# Airborne Digital Sensor System and GPS-aided Inertial Technology for Direct Geopositioning in Rough Terrain

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Abstract

High-resolution airborne digital cameras with onboard data collection based on the Global Positioning System (GPS) and inertial navigation systems (INS) technology may offer a real-time means to gather accurate topographic map information by reducing ground control and eliminating aerial triangulation. Past evaluations of this integrated system over relatively flat terrain have proven successful. The author uses Emerge Digital Sensor System (DSS) combined with Applanix Corporation's Position and Orientation Solutions for Direct Georeferencing to examine the positional mapping accuracy in rough terrain. The positional accuracy documented in this study did not meet large-scale mapping requirements owing to an apparent system mechanical failure. Nonetheless, the findings yield important information on a new approach for mapping in Antarctica and other remote or inaccessible areas of the world.

## Introduction

Many earth science mapping applications, especially in remote areas like Antarctica, can function more efficiently and economically by reducing ground surveys. This is achieved by the direct geopositioning of the exterior orientation of a digital camera using an integrated system comprising a Global Positioning System (GPS) receiver and an inertial navigation systems (INS) component. The GPS produces precise positions that are subject to errors from loss of satellite lock and resolution of phase ambiguities. Information from the INS can correct these errors while the GPS data continuously calibrate with the INS. When used together, these components provide a viable solution to positioning and orientation problems in topographic mapping applications. Nevertheless, the use of this technology is not without technical problems. An understanding of the limits of this technology is critical for addressing photogrammetric mapping accuracy, scale, and consistency that an integrated system can achieve.

Numerous documented GPS/INS-related field tests have been conducted over the years (Cramer, 1999; Cramer, Stallmann, and Haala, 2000). These tests, flown over mostly flat terrain, were successfully evaluated by private and public institutions to meet National Mapping Accuracy Standards (NMAS) and American Society of Photogrammetry and Remote Sensing (ASPRS) accuracy standards for large-scale mapping. However, tests

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flown over steep terrain resulted in higher than normal vertical positional bias that did not meet accuracy standards for large-scale mapping (Cramer, 1999; Colomina, 1999; Greening and others, 2000; and, Sanchez and Hothem, 2002).
The objective of this study, funded by the National Science Foundation and the U.S. Geological Survey, is to validate the terrain-mapping accuracy of the Emerge Digital Sensor System (DSS) in an area of rapidly varying relief and its potential for mapping in Antarctica.

## Project Test Area

The Lees Ferry, Arizona, test area is in the southernmost part of Glen Canyon (figure 1). The marked change in relief of the Glen Canyon provides an excellent test for measuring the potential of the DSS for terrain mapping (figure 2).

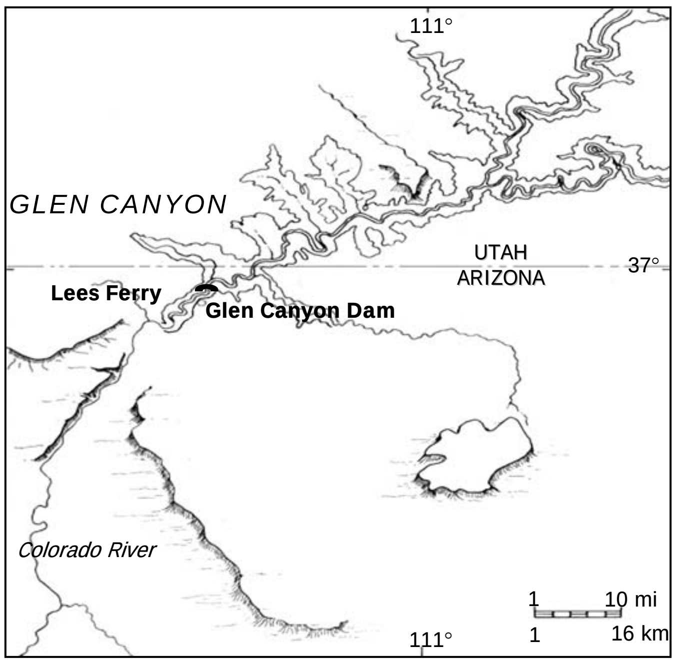


Figure 1. Project test area is located in Lees Ferry area.

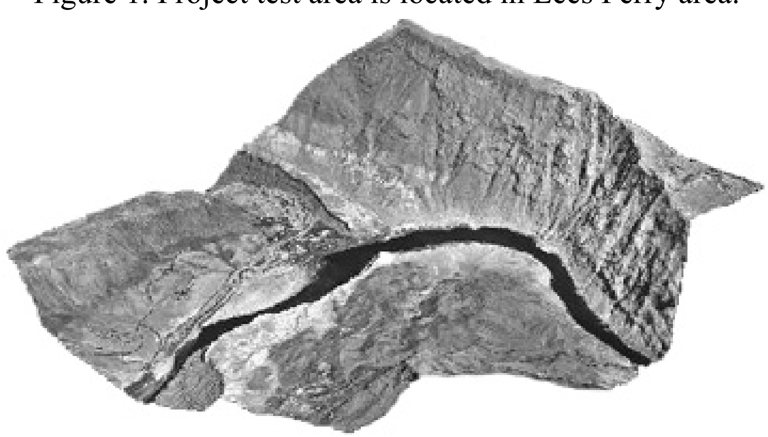

Figure 2. 3-D terrain relief depiction of Glen Canyon.

## System Configuration and Calibration

### *Sensor Configuration*

The commercial airborne integrated GPS/INS used in this project is the Emerge DSS and POS AV (Position and Orientation Solutions for Airborne Vehicles) 410 from Applanix Corp., Richmond Hill, Ontario, Canada. (In October 2003, Trimble, Applanix's parent company, acquired Emerge and its product design). The Emerge DSS is a medium format (4092 x 4079 pixels) sensor, Appendix A lists specifications of the DSS used in this study. The Applanix POS AV for Direct Georeferencing (DG) package includes four main components: (1) a dual-frequency L1/L2 carrier phase-embedded GPS receiver (NovAtel MiLLennium), (2) a POS Inertial Measurement Unit (Litton LR-86), (3) the POS computer system, and (4) the POSPac post-processing software. The National Geodetic Survey's (NGS) Continuous Operation Reference Station (CORS) in Flagstaff, Arizona, served as the base station *(http://www.ngs.noaa.gov/CORS/Arizona_fst1.htm1)*.

In addition, the author placed aerial panel points with documented horizontal and vertical coordinates along the flight corridor to test the accuracy of the position and height information. For the flight, the DSS and IMU are housed in an exoskeleton rigidly mounted to the port hole of a Cessna 172 aircraft and linked to the system computer. The GPS antenna is centered above the camera on top of the fuselage of the aircraft. Following the flight, the Applanix POSPac post-processing software computed the collected DSS raw data at the camera perspective center.

### *Boresight Calibration*

The spatial offsets between the different sensor components have to be identified to relate the position and orientation information provided by the GPS/IMU to the perspective center of the camera. "Boresight" components are the angular and linear misalignments between the POS IMU body frame and the imaging sensor. Before the actual fly-over of the Glen Canyon the boresight calibration occurred in a test flight over the Emerge test range in Florida. To resolve the boresight transformation, the Emerge staff compared the GPS/IMU positioning/orientation results with the aerial triangulation solution. The staff then used data from the POS/DG and aerial triangulation from the flight to resolve the fixed misalignment angles (omega, phi, kappa or $\omega$, $\Phi$, $\kappa$) between the IMU and the camera axes.

## Terrain Mapping

The Emerge aircraft carried out the overflight of the project area on July 21, 2003, at altitudes between 2,896 to 3,048 meters (9,500 to 10,000 ft). We applied the acquired misalignment angles from the boresight test flight to the POS/DG data. Then Applanix software computed the camera perspective center coordinates (in easting, northing, and elevation) and the camera orientation parameters (in angles $\omega$, $\Phi$, $\kappa$). Then the USGS applied the POS/DG-computed data at camera perspective center, as well as the camera's internal geometry and lens characteristics to geometrically correct the digital aerial frames using the Softcopy Exploitation Tool Set (Socet Set) software (Socet Set ® is a trademark of BAE Systems Solutions, Inc.).

### *Surveyed Reference Points*

To synchronize with the POS/DG data collection and to know the precise grid coordinate of any point in the project area, the author placed aerial panels along the corridor of the canyon before the over-flight. Many of these panels were placed over old survey markers.

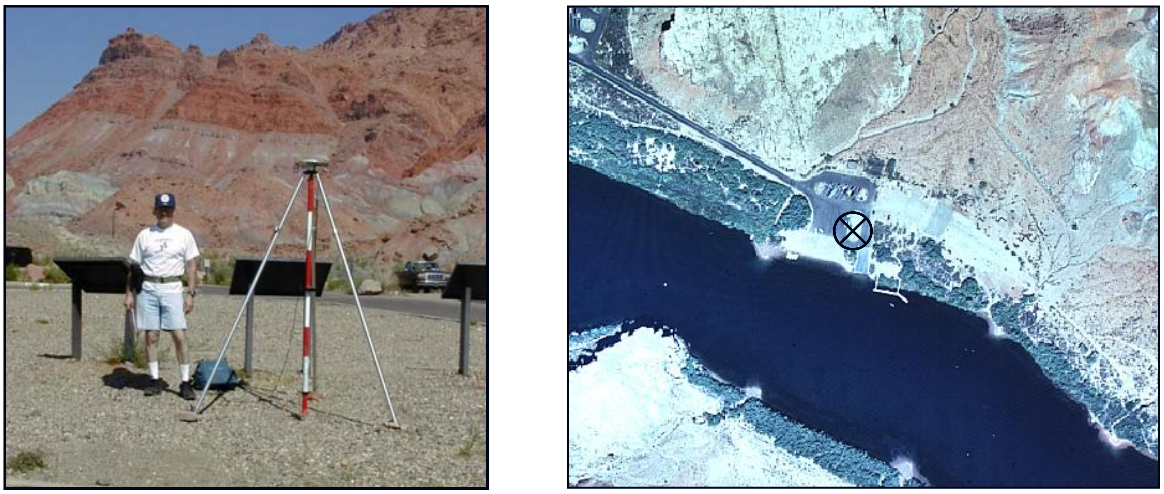

Figure 3. Validation of #212 aerial panel markers in Lees Ferry area

To validate the positional accuracy of the panels, we also conducted static surveys of these old monuments (see figure 3). The selected points were occupied for over 30 minutes and data logged at 5-second intervals using two Ashtech Z-12 receivers. We used traditional setup of the antenna over the survey marker in these static surveys. Downloaded GPS data from the NGS's Continuous Operating Reference Station (CORS) at Flagstaff (FST1) provided the known coordinates for the post-processing each of these monuments. For the post-processed geodetic coordinates and details about the survey markers within the vicinity of the Lees Ferry area, see appendix B.

### *Comparison with Survey Reference Points*

We examined absolute orientation using the horizontal and vertical coordinates of the visible panel point in the stereo models and the values of their corresponding surveyed reference positions. Then we measured the difference between the logged surveyed reference positions and corresponding panel points displayed in the stereoimage on the digital photogrammetric workstation. We determined the difference by subtracting the values of the panel point from the surveyed reference position. The measured panel point values in the stereoimage were roughly parallel to the ground level at an average vertical positional bias of +4.05 m. Table 1 show the results of the comparison of the panel point coordinates in the stereoimages against the values of the logged survey referenced positions.

| REF. NO | PANEL ID | d_Easting | d_Northing | d_Vertical |
|---|---|---|---|---|
| 1 | 211 | +4.04 | +1.34 | +3.92 |
| 2 | 212 | +3.17 | +1.44 | +4.67 |
| 3 | 214 | +3.08 | +1.38 | +3.56 |
| Average | | +3.43 m | +1.39 m | +4.05 m |

Table 1. The statistical difference or delta (e.g., d_Easting) between the ground-surveyed reference points and corresponding panel points measured on the digital photogrammetric workstation.

### Findings

The horizontal and vertical positional offset results of this study did not meet the sub-meter accuracy requirements set for large-scale mapping. Comparable but lower offset findings resulted using an RC-30 camera integrated GPS/inertial system in the same study area (Sanchez and Hothem, 2002).

Several factors may have contributed to the higher than normal positional offset between the coordinate values of surveyed reference points and corresponding aerial panel positions in the image. The most likely explanation is a system mechanical problem. All the same, the most demanding applications of large-scale airborne mapping, with mapping accuracies of 10- to 20-cm range, call for higher precision of the exterior orientation, which is largely dependent on the imaging sensor and flight altitude. In this study, we used a 55-mm calibrated focal length of the DSS and high-flying height of 2,896 to 3,048 meters (9,500 to 10,000 ft).

The 4-second cycle time of the Emerge 55-mm camera did not permit a suggested minimum of 1,000 m (3,300 ft) flight altitude which resulted in higher root mean square error values and a lower precision than desirable in large-scale mapping. Further, the aerial photographs flown separately for the boresight calibration at a lower flying height over flat terrain in Florida may have caused a shift in the Z value. No boresight test was flown in the Glen Canyon area either before or after the flight. A 1999 report (Grejner-Brzezinska, 1999) described in detail the influence of ground position errors resulting from imaging sensors and flight altitudes.

Several geodetic factors also may have contributed to the high RMS values in the exterior orientation solution. Because of the marked difference in canyon relief and changes in bedrock densities, there exists a “deflection of the vertical” (that is, an angle of departure of the gravity vector from the corresponding ellipsoidal normal). In the canyon area where there are marked geoidal undulations, the separation between the geoid and ellipsoid can vary rapidly in a nonlinear manner over distance.

## Recommendations

Although these slightly higher than normal positional offsets in rough terrain do not meet large-scale mapping accuracy standards, it is important to note the limits of any airborne mapping camera and balance the criteria for its use against practical considerations of large-scale mapping in Antarctica. The DSS's relative positional offset (averaging 1-4 m) is far outweighed by its benefits, that is, quick and cost-effective means to gather topographic map information without ground control or aerial triangulation. The DSS planned refinements in 2004 such as improvement in the imaging camera cycling time to 2.5 seconds and output of POSEO useable in SOCET Set should result in lower RMS values, higher precision large-scale mapping, and faster processing time. With these upcoming refinements, we recommend that another test be flown to rule out any system mechanical error. In addition, boresight tests should be flown in the project area before and after the flight. This remeasure of the terrain mapping accuracy is essential to determine whether the DSS can be successfully deployed in Antarctica to exploit the benefits of near real-time mapping. After this report's completion of this report, Applanix-Emerge agreed to refly the DSS over the San Andreas and Cucamonga fault corridors near the foothills of the San Bernardino Mountains, California. These particular fault corridors were in the path of the wildfires of October 2003. The bare ground left behind and varying relief of these fault corridors will provide a good test of GPS-aided inertial technology and navigation-base photogrammetry for terrain mapping, as well as furnish vital information to the USGS Earthquake Hazards Program.

## Acknowledgments

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APPENDIX A

## APPLANIX-EMERGE DSS SPECIFICATIONS FOR GLEN CANYON FLIGHT

Aerial Platform

| | | | |
|---|---|---|---|
| Type aircraft: | Cessna 182 | Ground velocity: | 90-120 mph |
| Altitude: | 3,000+ m | Photo date: | 7/21/03 |

Imaging Camera

| | |
|---|---|
| Type camera: | Contax/Megavision-Emerge |
| Lens type: | Zeiss |
| Focal length: | 54.9849 mm |
| Frame/format Size: | Size X = 36.83 mm Size Y = 36.70 mm |
| Solid State CCD, full frame: | X = 4,092 pixels x Y = 4,077 pixels |
| Pixels per frame: | 16,683,084 |
| Pixel spacing: | 9 microns, center to center |
| Pixel size: | 9 x 9 microns (X = 0.009 mm x Y = 0.009 mm) |
| GSD: | 37 cm |
| Cycle time: | 4 seconds |

| | | | |
|---|---|---|---|
| File Size: | CIR 650 mb | Coordinate System: | UTM |
| Format: | TIFF | Zone: | 12 |
| Datum: | NAD 83 | Units: | meters |

APPENDIX B

## FIELD RECORD SUMMARY – GLEN CANYON

| SITE NAME | COORDINATES[1] | SURVEY MARKER | STAMP MARKING |
|---|---|---|---|
| GCP 6BC | LAT: 36° 52' 28.668" N.<br>LON: 111° 33' 27.783" W.<br>ELLIP. HT: 939.401 meters<br>MSL: 962.824 meters | 92.5 mm in diameter brass survey marker | BUREAU OF RECLAMATION |
| GCP 211 | LAT: 36° 51' 48.143" N.<br>LON: 111° 34' 37.317" W.<br>ELLIP. HT: 936.652 meters<br>MSL: 960.055 meters | 92.5 mm in diameter brass survey marker | U.S. COAST & GEODETIC SURVEY |
| GCP 212 | LAT: 36° 51' 57.560" N.<br>LON: 111° 35' 12.314" W.<br>ELLIP. HT: 930.269 meters<br>MSL: 953.664 meters | 60 mm in diameter aluminum survey marker | BANNER INC. |
| GCP 214 | LAT: 36° 51' 48.236" N.<br>LON: 111° 35' 55.438" W.<br>ELLIP. HT: 939.976 meters<br>MSL: 963.352 meters | 12.7 mm in diameter unthreaded rebar | NO STAMP MARKING |
| GCP 114 | LAT: 36° 53' 11.180" N.<br>LON: 111° 31' 51.770" W.<br>ELLIP. HT: 951.340 meters<br>MSL: 977.784 meters | 92.5 mm in diameter brass survey marker | BUREAU OF RECLAMATION |
| GCP 115 | LAT: 36° 53' 10.410" N.<br>LON: 111° 31' 10.301" W.<br>ELLIP. HT: 947.940 meters<br>MSL: 971.383 meters | No survey marker; X 10x10 Bldr RL 9- mile | NO STAMP MARKING |
| GCP G307B | LAT: 36° 52' 28.890" N.<br>LON: 111° 34' 00.980" W.<br>ELLIP. HT: 935.380 meters<br>MSL: 958.799 meters | No survey marker; photo location RL | NO STAMP MARKING |

[1] NAD83/GRS80; mean sea level (MSL) heights derived from NAVD88 values (NAD83+Geoid99)