UAS-based Orthomosaic and Elevation Modeling for Montezuma Wetland Restoration Project
San Francisco Estuary

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Geospatial Analyst
1. Background
2. Benefits of Unmanned Aerial Systems (UAS) for wetlands mapping
3. Project goals
4. Setup and aerial data acquisition
5. Photogrammetric image processing
6. Results
7. Challenges and recommendations
Background

UAS - Montezuma Wetland Restoration Project

- 2,400-acre dredged sediment disposal, management, and reuse site located in the Suisun Marsh in the San Francisco Estuary
Background

UAS - Montezuma Wetland Restoration Project

- Project permitted by regional, state, and federal agencies:
  - Regional Water Quality Control Board (RWQCB)
  - Solano County
  - State Lands Commission
  - U.S. Army Corps of Engineers

- Additional oversight by Technical Review Team (TRT)
Background

UAS - Montezuma Wetland Restoration Project

- The site was previously diked and drained for agricultural use over 100 years ago—with up to 10 feet of subsidence
Background

UAS - Montezuma Wetland Restoration Project

- Four Phases of restoration
- Aerial survey of Phases I, II, and IV
- 17 million cubic yards (cy) design capacity
- Sediment will be used to raise the surface elevations to create 1,800 acres of tidal and seasonal wetlands
Benefits of UAS for Wetlands Mapping

UAS - Montezuma Wetland Restoration Project

- Higher resolution data in less time and at lower cost than traditional survey methods
- Real-time or near real-time support for adaptive management
- Comprehensive spatial coverage
- Access to difficult-to-reach areas with reduced risk to staff and wildlife
Benefits of UAS for Wetlands Mapping

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- High spatial and temporal sampling density
- Easily repeatable
- Greater signal to noise ratio
- Spatial/temporal correlation of multiple data sources
- Compliance with ASPRS standards (2014): map scale/contour scale to GSD (digital)
Project Goals

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- Baseline mapping: end of dry season (Sept)
- Orthomosaic imagery: 1-inch per pixel ground sample distance (GSD)
- Digital Surface Model (DSM)
- Elevation contours: 1-foot contour intervals
- Vertical accuracy: 2 inches (6 cm) root-mean-square error (RMSE)
- GIS and AutoCAD compatible data products
Project Goals

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Data Uses

- Accurate volume calculations
- Adaptive management
- Invasive species monitoring
- Slope and seismic stability
- Erosion and subsidence monitoring
Project Setup and Aerial Data Acquisition

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- **UAS platform**: DJI Inspire-1 quadcopter
- Vertical take-off and landing (VTOL)
- Good stability and endurance characteristics
- Reliability for multi-day missions

<table>
<thead>
<tr>
<th>Make</th>
<th>DJI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Inspire-1</td>
</tr>
<tr>
<td>Endurance</td>
<td>18 mins</td>
</tr>
<tr>
<td>Payload</td>
<td>1700 g (3.7 lbs)</td>
</tr>
<tr>
<td>Operating Range</td>
<td>2000 m (1.2 mi)</td>
</tr>
<tr>
<td>Top speed</td>
<td>22 m/s (29 mph)</td>
</tr>
<tr>
<td>Max. wind resistance</td>
<td>10 m/s (22 mph)</td>
</tr>
</tbody>
</table>
- Integrated micro four-thirds camera designed for aerial photography

<table>
<thead>
<tr>
<th>Camera</th>
<th>Zenmuse X5</th>
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</thead>
<tbody>
<tr>
<td>Sensor type</td>
<td>CMOS</td>
</tr>
<tr>
<td>Sensor resolution</td>
<td>4608 x 3456 = 16 Mpxixels</td>
</tr>
<tr>
<td>Sensor dimensions</td>
<td>17.31 x 12.98 mm</td>
</tr>
<tr>
<td>Pixel dimensions</td>
<td>3.8 µm</td>
</tr>
<tr>
<td>Format</td>
<td>JPEG, 8-bit</td>
</tr>
<tr>
<td>Focal length</td>
<td>15 mm (30 mm equiv.)</td>
</tr>
<tr>
<td>Shutter</td>
<td>electronic</td>
</tr>
<tr>
<td>Gimbal</td>
<td>3-axis</td>
</tr>
<tr>
<td>Video</td>
<td>4K, 30 fps</td>
</tr>
</tbody>
</table>
Project Setup and Aerial Data Acquisition

UAS - Montezuma Wetland Restoration Project

**Mission Planning**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area mapped</td>
<td>2,154 acres = 8.7 km²</td>
</tr>
<tr>
<td>GSD</td>
<td>1 inch = 2.5 cm/pixel</td>
</tr>
<tr>
<td>Average Altitude</td>
<td>340 ft = 104 m</td>
</tr>
<tr>
<td>Overlap / Sidelap</td>
<td>70 – 75%</td>
</tr>
<tr>
<td></td>
<td>50 – 60%</td>
</tr>
<tr>
<td>Total no. of images</td>
<td>8,428</td>
</tr>
</tbody>
</table>

70 – 75% overlap between images (forward overlap)

50 – 60% overlap between images (sidelap)
Mission planning

Test flight

Challenges

Fly

- Advance site visit and test flights were used to identify potential challenges and solutions
  - Limited access and home locations
  - Wind and weather conditions
  - Consistent image exposure
  - Battery supplies and charging for multi-missions
  - Continuous data quality control
  - Verification of data completeness – avoid data gaps
Project Setup and Aerial Data Acquisition

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- **Controllable factors**
  - Breaking down the area into manageable size
  - Choosing home locations / staging to maximize battery efficiency
  - Keeping flight logs to organize images, track completeness

- **Uncontrollable factors**
  - Wind – variable, up to 20 mph
  - Duration of daylight
  - Cows, equipment traffic damaging ground control targets
  - Accuracy of client’s ground control survey
Project Setup and Aerial Data Acquisition

UAS - Montezuma Wetland Restoration Project

- **Ground Control Network**
  - 76 control points used to calibrate the model
  - 18 check points used to verify the accuracy of the model
Project Setup and Aerial Data Acquisition

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Area Divided Into 35- to 50-Acre Sections

Flight Paths and Image Overlap
Mission Statistics:
- 5 days to complete
- 70 missions
- 8,439 images
Computing platform:
- CPUs: 12 cores (dual 6-core Xeon processors--no hyperthreading)
- GPU: Nvidia GeForce 980Ti
- RAM: 128 Gb

Software:
- Agisoft Photoscan Pro v. 1.2.6
## Workflow

<table>
<thead>
<tr>
<th>Step</th>
<th>Approx. time to compute (hours)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image alignment – sparse point cloud</td>
<td>6</td>
<td>&gt;27 million tie points</td>
</tr>
<tr>
<td>Optimization of sparse pt. cloud</td>
<td>8 (operator)</td>
<td>&gt;12 million tie points</td>
</tr>
<tr>
<td>Dense point cloud</td>
<td>16</td>
<td>&gt;240 million points = 27.5 points / m²</td>
</tr>
<tr>
<td>Digital Surface Model (DSM)</td>
<td>0.6</td>
<td>~600 million pixels 19-cm grid</td>
</tr>
<tr>
<td>Orthomosaic</td>
<td>3</td>
<td>~30 billion pixels = &lt;1-inch (2.38 cm) / pixel</td>
</tr>
<tr>
<td>Elevation contours</td>
<td>1</td>
<td>1-foot intervals</td>
</tr>
</tbody>
</table>
### Data Management

<table>
<thead>
<tr>
<th>Data Product</th>
<th>File Size (Gb)</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>8,428 images (16 Mp)</td>
<td>63 (~7 Mb/image)</td>
<td>JPEG (8-bit)</td>
</tr>
<tr>
<td>Dense point cloud</td>
<td>21</td>
<td>DXF</td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>LAS</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>XYZ</td>
</tr>
<tr>
<td>Digital Surface Model (DSM)</td>
<td>1.4</td>
<td>GeoTIFF</td>
</tr>
<tr>
<td></td>
<td>7.3</td>
<td>XYZ</td>
</tr>
<tr>
<td>Orthomosaic</td>
<td>62</td>
<td>GeoTIFF</td>
</tr>
<tr>
<td>Elevation contours</td>
<td>1</td>
<td>1-foot intervals</td>
</tr>
</tbody>
</table>
Results

UAS - Montezuma Wetland Restoration Project

Orthomosaic

Digital Surface Model

Contours

50 m
Results

UAS - Montezuma Wetland Restoration Project

Orthomosaic

Digital Surface Model

Contours

10 m
Results

UAS - Montezuma Wetland Restoration Project

Orthomosaic

Digital Surface Model

Contours
# Results

## UAS - Montezuma Wetland Restoration Project

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Horizontal (XY) RMSE</th>
<th>Vertical (Z) RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control points (76)</td>
<td>1.3 inch 3.4 cm</td>
<td>0.2 inch 0.6 cm</td>
</tr>
<tr>
<td>Check points (18)</td>
<td>3.9 inches 9.8 cm</td>
<td>3 inches 7.5 cm</td>
</tr>
<tr>
<td>Reprojection error</td>
<td>0.6 pixel 1.4 cm</td>
<td></td>
</tr>
</tbody>
</table>

**RMSE** = root-mean-square error
## Challenges and Lessons Learned

**UAS - Montezuma Wetland Restoration Project**

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large site with limited access</td>
<td>Advanced reconnaissance, careful mission planning, and quality control were critical for success</td>
</tr>
<tr>
<td>Fixed-wing UAS was initially planned because of increased range, but was unavailable to fly</td>
<td>Rotary-wing UAS (quadcopter) performed reliably for multiple missions; VTOL was advantageous for limited access</td>
</tr>
<tr>
<td>Client augmented existing ground control network with additional aerial targets</td>
<td>Perform comprehensive ground control survey</td>
</tr>
<tr>
<td>Damage to ground control targets</td>
<td>Limit elapsed time between ground control survey and aerial data acquisition to reduce potential damage</td>
</tr>
<tr>
<td>Initial software used for modeling didn’t meet vertical accuracy requirements</td>
<td>For this project, Photoscan Pro software produced a more accurate model, but requires more operator expertise</td>
</tr>
</tbody>
</table>
References


Contacts

UAS - Montezuma Wetland Restoration Project

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