PHOTOGRAMMETRIC RESECTION DIFFERENCES BASED ON LABORATORY vs. OPERATIONAL CALIBRATIONS

Dean C. MERCHANT
Topo Photo Inc.
Columbus, Ohio USA
merchant.2@osu.edu

KEY WORDS: Photogrammetry, Calibration, GPS, Resection

ABSTRACT

Combinations of airborne sensors, including photogrammetric cameras, Global Positioning System and others, give rise to need for system calibration. This paper discusses results of comparisons of GPS to photogrammetrically resected camera station coordinates obtained by both laboratory and *in situ* calibrations. Systematic influences produced by the aerial environment on the resected elevations were found to produce errors as much as one part in 730 of the flight height above ground for the open-ported aerial system.

1. INTRODUCTION

Recent interests in combining camera imagery measurements with information from additional sensors for photogrammetric purposes has led to concern about systematic spatial or orientational errors relating the camera to the object space and to the added sensors. One of these concerns is the role played by calibration in relating the camera exposure station coordinates to those provided by the Global Positioning System (GPS).

This paper presents comparisons of camera station coordinates obtained from photography at typical mission altitudes ranging between 1200 to 5800 meters over a test range to those obtained by GPS. The comparison is done for resections based both on imagery corrected by laboratory and by *in situ* [operational] calibration results. Each photograph tested contained a large series of well-distributed images of targets. All targets were related by GPS ground surveys to a three-dimensional accuracy of better than 2 cm. The GPS base station during all flights was located within ten kilometers of exposure stations.

Results indicate a strong influence of the systematic error in those applications using a conventional laboratory based calibration. Operational camera calibrations based on in-flight imagery demonstrated substantially smaller bias errors in elevation. A typical bias between laboratory based resected results and GPS elevations for flights in an open-ported aircraft at 1245 meters above ground elevation was 1.7 meters. For the flight altitude, this represents a systematic error of one part in 730 of the flight height, a value equal to at least an order of magnitude greater than experienced when conventional ground control methods are used to control the photogrammetric process. Real data examples from both pressurized and un-pressurized aircraft are presented.

2. BACKGROUND

It has long been recognized that an environmental influence exists in the metric characteristics of the aerial photogrammetric system. Duane Brown [1969] demonstrated an order of magnitude improvement in spatial accuracies by applying the bundle block adjustment with self-calibration to film-based images obtained by the United States Air Force (USAF) USQ-28 system flying at 6100 meters over the McClure test range in Ohio. This *in situ* approach to calibration clearly demonstrated the existence of systematic influences due to environment.

Brown's results, approaching one part in 300,000 of the flight height, motivated a second experiment that was conducted by the USAF using a Zeiss RMK-AR 15/23 camera [Merchant, 1974]. In this experiment, Mt. Graham in eastern Arizona provided a significant depth of control field to permit separation of the linear elements of interior from exterior orientation. From a flight height of about 3050 meters above the base of Mt. Graham, points with an elevation difference of 915 meters were imaged on a single photo. This imagery, combined with imagery from the more dense range at Casa Grande, Arizona, provided sufficient information for conducting a self-calibration adjustment. The results of this *in situ* calibration made it possible to compare exposure station coordinates based on a standard laboratory to an *in situ* calibration. A series of single photo resections were computed by using both calibration results. The differences in exposure station coordinates were large, particularly in elevation, signifying again the contributions made by the environment to the aerial photogrammetric measurement process. Differences of 6 meters in resected elevation for the same photograph was not unusual.

With the advent of the Global Positioning System (GPS) to provide exposure station position, and affordable inertial systems to provide orientation, the logical trend has been to rely on these devices to supplement or replace the need for ground control. The ideal application of airborne GPS as control should, in theory, permit a complete and adequate solution for a photogrammetric block without need for ground control other than for checking and quality control purposes. Current experience in practice seems to indicate that ground control, at least in the corners of the block, is still required. Perhaps this could have been predicted from the Mt Graham/Casa Grande experiment.

The following discussions describe experiments and results of comparisons of resected exposure stations based on *in situ* and laboratory (conventional) camera calibrations.

3. OPERATIONAL EXPERIMENTS

The primary objective during this investigation is to measure the differences in photogrammetrically determined exposure station coordinates based on both *in situ* and laboratory camera calibrations to corresponding coordinates determined by GPS. For these experiments the Trimble 4000 GPS receivers were used. Appropriate atmospheric models were used in all cases for alteration of the images. The magnitude of differences between the photogrammetric and the GPS coordinate values provides insight into the adequacy of the two methods of calibration.

Since GPS is used here as a standard of comparison, it is necessary to assure that GPS itself is not a significant contributor to the coordinate differences. Discussions with GPS specialists gave assurance that for these short distances to the base station and these small altitude differences, the error contribution by GPS is probably negligible.

3.1 THE MADISON TEST FIELD

The Madison Calibration Range [low altitude] is located a few miles north of London, Ohio. It was established and is maintained by the Ohio Department of Transportation for the calibration and test of its own and contractor's airborne photogrammetric systems.

The range consists of 102 targeted points located within a rectangular region 2.25 km east to west and 1.80 km north to south. Assuming a conventional 15/23 mapping camera, and allowing for a 10% navigational error, photography is normally acquired at 1370 meters above ground level. This assures a wide distribution of imagery for calibration purposes. The targets consist of flat white circles 0.80 meters in diameter centered on flat black circles 2.4 meters in diameter.

For purposes of *in situ* calibration and test of airborne digital cameras, a portion of the targets are distributed radially from a four-way road intersection beginning with a separation of only 20 meters. The interval is increased radially by the cube root of two to provide adequate distribution density for the narrow field angles typical of today's digital cameras.

The range was surveyed by GPS methods and adjusted. Three bracketing high accuracy [HARN-NAD83 (1995)] stations were held fixed, including MAD1, the ground base station used during airborne GPS operations. For purposes of this investigation, in order to preclude any possible significant contribution due to knowledge of geoidal undulations, the coordinates of all stations were transformed into a local three-dimensional rectangular system with origin at MAD1 plus offsets. Standard deviations after adjustment indicated that the easterly and westerly components of error were less than 0.008 meters and elevation less than 0.017 meters.

3.2 TIME/SPACE OFFSET MEASUREMENTS

Coordinate differences between the GPS antenna phase center and the center of the entrance pupil of the camera lens (entrance nodal point), in a coordinate system parallel to the photo coordinate system, are defined as the “spatial offsets”. These offsets were determined for the systems investigated here by the following procedure. First, the nominal pitch attitude during flight was re-established on the ground and the aircraft stabilized. The camera was then leveled and the swing set to zero. A simple laser device, oriented to vertical, was then located below the camera and adjusted to point at the center of the aperture of the camera lens. This position was marked on the pavement and subsequently located by GPS methods. This provided the local rectangular horizontal coordinates of the camera entrance node. For the vertical component, the vertical distance was measured to a tangible point on the camera which was related in distance to the entrance pupil. This distance was supplied by the camera manufacturer. These measurements provided some components of the vertical spatial offsets. With the aircraft stabilized, GPS observations were made by the aircraft system thereby provided coordinates of the aircraft antenna phase center. Provided the spatial offsets in the horizontal were within a few centimeters, the differences between the phase center and the entrance node were measured and provide the spatial offsets to within a few millimeters in a nominal operational environment.

The offset in time was the difference in time between the event mark generated by the camera and the effective time of exposure. Modern cameras provide event markers as an electronic pulse at the mid-point of open shutter. Other cameras can be so equipped. For purposes of this investigation, the effective time of the event mark was measured by a device placed in the plane of focus and measured the first and last point of light to an accuracy of about ten micro-seconds.

3.3 OHIO DEPARTMENT OF TRANSPORTATION EXPERIENCES [ODOT]

ODOT has long been interested in calibration and test of their airborne photogrammetric systems. The first test field was established in the late 1970s and at the time of this investigation consisted of three fields located in Ohio. The first is for low altitude missions and is flown at 1370 meters above ground, the second is for mid-altitude applications and is flown at 3000 meters, and the third is for high-altitude applications and is flown at 6100 meters above ground.

The aircraft used by ODOT is a light, twin engine, open ported, Partenavia “Observer” and is shown in Figure 1. The camera is a Zeiss LMK 15/23 on a stabilized mount. Approximately 40 well-distributed target images appear on each photo.

Figure 1. ODOT Open Photo Port Partenavia Preparing to Fly the Madison Ranges

3.3.1 LOW-ALTITUDE INVESTIGATION

Results of the low altitude investigation shown in Table 1. are in terms of comparisons of exposure station coordinates determined by GPS to those determined by single photo resection (SPR) based on *in situ* and on laboratory calibrations. For details see Merchant [1996].

		EAST		**NORTH**		**UP**	
		in situ	**lab**	**in situ**	**lab**	**in situ**	**lab**
bias		0.033	0.045	-0.015	-0.028	0.004	1.671
std. dev.	about mean	0.064	0.094	0.038	0.105	0.051	0.044
std. dev.	about GPS	0.073	0.106	0.041	0.109	0.051	1.805

Table 1. Coordinate Discrepancies Between GPS and Single-Photo Resections Based on *In Situ* and Laboratory Calibrations for Seven Photos at 1245 Meters Above the Ground [meters]

3.3.2 MID-ALTITUDE INVESTIGATION

The same aircraft and camera system were next flown over the mid-altitude range . Results of exposure station comparisons are shown in Table 2. For details, see Merchant [1997].

		EAST		**NORTH**		**UP**	
		in situ	**lab**	**in situ**	**lab**	**in situ**	**lab**
bias		0.125	0.096	0.015	0.016	-0.005	1.417
std. dev. .	about mean	0.148	0.152	0.177	0.185	0.065	0.073
std. dev.	about GPS	0.198	0.183	0.177	0.186	0.065	1.505

Table 2. Coordinate Discrepancies Between GPS and Single-Photo Resection Based on *In Situ* and Laboratory Calibrations for Nine Photos at 3070 Meters Above Ground [meters]

3.4 NATIONAL GEODETIC SURVEY EXPERIENCE [NGS]

The NGS of the National Ocean and Atmosphere Agency [NOAA] has also conducted *in situ* calibration tests in cooperation with the United States Geological Survey [USGS]. See Merchant (1995). In this case, a pressurized twin jet Cessna Citation aircraft and a Wild RC-20 15/23 camera were used. This aircraft is pictured in Figure 2.

For this experiment, the aircraft was flown at 5800 meters above the ground and cabin pressure was maintained equivalent to that of 2000 meters. Between 10 and 14 widely spaced target images appear on each photo. Results of comparisons of exposure station coordinates is provided in Table 3.


Figure 2. The NOAA Pressurized Cessna Citation Preparing to Fly the Madison Ranges

		EAST		**NORTH**		**UP**	
		in situ	**lab**	**in situ**	**lab**	**in situ**	**lab**
bias		-0.150	-0.123	-0.265	-0.051	0.020	0.806
std. dev.	about mean	0.324	0.648	0.337	1.145	0.119	0.229
std. dev.	about GPS	0.367	0.663	0.455	1.146	0.121	0.958

Table 3. Coordinate Discrepancies Between GPS and Single-Photo Resections Based on *In Situ* and Laboratory Calibrations for Four Photos at 5800 Meters Above Ground [meters]

4. CONCLUSION

This investigation is intended to assess the influence of the operational environment on spatial coordinates computed photogrammetrically to those determined by GPS. For this purpose, single photo resected coordinates from *in situ* calibrations were compared to laboratory based calibrations. All data was based on imagery collected over controlled test ranges and under operational circumstances. Both ported and pressurized aircraft were investigated. Bias errors in elevation of 1.6 meters correspnding to one part in 730 of the flight height were observed.

It is concluded that calibrations based on data from operational conditions are subject to substantially smaller systematic error than those based on traditional laboratory methods.

Further investigations are warranted to clearly identify causes of this bias that is primarily in elevation. It is further concluded that environmental factors play a strong role in the calibration of added airborne sensors and the relative spatial relationships within any airborne system of sensors.

ACKNOWLEDGMENTS

Many individuals made important contributions during the course of this investigation. At ODOT, of particular note are James Crowl, Ed Kroman and Milan Kofron for their enthusiasm and continued support. The direct involvement and interest of Capt. Lewis Lapine and James Lucas [NGS] and Donald Light [USGS], made the high-altitude project possible and enjoyable.

REFERENCES

Brown, D. C. , (1969), “Advanced Methods for the Calibration of Metric Cameras”, presented at the Symposium on Computational Photogrammetry, SUNY, Syracuse University, New York, January 1969

Merchant, D. C., (1974), “ Calibration of the Air Photo System”, Photogrammetric Engineering, pp 605-617, May 1974

Merchant, D.C., (1995), “Testing Calibrations in Application to Airborne GPS Controlled Photogrammetry”, Final Report for National Mapping Division, USGS, Reston, VA. March 28, 1995

Merchant, D.C., (1996), “Development of Airborne GPS Photogrammetry for Use by the Bureau of Aerial Engineering - ODOT”, Final Report FHWA/OH-97/004 for Ohio Department of Transportation, December 6, 1996

Merchant, D.C., (1997), “Development of Airborne GPS Control for Medium Scale Photogrammetry”, Final Report FHWA/OH-97-006 for Ohio Department of Transportation, June 18, 1997