INTEGRATION OF GPS AND PHOTOGRAMMETRY REDUCES FLYING STRIPS IN HIGHWAY MAPPING

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ABSTRACT: Using Kinematic GPS procedures with analytical photogrammetry enabled successful reduction in number of flying strips required for control densification in highway mapping. Ground control was established by GPS methods. Two test areas were selected. Three flight strips were flown as usual on two different days. GPS receivers were used in the airplane and on ground. Photogrammetric mensuration was done on the analytical plotter. Bundle adjustment program was used to process data. Single and multiple strips were processed separately. The results were statistically analyzed. The output from single flight proved more accurate and economical. Our tests in integrating GPS and photogrammetry showed significant benefit in precision and accuracy well in excess of the existing standards.

KEY WORDS:

Aerotriangulation, GPS, Integrated System, Photogrammetry, Mapping.

INTRODUCTION

Photogrammetric mapping based on field control has in the past been bedrock for highway mapping. This field control was required for aircraft navigation and for the identification of control points on the aerial photograph. For each strip of photographs, it necessitated setting up panels at many short intervals along the highway. This is a slow, costly and often dangerous process.

In an attempt to save money in the generation of control points in 1986, the Texas Department of Transportation (TxDOT) instituted a pilot project to test the newly developed concept of deploying a Global Positioning System (GPS) receiver in an airplane. This project was a joint venture between TxDOT, National Geodetic Service (NGS)/NOAA and Applied Research Laboratory, University of Texas (ARL:UT) Austin Texas. For this joint project, several aerial GPS missions based on two Texas sites were flown and data collected. In addition, TxDOT independently applied data collected on aerial GPS missions to several productions projects. This paper describes the various steps involved in the process and lists the results of accuracy repeatability tests for years 1990-1991.

The objective of the project was to conduct a feasibility experiment to determine whether a GPS receiver in an airplane can be used to provide precise positioning of aerial camera. The second objective was to gain first hand experience and an early access to the software developed for this new technology. These objectives have been realized and findings have been reported periodically, as the project was developing. However, it was desired that a statistical analysis be conducted to examine the quantitative differences between the outputs from GPS control and ground Control used in the Aerial Triangulation. The objective of this study is to present the results of the statistical analysis

METHODS

The hardware components of the GPS system includes a GPS receiver and antenna, data storage media and power connectors. There are hook ups to laptop and a display unit. The other components included an airplane, Wild RC 20 camera and a photo event timer port, to relate camera exposure to the GPS event times. A realtime radio link is also on board to receive differential position corrections. A GPS antenna is mounted on the top of the aircraft body. The structure of the aircraft does not permit the antenna to be mounted vertically above the camera. However, consideration is given to the location that incoming GPS signal is not in any way obstructed by any part of the airplane. A second airborne GPS receiver is kept in the airplane for navigation purpose. A radio signal is utilized to transmit the differential corrections from the static station set up in the project area. The laptop computer executes a program and computes the positions of the desired points. Several wayside points are input to the program and a navigation output is displayed on a display unit. The output from the navigation utility consists of azimuth, latitude, longitude, offset from the approaching point, and a velocity vector. Also indicated are distance to be traveled and time to be flown. The hardware and equipment are shown in figure 1.

FLYING PROCEDURE

An airborne GPS mission began with moving the airplane into a position at the airport. A reference point is established at the airport in advance. Usually the reference point is located in one corner of the flying strip to avoid any interference with the flying of aircrafts. The indexing of the airborne antenna of the aircraft is done by setting up an index point vertically below the antenna. The offset between the index point and the airborne antenna is measured in east, west and up components. The height of the instrument at the reference point is also measured and recorded.

Once the aircraft has been positioned both receivers begin tracking four selected satellites and attempt to acquire as many as desired in the mission plan chart. After about five minutes receivers are switched from one minute to a one second recording rate. The tracking loop bandwidth is expanded to the 16 HZ used for kinematic GPS applications. About 5 minutes of data is recorded before the plane takes off. A minimum elevation angle of 20 degrees is selected for all satellites. A satellite window with a Geometric Dilution of Precision (GDOP) value of 5 or less is selected.

During flight the camera is leveled and then locked before the first flight strip. It is done to maintain a fixed relationship with the aircraft orientation.

A forward overlap of 70 to 80 percent is planned when camera is kept locked up to avoid any gaps in the stereopair. Flying height in highway mapping is usually 500 meters which provides a photo scale of 1:3000. Three flight strips are flown over a highway tangent and a side overlap of 60 percent is maintained.

On completion of the mission, the airplane returns to the airport. The pilot limits the angle of decent during landing at the airport. After landing the plane returns to the index point and the same procedure is followed for recording the offset of the antenna from the new index mark. About 5 minutes of data is further collected again while the plane is stationary. This additional data is used to check for systematic drifts or biases in the GPS solutions.

Diapositives are developed and analytical plotter is used to measure photogrammetric data. The operators observe all stereopairs of the three strips. Well defined pass points are selected along the Y-axis. The ground control points, which are targeted are also observed in all three strips.

Eight fiducial points are measured in each frame and this data is used in an eight parameter general affine transformation to remove film distortions.

Thirteen control points were established as ground truth to evaluate the differences between the single strip and a block of three strips. Four points had horizontal and vertical coordinates and nine were only elevation points.

All the four points were observed by GPS relative positioning procedures and the 9 elevation points were spirit leveled and adjusted.

DATA PROCESSING

GPS data was processed using OMNI, a software developed by Dr. G. L. Maider of NGS/NOAA. The initial position of the airborne antenna, the Geocentric Cartesian coordinates of the index point, corrected for offset and height of the antenna, is an input to OMNI program and is enforced on the solution. The airborne antenna's terminal position is also known and should agree with the coordinate obtained from the solution. The output from OMNI consists of time, X,Y, Z coordinates. The file is an output to the analytical bundle adjustment program.

GPS assisted Photogrammetry Package (GAPP) written by Jim Lucas, NGS/NOAA was used to process the analytic Photogrammetric data. The final output from this program is the precise camera positions, including camera orientation parameters and ground control position of all points observed in the photogrammetric mensuration. The SAS system, a software package for data analysis was used to analyze the data. The null hypothesis was tested and the Univariate procedure were used.

DESIGN OF EXPERIMENTS

The main interest of this work was to compare the difference between 3-D coordinates of point on ground derived from a single strip and combined three strips. The statistical analysis in the experiment was performed assuming that sampling is done from two normal populations with different means but identical variances. The experiment was designed to assess the statistical accuracy of the flight strip by obtaining coordinates through aerotriangulation process.

The experiment was developed to minimize errors caused by photographic processing, operator, instrument and type of ground coordinates. A completely randomized block model was defined with a single and three combined strips, sizable ground control points, 39 and 52 respectively, type of control GPS and ground control, for a given day. The experiment was repeated on another day from a different site.

Using the data from the two samples, single strip and combined three strips, a comparison was made between the population means of Eastings, Northings, and Elevations of all control points. In particular we made an estimate and test of an hypothesis concerning the difference of the means. A logical point estimate for the difference in populations means the sample difference of $\bar{y}1-\bar{y}2$. The mathematical model is shown in equations 1 through 4.

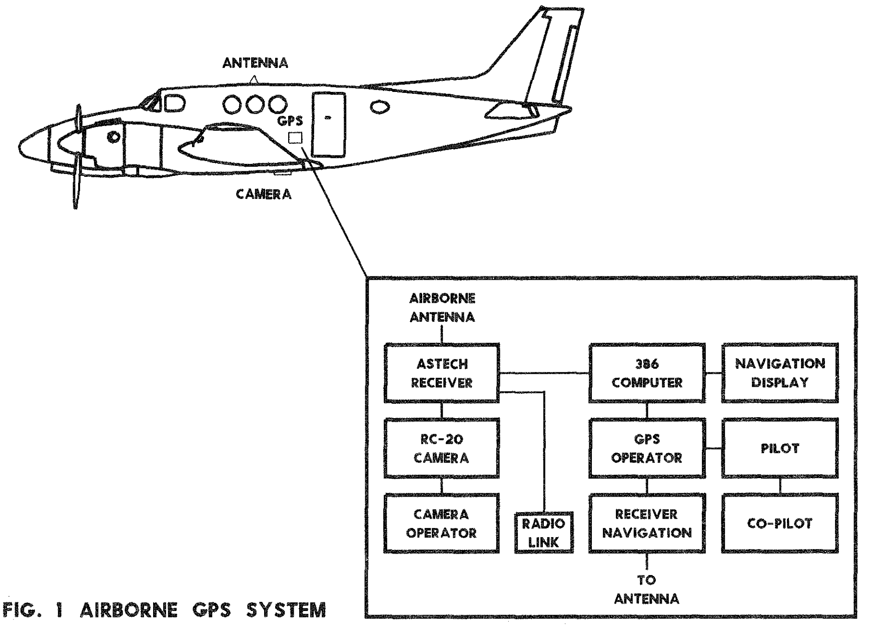

FIG. 1 AIRBORNE GPS SYSTEM

Let us specify that the difference U1 - U2 = DO where DO = 0.0

Then null hypothesis,
HO: $\bar{Y}1-\bar{Y}2 = 0$ (1)

Alternate hypothesis Ha,
Ha: $\bar{Y}1-\bar{Y}2 \neq 0.0$ (2)

Test statistics (T.S.),

T.S.: t = $(\bar{Y}1 - \bar{Y}2 - DO)/$
S*SQRT (1/n + 1/n2) (3)

Rejection Region (R.R.),

R.R.: For type I error , and df= n1 + n2 - 2

Reject Ha if t > t a (4)

where

S = an estimate of the standard deviation of two populations and is formed by combining information from the two samples.

n1, n2 = number of observations in samples
df = degree of freedom

For Day 241 the hypothesis,
HO= .0090 = 0.0

Ha: $\bar{y}_1 - \bar{y}_2 \neq 0.0$

T.S.: t = 0.0002

R. R.: For ta = .05 the critical value for a one tailed test with df = 76, is = 1.645

Since t (0.0002) is not greater than ta (1.645) therefore we accept null hypothesis and conclude that there is no significant difference between the Eastings coordinates of a control point obtained from single strip and combined three strips.

The conclusions are similar in respect of Northings and Elevations for GPS and Ground control samples referred in tables 1 to 4.

TABLE 1. Results of the Statistical Test concerning the difference between two GPS, data population means, containing single strip and three strips with identical variances of day 241.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
1 Strip						
GREAST	39	1021231.167	200.519	1020829.035	1021615.448	32.109
GRNORTH	39	3137314.673	535.945	3136306.253	3138079.284	85.820
GRELEV	39	123.540	1.723	119.628	126.277	0.276
3 Strips						
GREAST	39	1021231.158	200.534	1020828.923	1021615.393	32.111
GRNORTH	39	3137314.688	535.900	3136306.335	3138079.220	85.813
GRELEV	39	123.540	1.719	119.628	126.372	0.275

TABLE 2. Results of the Statistical Test concerning the difference between two ground data population means, the single strip and three strips with identical variances of day 241.

Variable	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
1 Strip						
GREAST	39	1021231.187	200.4936	1020829.155	1021615.444	32.1047
GRNORTH	39	3137314.698	535.9318	3136306.344	3138079.299	85.8178
GRELEV	39	123.538	1.7307	119.610	126.273	0.2771
3 Strips						
GREAST	39	1021231.221	200.4634	1020829.262	1021615.364	32.0998
GRNORTH	39	3137314.702	535.9318	3136306.378	3138079.252	85.8165
GRELEV	39	123.543	1.7307	119.593	126.342	0.2771

TABLE 3. Results of the Statistical Test concerning the difference between two ground data population means, single strip and three strips with identical variances of day 192.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
Strip 1						
GREAST	52	390203.313	519.7004	389183.229	391157.243	72.0695
GRNORTH	52	5253260.376	678.7267	5251998.872	5254496.995	94.1225
GRELEV	52	21.463	1.9509	15.684	23.729	0.2705
3 Strips						
GREAST	52	390203.309	519.6922	389183.180	391157.240	72.0683
GRNORTH	52	5253260.377	678.7336	5251998.747	5254497.016	94.1234
GRELEV	52	21.462	1.9600	15.581	23.741	0.2718

TABLE 4 results of the Statistical Test concerning the difference between two GPS data populations means, single strip and combined three strips with identical variances.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
1 Strip						
GREAST	52	390203.317	519.6848	389183.198	391157.226	72.0673
GRNORTH	52	5253260.360	678.7118	525998.830	5254496.949	94.1204
GRELEV	52	21.443	1.9586	15.578	23.791	0.2716
3 Strips						
GREAST	52	390203.349	519.6889	389183.207	391157.266	72.0679
GRNORTH	52	5253260.356	678.6995	5251998.761	5254496.924	94.1187
GRELEV	52	21.444	1.9628	15.498	222223.731	0.2722

RESULTS AND DISCUSSION

The value of the Test Statistics from Statistical Tables for a = .05, at 95 ./. level is given by percentage points of the t distribution. The tables 1 to 4 contain a set of two populations. These are single strip and combined three strips. The Test Statistic is 1.645. When compared with computed t value it showed that there is no significant difference between coordinates of a control point obtained from these four types of data sets. In all four data sets the accuracy of the Easting, Northing and Elevation as individual components of a control point was identical. The quality of the control from a single strip was as accurate as obtained from flying three flight strips.

CONCLUSIONS

In highway mapping the aerial photography flown by a single strip instead of 3 strips provides the control with the same accuracy and eliminates two strips. The errors due to poor geometry and propagation of errors are eliminated. The highway engineering map is a narrow strip which is usually within two inches from the nadir point of air photograph. Errors due to tilt, tip and swing are minimal at such a central narrow band. The adjustment errors of a single strip are contained and restricted by a few ground points. All these add up to improve the output of coordinates from a single strip. It is economical to fly single strip and be more accurate.

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