nm (green)</td>
<td>532 nm (green) X 2 and 1064 nm (IR)</td>
<td>532 nm (green) and 1064 nm (IR)</td>
<td>532 nm (green) and 1064 nm (IR)</td>
<td>532 nm (green)</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>short</td>
<td>long</td>
<td>long</td>
<td>long</td>
<td>short</td>
<td>short</td>
</tr>
<tr>
<td>Maximum Pulse Repetition Frequency (kHz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Topography</td>
<td>70 kHz</td>
<td>N/A</td>
<td>100 - 400 kHz</td>
<td>20 kHz</td>
<td>400 kHz</td>
<td>520 kHz</td>
</tr>
<tr>
<td>Shallow bathymetry</td>
<td>70 kHz</td>
<td>N/A</td>
<td>35 kHz</td>
<td>N/A</td>
<td>36 kHz</td>
<td>520 kHz</td>
</tr>
<tr>
<td>Deep bathymetry</td>
<td>10 kHz</td>
<td>1.5 kHz</td>
<td>10 kHz</td>
<td>3 kHz</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Laser Energy per pulse at 532 nm (green)</td>
<td>3 mJ</td>
<td>7 mJ</td>
<td>3 mJ</td>
<td>4 mJ</td>
<td>0.1 mJ</td>
<td>0.02 mJ</td>
</tr>
<tr>
<td>Nominal Flying Height</td>
<td>400 m</td>
<td>400 - 700 m</td>
<td>250 - 500 m</td>
<td>300 - 400 m</td>
<td>250 - 600 m</td>
<td>600 m</td>
</tr>
<tr>
<td>Nominal Laser footprint @ water surface (@ 532 nm green) at nominal flying height</td>
<td>2 m</td>
<td>3 m</td>
<td>4 m (deep); 2 m (shallow)</td>
<td>2 m</td>
<td>1.5 m</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Point density (points per square meter) at nominal flying height</td>
<td>0.25 to 1</td>
<td>0.25 to 0.025</td>
<td>13 (topo); 0.3 - 1.2 (bathy)</td>
<td>0.025 - 0.04</td>
<td>13 (topo); 1.2 (bathy)</td>
<td>6 - 10 (topo and bathy)</td>
</tr>
<tr>
<td>Typical maximum water depth (measured as Secchi depth)</td>
<td>2.5 - 3</td>
<td>2.5 - 3</td>
<td>2 - 2.5</td>
<td>2 - 2.5</td>
<td>1.0 - 2.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Not an exhaustive list

http://www.lidarnews.com/PDF/LiDARMagazine_Quadros-BathymetricLiDARSensors_Vol3No6.pdf

Slide courtesy of Amar Nayegandhi, Dewberry
Riegl VQ-820-G

New commercial topo-bathy system:
- narrow laser beam
- high range resolution
- high measurement rate
- compact and lightweight design

Designed for:
- high-resolution mapping of shallow waters
- focus on min. depth capturing (shallow water)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Wavelength</td>
<td>532 nm (visible green)</td>
</tr>
<tr>
<td>Measurement range Topography</td>
<td>10 – 1500 m at ρ ≥ 20%</td>
</tr>
<tr>
<td></td>
<td>10 – 2500 m at ρ ≥ 60%</td>
</tr>
<tr>
<td>Measurement range Bathymetry</td>
<td>1 Secchi depth</td>
</tr>
<tr>
<td>Ranging accuracy</td>
<td>25 mm</td>
</tr>
<tr>
<td>Full scan angle</td>
<td>42°, 60°*</td>
</tr>
<tr>
<td>Beam divergence</td>
<td>1 mrad</td>
</tr>
<tr>
<td>Measurement rate</td>
<td>520 kHz</td>
</tr>
<tr>
<td>Scan rate</td>
<td>50 – 200 lines/sec</td>
</tr>
<tr>
<td>Laser safety</td>
<td>Laser Class 3B</td>
</tr>
</tbody>
</table>
June 2013 Data Acquisition

NOAA Hawker Beechcraft King Air 350ER

Furthest aft: Riegl VQ-820-G topo bathy lidar. Foreground: Applanix DSS DualCam digital aerial camera; twin Riegl IR lidars LMS-Q680i/Q780 (1550nm and 1064nm)

Sept 2013 Data Acquisition

NOAA DeHavilland Twin Otter (DHC-6)

Left: Riegl LMS Q-680i, Right: Riegl VQ-820-G
Acquisition: Sensor Suite

**Topo-Bathy Lidar: VQ820G**
- 532 nm laser
- 1 Secchi Depth System
- Effective Measurement Rate: 200,000 meas./sec.

**Topo Lidar: Q680i**
- 1550 nm laser
- Effective Measurement Rate: 266,000 meas./sec.

**Applanix Digital Sensor System: DSS 439**
- 39 Mega Pixels
- True Color: Red/Green/Blue
Acquisition: Operations

Topo-Bathy Lidar: VQ820G

- **AGL: 1000 feet**
  - Nominal Point Density: 18 pt/m²
  - Swath Width: 234 meters

- **AGL: 2000 feet**
  - Nominal Point Density: 9 pt/m²
  - Swath Width: 468 meters

- **Operational Parameters:**
  - 50% sidelap of swaths
  - 42° Field of View
Barnegat Inlet, NJ

September 2013

Barnegat Bay, NJ

National Oceanic and Atmospheric Administration
Project Statistics and Accuracy Assessment

- Total # of Lidar Returns: 1,130,349,822
- Bathymetric Points: 508,802,577 (some of these might be water column noise, etc.)

- Accuracy Assessment (meters) based on 27 GPS Control Points
  - Average dz: -0.001
  - Minimum dz: -0.039
  - Maximum dz: +0.056
  - Average magnitude: 0.023
  - Root mean square: 0.027
  - Std. Deviation: 0.028
Areas of common overlap of W00279 (lidar survey) and H12596 (hydrographic survey) are in harmony, with occasional exceptions. W279 soundings are in red color, with H12596 in blue color. Lidar 09/23/2013 – 09/24/2013 H12596 07/18/2013 – 10/30/2013
Barnegat Inlet Point Density

- 40 points/sq meter
- 30 points/sq meter
- 30 points/sq meter
- 10 points/sq meter
- 40 points/sq meter
Uncharted Shallows
Point Cloud Derivatives

- Elevation with Water Surface
- Topobathy without water surface
- Pseudo Reflectance
- RGB Encoded
Elevation

Classified Point Cloud

RGB Encoded

Topobathy Bare Earth
Acquire coastal lidar and process to point cloud

Edit Lidar Point Cloud

Lidar Shoreline Mapping Process

Contour Shoreline from DEM

Editing, Attribution, and QA/QC

VDatum
Final Geographic Cell (GC) for Barnegat Inlet
SOW for Contract Topo-Bathy Lidar in Sandy-Impact Region:

- Contracted imagery and topo-bathy lidar acquisition to support update of the National Shoreline in Sandy region
  - Additional uses: mapping, charting, geodesy services, marine debris surveys
- Deliverables (partial list):
  - Merged, cleaned topo-bathy point clouds in LAS 1.2 format
  - Topo-bathy DEMs
  - GeoTiff RGB/NIR orthomosaics
Project Area

- Supplemental Sandy Topobathy LiDAR and Imagery Task for the NOAA NGS Shoreline Mapping Program
- Dewberry tasked as prime contractor under the NOAA CGSC II contract
- Subcontractors – Quantum Spatial (LiDAR and Imagery), Woolpert (Imagery)
- Project is currently underway (acquisition began Nov 21, 2013).
- 3 aircraft with topobathy LiDAR being deployed
- Current acquisition status: 89% complete
  - Block 1 – 100% complete
  - Block 2 – 96% complete
  - Block 3 – 69% complete
LAS 1.4: Topo-Bathy Domain Profile

• New point classes:
  – Bathymetric point (e.g., seafloor, riverbed; AKA - submerged topography)
  – Water surface (observed)
  – Water surface (derived)
  – Submerged object
  – IHO S-57 object
  – Bottom-not-found depth

• New attributes:
  – (pseudo)-reflectance
  – XYZ Uncertainty
  – Water column optical depth
  – Figure of Merit
  – Flags

In Closing

Topobathy Lidar is proving to be a valuable tool to meet NOAA’s requirements

• IOCM multi-use
  – Shoreline mapping
  – Charting
    • Fill in data gap (“white ribbon”) along coast
  – SLR inundation modeling
  – Benthic habitat mapping
  – Coastal zone management, coastal science

• Potential for increased efficiencies in operations
  – Initial airborne Lidar survey to then support hydrographic operations

• Opportunity for both the Terrestrial and Bathymetric communities to incorporate the data for their needs
  – Software on both sides needs to ingest LAS 1.4 – Littoral processing
  – Orthoimagery also needs to be easily ingestible especially in bathymetric processing workflows.
Airborne Topo-bathy Lidar

- New generation of systems designed:
  - Very high-res, seamless data in littoral zone
  - Multiple pts/m²
- IOCM multi-use
  - Shoreline mapping
  - Charting
  - Fill in data gap (“white ribbon”) along coast
  - SLR inundation modeling
  - Benthic habitat mapping
  - Coastal zone management, coastal science

Slide courtesy of Amar Nayegandhi, Dewberry
AHAB Chiroptera

- Topo up to 400 KHz
- Bathymetric survey 35 KHz
- Depth penetration adapted to bathymetric needs
  - Full coverage to $K_d x D_{\text{max}} > 2$
- High energy laser and fast system response time
  - Excellent target detection and shallow water capability
  - Oblique scanner principle
  - Automatic water refraction correction

Images courtesy of Anders Ekelund, AHAB

National Oceanic and Atmospheric Administration
Derived MLLW Shoreline distance to MHW shoreline less than threshold needed to be depicted on Nautical Chart.
RSD In-house & Contract ALB to HSD & MCD

**RSD**
- ALB Acquisition (contractor or in-house)
  - Processes/cleans ALB data (contractor or in-house)
  - Final LAS Data (Point Cloud) for HSD (+) down for bathy & Remove topo (done in-house)
  - RSD Derives Preliminary Shoreline (done in-house)
  - Final Feature Attributed Shoreline completed at chart scale (contractor or in-house)

**HSD**
- Regular pipeline Hcell creation
  - Ops will decide which data will go to AHB or PHB based on workloads, junction, etc. (i.e. each area will be decided on a case by case basis)
  - RSD provides HSD with:
    - LAS files (processed point cloud data with the ability to see rejected data)
    - Verified Final Feature Attributed Shoreline shapefiles at chart scale
    - 35 cm ortho imagery
    - Metadata – how, when, where, spot spacing, projection, etc.

**MCD**
- HSD provides MCD Hcell with final attributed and chart scaled shoreline etc.
Depth of 1.5m relative to MLLW