Coastal California Ortho
Final Project Report

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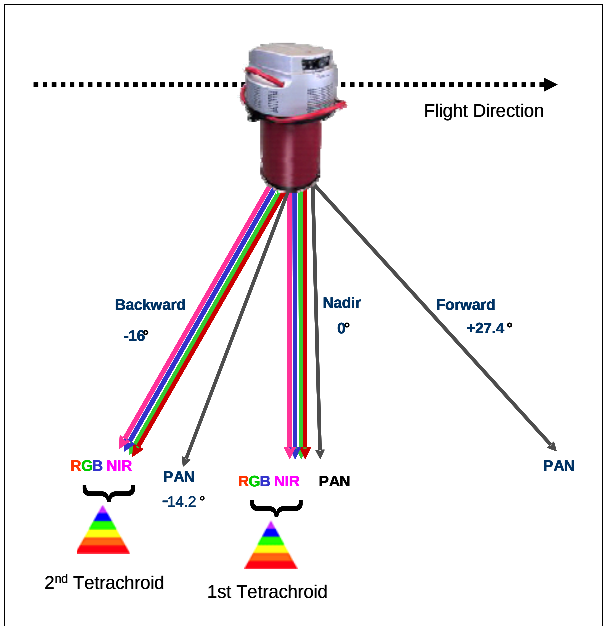
1 PROJECT OVERVIEW

1.1 Project Goals

The NOAA Coastal Services Center (CSC) in partnership with the California State Coastal Conservancy (SCC) Ocean Protection Council prepared a Statement of Work (SOW), dated February 2011 entitled *"Coastal California LiDAR and Digital Imagery"* for data acquisition and processing for use in coastal management decision making, including applications such as sea level rise. This report focuses on the Ortho acquisition and processing portion of the project.

1.2 ADS40-SH52 Ortho Digital Camera

The ADS40-SH52 is also equipped with an Applanix POS inertial measurement unit mounted on a PAV30 gyro-stabilized platform. The digital imagery, GPS, and IMU position and orientation data are recorded during each sortie and are written to the mass memory system that is part of the camera control unit. After completion of the AT, the ADS40 bands can be exported as stereo pairs in all commonly read formats to develop planimetric, topographic, and other types of photogrammetrically-derived data products. The stereo models are accompanied by a digital file containing the exterior orientation parameters derived from the bundle triangulation adjustment and their coverage is controllable by the technician; a typical model size is 12,000 by 5,000 pixels with a 200 pixel overlap between models along track.



ADS40-SH52 Sensor Configuration

It should be noted that all of the CCD arrays are uniform in pixel resolution. All spectral bands are collected at the same native pixel resolution; therefore pan-sharpening of color and IR bands is not necessary. This provides greater radiometric integrity for image classification and thematic mapping applications. There are also no dead pixels in any of the CCD arrays. Digital imagery from the ADS40-SH52 is processed using our unique Pixel Factory processing suite, combined with Fugro EarthData's large parallel processing capacity (96 parallel processors of 3GHz each). With the system's powerful auto-correlation algorithms, imagery from the ADS40-SH52 can be rapidly developed into orthophotography and DEM products.

1.3 Project Design

In order to meet the required survey and accuracy specifications for this project, the parameters for data capture were planned as follows:

Flight Parameters					
Acquisition Option	Ortho Pixel Resolution	Flying Height	Sidelap	Flight Line Miles	Number of Lifts
Standard	30cm	9,494'	30%	3833.74	13

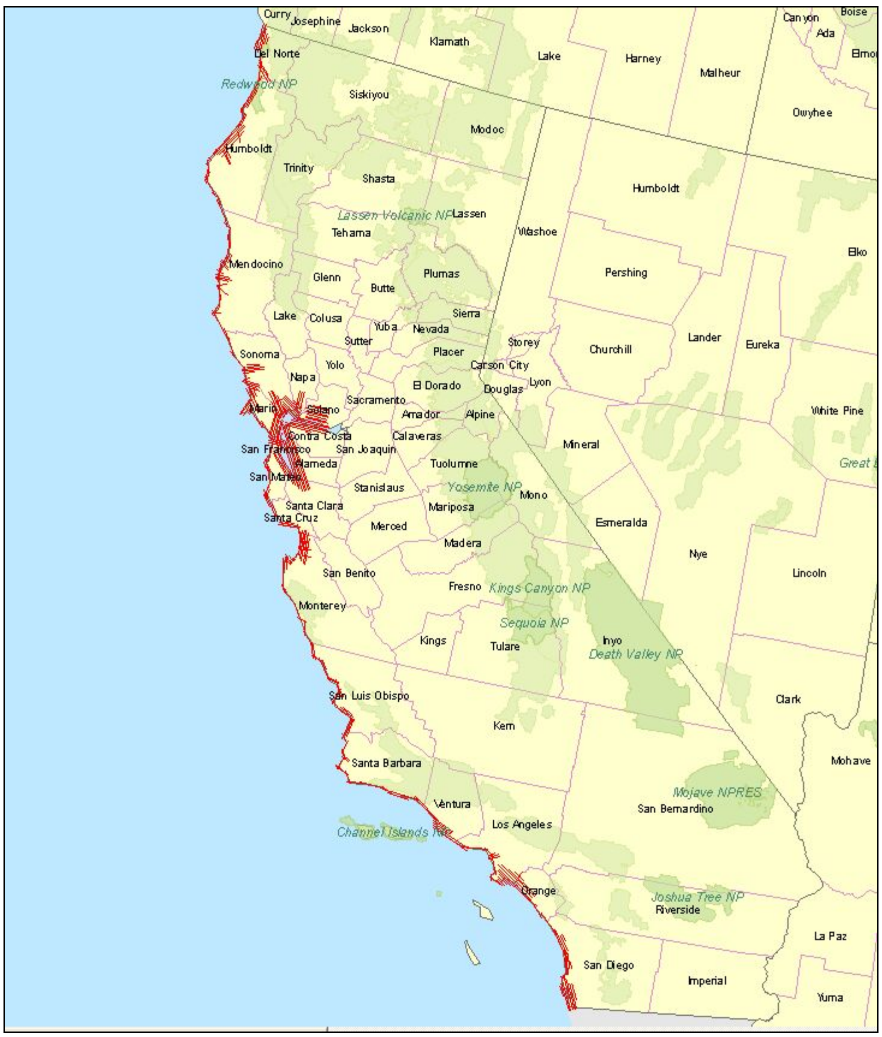
Aerial acquisition planning includes timing of missions to coincide with the strength of the GPS constellation; flight line length is designed to ensure peak performance of the IMU and the use of continually operating reference stations (CORS); and the deployment of GPS base stations will incorporate sufficient flexibility to allow for weather and air traffic restrictions.

The aerial acquisition plan for NOAA CSC was developed using a CAD-based application developed by Fugro EarthData called “J-Flight”. Using that text-based information and the project boundary, the application creates a series of CAD files that include:

- Flight line locations with start and stop points for each acquisition block
- Ortho tile boundaries
- GPS base station locations

The digital files created by the J-Flight application are readable by the Leica FCMS on-board flight management system that is used for operation of the ADS40-SH52 camera system. The configuration of acquisition blocks may require modification due to weather or air traffic considerations, and these changes can be easily incorporated into the overall acquisition design using J-Flight and FCMS. A copy is provided with this report.

(Attachment-A Coastal_CA_Ortho_Flight_and_Control_Plans.zip)



1.4 Project Specifications

The following specifications were understood prior to and throughout the project:

1. Planned acquisition window between September 1, 2010 through December 1, 2010, as tidal and weather constraints allow:

a. Collection within 1.5 hours of MLLW for the following regions: Klamath River, Tijuana River Estuary, Humboldt Bay/Eel River Delta, San Elijo Lagoon, San Francisco Bay, Pescadero River, and Elkhorn Slough. A minimum of two tidal windows shall be attempted and if collection cannot be completed during those two windows the MLLW tidal requirement shall be removed.

b. Clouds and Haze: No clouds, shadows, or haze that obstructs ground cover will be accepted.

2. Base stations for GPS surveys:

    a. Shall be based on first or second order survey control stations that are part of the National Geodetic Survey's Spatial Reference System.

    b. Any new control stations will have to be established using NGS-58 Guidelines for Establishing GPS- Derived Ellipsoidal Heights (Standards: 2 cm and 5 cm).

    c. New control stations will be sufficiently monumented to hold their position.

3. The spectral band set shall be set to the normal Blue, Green, Red, Near-Infrared channel. Digital sensor data shall be delivered as 4 band (Blue, Green, Red, Near IR) images.

4. The radiometric resolution of the image composites shall be 8-bit, and the data type shall be unsigned integer.

    a. The radiometric resolution of the image composites shall also be delivered as 16-bit. FEDI will balance the across-track brightness (due to sensor and illumination differences) within each flight line and will perform a histogram normalization of all flight lines throughout the corridor while maintaining the 12-bit dynamic range of the band data. We will not attempt additional color balancing to force brightness to match between flight lines to preserve the dynamic range of the data.

5. The imagery shall be processed to remove atmospheric effects such as haze.

6. The imagery shall have a minimal exposure variation between adjacent flight lines.

7. The ortho-imagery shall be tiled into 1500 meter by 1500 meter tiles on even boundaries for UTM zones 10 and 11 North. Naming shall indicate the lower left corner of the tile and the scheme shall be Cxxxx_yyyyy where 'C' stands for California, 'xxxx' is the first 4 digits of the UTM eastings (e.g. the tile with westernmost eastings of 517500 will have 'xxxx' equal to 5175), and 'yyyyy' is the first 5 digits of the northings (e.g. the tile with southernmost northing of 33600000 will have 'yyyyy' of 33600).

8. No double-images or ghosts from interleaving of overlapped flight lines will be acceptable, with the exception of bridges.

9. Spatial resolution (pixel size) of the MS bands shall be 30 centimeter x 30 centimeter.

10. Overlap - 60% endlap, 30% sidelap or appropriate percent to develop orthophotos. Contiguous flight lines shall have sufficient overlap to insure entire AOI is collected.

11. Crab must not exceed five-degrees between any two consecutive flights, nor more than three degrees on any one flight line.

12. No band offsets will be tolerated.

13. Use the Pixel Factory auto-correlated DSM for orthorectification.

14. The ortho-imagery tiles will be delivered in GeoTIFF format following the naming convention specified above.

15. Fugro EarthData shall correct aerial imagery that does not meet defined specifications. All re-flights shall be centered on the original plotted flight lines and shall be taken with the same camera system under the same requirements and specifications. New imagery to replace rejected photographs or flight lines shall be acquired at the earliest opportunity.

16. A pilot area shall be delivered to NOAA CSC for review prior to final processing and delivery of final imagery.

2 DATA ACQUISITION

Fugro EarthData acquired data from August 26, 2010 through November 29, 2010 and on August 23, 2011 (this lift was flown to minimize building lean around San Francisco). Aircraft operations were undertaken from ten airports starting at McClellan-Palomar Airport (KCRQ) up to Arcata Airport (KACV). All collections were flown with Conquest (N441S), King Air (N652L), and Piper Navajo (N76JN) aircrafts.

A total of 296 lines were flown in 37 lifts during the course of data acquisition; 81 lines required tidal restrictions within 1.5 hours of MLLW in the following regions:

- Klamath River
- Tijuana River Estuary
- Humboldt Bay/Eel River Delta
- San Elijo Lagoon
- San Francisco Bay
- Pescadero River
- Elkhorn Slough

A minimum of two attempts at meeting tidal window restrictions was required. It was determined that if collection could not be completed within these two attempts, the MLLW tidal requirement would be removed.

On November 22, 2010 NOAA CSC gave Fugro EarthData approval to acquire data at MLLW plus 3 feet.

Fugro EarthData made two attempts without being able to acquire data at the MLLW tidal requirement due to weather and other project constraints; therefore, this tidal requirement for Klamath River (lines I020, I021, and I022) was removed; the lines for Klamath River were flown as non-tidal on September 24, 2010. Details are provided in the attached report:

(Attachement-B_E10-0041-00_CACoastalMapping_10MContour_Ortho_AcquisitionReport_011711.zip)

3 GROUND CONTROL

The field survey of ground control for the project was completed by TerraSurv between August 30, 2010 and October 21, 2010. The report of survey is provided with this final report. This control suppliments the ground control provided for the JALBTCX Ortho project. See attached report for additioanl details:

(Attachment-C_ Coastal_CA_Ortho_Ground_Control_Report_122110.zip)

4 DATA PROCESSING

2.2.1 Aerotriangulation (AT

Once the ADS40-SH52 data was collected and accepted, the AT phase began. Following is a step-by-step description of the AT process:

Step 1 AT was accomplished as a component of Fugro EarthData's exclusive Pixel Factory process. The ground control, GPS, and IMU solution was ingested and tie points between strips were identified. Normally, only five tie points are needed between adjacent flight lines. We used automated tie point selection function in Pixel Factory which allowed us to increase the amount of tie points.

Step 2 The technician performed AT process and applied the bundle adjustment result to the images of each AT block (consisting of multiple lifts). The results of the adjustment were verified through the generation of the full resolution panchromatic ortho chips over the ground control points for the data sortie. The ortho chips were inspected by the photogrammetric technician to identify any errors in the adjustment to ensure the accuracy meets project specification. The technician also generated and visually reviewed ortho strips covers across all flight lines to ensure edge matching between flight lines. Documentation of the methodology and AT report containing the RMSE and residual calculations of the tie and ground control points used in block adjustment was prepared and delivered to NOAA CSC.

2.2.2 Pilot Project

Before the start of full production, Fugro EarthData provided NOAA CSC with a pilot dataset over the following tiles: C4725_36510, C4725_36525, C4725_36540, C4740_36495, C4740_36510, C4740_36525, C4740_36540, C4755_36495, C4755_36510, C4755_36525, and C4755_36540. This dataset gave NOAA CSC an opportunity to review and approve data products prior to the start of full production. The pilot project consisted of 8-bit and 16-bit, 4-band multi-spectral ortho-imagery tiles.

2.2.3 Production using the Pixel Factory™

The following section describes the Pixel Factory digital image production sequence. This workflow is unique to Fugro EarthData and has been developed specifically for push-broom sensors like the ADS40-SH52. This is a mature, stable workflow and incorporates all production components into an integrated series of tools to accomplish elevation model development, ortho production, and finishing.

Step 1 The digital elevation data was correlated using the stereoscopic CCDs that are part of the ADS40 camera system. Using several tools that are part of the Pixel Factory workflow, a digital surface model (DSM) was correlated at an appropriate post spacing for the final accuracy requirement. The Pixel Factory correlation algorithm computed the X,Y,Z value for each DSM post utilizing every stereo angle that was available. A series of DSM files were created for acquisition block, one for each stereo look angle. A mosaic was then created from the separate DSM files where the best vertical value for each posting was selected from all look angles compared against the aerotriangulation adjustment which is incorporated into the mosaic.

Step 2 The digital imagery for each acquisition sortie was differentially rectified to produce 4-band ortho-imagery at the appropriate pixel resolution. The Pixel Factory used the cubic convolution algorithm in its processing to remove image displacement due to topographic relief, tip and tilt of the aircraft at the moment of acquisition. Each individual strip of imagery from each flight line was rectified and radiometrically processed.

Step 3 In order to achieve maximum efficiency in data processing, the digital orthophoto technician produced quicklooks for automated seamline generation and radiometric processing of the imagery. Quicklooks are a rendition of each scale of imagery at 1/64 of the actual resolution of the orthophotography. The goal of the radiometric adjustment is to minimize tonal changes of ground features on adjacent strips of imagery giving a balanced look across the entire project.

Step 4 The results of the radiometric adjustment and seamline generation were used to create a mosaic for each block. The seamlines were then reviewed to ensure that the aesthetic impact on features and the final product was minimized. The data for all blocks was then processed to create a uniform and seamless appearance for the entire area.

Step 5 The final ortho-image tiles were processed to the required projection and datum and are clipped out using the approved tiling grid and naming convention.

Step 6 Fugro EarthData provided NOAA CSC with the pilot ortho-imagery for selected portions of the overflight at full resolution for review and approval of tone (color) and contrast of the imagery.

Step 7 Digital ortho-imagery was then quality controlled internally. Based on the feedback from QC procedures, Fugro EarthData performed final corrections to the orthoimage, depending on the nature of the artifacts to be corrected. Minor artifacts were corrected using Adobe Photoshop in an interactive editing session.

Step 8 Final digital ortho-imagery tiles were written out into GeoTIFF deliverable format with internal corresponding georeferencing and copied to hard drives for delivery.

4.1 ADS40-SH52 Quality Control

2.3 Digital Ortho-imagery Quality Control

Both manual and automated QC activities have been integrated throughout the production process as an effective method for identifying errors early in the production process, instead of reviewing only the final deliverable. These QC techniques detect failures in the system and then, through corrective action reviews and routines, link QC and quality assurance (QA) practices.

Fugro EarthData's approach to quality includes detailed quality procedures and plans based on project specifications and industry standards. This approach is designed to:

- Ensure that all data products meet or exceed NOAA CSC's expectations for quality and accuracy
- Ensure high first-time acceptance rates – on time – by incorporating QA and QC throughout the production lifecycle, not just final deliverables
- Minimize NOAA CSC's responsibility and administrative burden for ensuring that all data products meet their expectations and the expectations of their users

Fugro EarthData has very detailed processes and production workflows that govern each phase of production, from data acquisition through processing and product finishing.

2.3.1 QC Process for AT

QA/QC is integrated into the AT process. A final AT report was prepared with information on such parameters as altitude; camera focal length and serial number; number of flight lines; source of ground control; original values of the ground control; data fit to control and root mean square errors (RMSEs). Each point is listed with its corresponding vertical and horizontal coordinates (X, Y, and Z). The final AT report was reviewed by Mr. McClellan and Dr. Qassim Abdullah, our Chief Scientist.

2.3.2 QC Process for Digital Ortho-imagery

During the processing of the imagery, there were several QA/QC steps performed. The surface model was checked for corruption and missing coverage prior to initiating the rectification process. After the images were rectified, they were reviewed for coverage and quality. Then using the mosaics, the seamlines were panned along at map scale to inspect the image joins and that the established radiometrics have been applied and were acceptable. Absolute accuracy was verified by overlaying and comparing the locations of the paneled control that are visible on select full resolution images against the known control point locations found in a vector file. Then the final visual inspection was completed at map scale on each ortho-image tile. At each step, the technician made the necessary corrections to the data as necessary until the quality was validated as acceptable and preceded to the next step.

2.3.3 Final Delivery Quality Control

The project manager for the project was responsible for conducting a final overview QC of all deliverables leaving the department. A review of the lead technician's QC, file management procedures, and delivery format and coverage were all checked a final time before the deliverables were submitted. Reporting of deliveries and submitting any QC reports was the direct responsibility of the project manager.

5 PROJECT DELIVERABLES

The following deliverables were submitted to NOAA CSC for this project:

- Work plan
- Quality control plan
- Project kickoff meeting
- Project kickoff meeting minutes
- Monthly progress reports
- Weekly progress reports during the acquisition phase
- Digital ortho-imagery flight plans
- Digital ortho-imagery control plan
- Digital ortho-imagery mobilization

- Digital ortho-imagery acquisition 25% complete
- Digital ortho-imagery ground control survey report
- Digital ortho-imagery aerial acquisition report
- Digital ortho-imagery pilot area
- Digital ortho-imagery: 4-band multi-spectral ortho-imagery tiles with 30 cm pixel ground resolution, configured to display as 8-bit color-infrared and capable of being redisplayed as 8-bit natural color
- Digital ortho-imagery: 4-band multi-spectral ortho-imagery tiles with 30 cm pixel ground resolution, configured to display as 16-bit color-infrared and capable of being redisplayed as 16-bit natural color
- Final flight lines and any control stations used
- Mosaic lines used as part of the ortho-imagery creation process
- QA/QC report(s) on aerial photography capture and image processing
- Aerotriangulation report
- NSSDA Spatial Accuracy analysis report
- FGDC-compliant metadata
- Digital ortho-imagery final report

6 PROJECT ACCURACY STATEMENT

The spatial accuracy of the georeferenced imagery shall be 2 m or better at the 95% confidence level as computed in accordance with the FGDC National Standard for Spatial Data Accuracy (NSSDA). Fugro EarthData shall be responsible for collecting Independent Control Points and conducting the NSSDA spatial accuracy test. See attached report for accuracy details:

(Attachment-D_Coastal_CA_Ortho_NSSDA_Accuracy_Reports_090811.zip)

Compliance with the accuracy standard was ensured by the collection of ground control and the establishment of a GPS base station at the following airports: McClellan-Palomar, Oxnard, Monterey Peninsula, Hayward Executive, Charles M. Schulz - Sonoma County, Shelter Cove, Ukiah Municipal, Jack McNamara Field, Arcata, and Santa Maria Public. The following checks were performed:

- The digital ortho-imagery accuracy was validated by performing a full analytical bundle aerotriangulation adjustment and then checking it against the ground control prior to generating a digital surface model (DSM) or other products
- Digital ortho-imagery was validated through an inspection of edge matching and visual inspection for quality

The following methods were used to ensure digital ortho-imagery data accuracy:

- Use of a ground control network utilizing GPS survey techniques
- Use of airborne GPS and IMU during the acquisition of imagery
- Measurement of quality control ground survey points within the finished product

7 ATTACHMENTS

7.1 Attachment A: *Attachment-A Coastal_CA_Ortho_Flight_and_Control_Plans.zip*

7.2 Attachment B:

Attachement-B_E10-0041-00_CACoastalMapping_10MContour_Ortho_AcquisitionReport_011711.zip

7.3 Attachment C: *Attachment-C_ Coastal_CA_Ortho_Ground_Control_Report_122110.zip*

7.4 Attachment D: *Attachment-D_Coastal_CA_Ortho_NSSDA_Accuracy_Reports_090811.zip*