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DEVELOPMENT OF AERIAL PHOTOGRAMMETRIC NAVIGATION BY GPS

FINAL REPORT

Sponsored by
Ohio Department of Transportation
and
US Department of transportation, FHWA

Report No.FHWA/OH-98/001

By

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October 24, 1997

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Executive Summary Report

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At the conclusion of the program, the photo-nav equipment was installed in the ODOT Partenavia aircraft and demonstrated. The final report includes the objectives of the program and descriptions of hardware, software, and results.

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16. Abstract

Airborne GPS methods have been developed at the National Geodetic Survey (NGS) to facilitate all aspects of photo-navigation for collection of photography for photogrammetric purposes. The objective of this research was to implement a similar photo-nav system for ODOT, tailored to the larger scale characteristics of the ODOT photo missions. Drawing on these developments, the ODOT photogrammetric system, which includes a geodetic quality airborne GPS receiver, was augmented with a laptop computer and supporting devices to provide the photo-navigator with full view and control over the various system components. Software developments facilitated the office flight-planning phase, the field operations, and subsequent download processing of data.

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It is my pleasure to acknowledge the support offered by the personnel of the ODOT Office of Aerial Engineering during the course of development of the airborne GPS-controlled photo-nav system. Of particular note is the enthusiasm and contributions of Mr. Ed Kroman, the ODOT photo-navigator.

In addition, Cmdr. Pete Conners and LtCmdr. Jon Bailey were helpful and supportive in demonstrating hardware and software components of the NGS photo-nav system.

Contributions of both ODOT and NGS personnel are recognized and appreciated.

DEVELOPMENT OF AERIAL PHOTOGRAMMETRIC NAVIGATION BY GPS

1. INTRODUCTION

Recent advances in airborne photogrammetry are due primarily to the introduction of digital methods and the advent of The US Department of Defense's Global Positioning System (GPS). Geodetic control, required to link the map to the ground, can now be provided during the flight mission to accuracies approaching one part in 18,000 of the flight height [Merchant, 1997]. Such high accuracies can only be achieved by post-processing the data. As a consequence the result is not available for purposes of navigating the photo aircraft to assure the planned photographic coverage. However, spatial accuracies better than 100 meters is available in real time and may serve for purposes of navigation. Higher accuracies, if required, can be obtained in real time if required. The added accuracy is achieved by broadcasting correction (RTCM) information from a ground-based station or eventually directly from commercial satellites.

The National Geodetic Survey (NGS) pioneered in the development of a GPS based airborne photo navigation system to meet operational requirements (P. Conners 1993). Navigation messages generated by the GPS receiver were presented graphically superimposed on a topographic background. This graphical information along with altitude and "geographic dilution of precision" (PDOP) was displayed by an airborne computer and updated at one second intervals. Additional real time information was displayed by the GPS receiver to efficiently aid in directing the aircraft.

It was the success of the NGS photo navigation system that served as motivation for development of a similar system to meet ODOT requirements.

This report presents the approach taken to implement an airborne photo-navigation system for ODOT, results of the development, and recommendations.

2. RESEARCH OBJECTIVE

Objective of the research and development is to provide an integrated GPS, computer based system for providing real time, photo navigation information for low altitude photographic missions. Provisions will also be made to facilitate mission planning and waypoint uploading to the airborne computer.

3. GENERAL APPROACH

Initially, a meeting was held with NGS personnel associated with the development and use of their successful high-altitude photo navigation system. Their hardware consisted of a portable 386 computer with an optical disk drive and a Trimble SSE GPS receiver with appropriate interfaces for power and antenna. A bench demonstration was given by NGS using software developed to use Delorme's Mapping System.

3.1 Hardware

Using the NGS system as a guide, and taking advantage of the rapid rate of technology development in the computer field, a "lap-top" computer produced by WinBook, Model XP was obtained. The computer uses a 486 CPU running at 100 mega-Hertz. However, an optical disk drive was required. An external drive was used initially but subsequently replaced by a docking station equipped with an optical drive.

The GPS receiver adopted for aerial collection by ODOT is the Trimble 4000 SSE. Added capability includes a one pulse per second output signal for coordinating external events, an external event marker for recording external signals with GPS internal records of time, provisions for output of navigation, and position messages. This equipment is normally operated at a one second collection rate and a ten degree mask angle.

Power requirements for both the computer and receiver are met by a gel-cell battery (30 amp/hour) and a DC/AC convertor. The photo-nav system is isolated from the aircraft power system due to potential power surges within the aircraft electrical system.

The mounting rack for the computer, GPS receiver, and battery were designed and fabricated by the Department of Aviation of ODOT. The rack was designed to affix to the seat rails, thereby requiring no special approval for purposes of flight. The displays and keyboard locations from the view-point of the photo-navigator in the Partenavia Observer aircraft are seen in Figure 3.1. From top (background) to bottom, the system

Figure 3.1 Photo-Nav Equipment as Seen from Photo-Navigator's Position

components are the airborne computer, the GPS receiver, and the camera controls and view finder/intervalometer. These same components are seen in Figure 3.2, but as seen from the entry door. The battery unit is located on the deck directly below the GPS receiver.

Details of the airborne hardware are found in Appendix B.

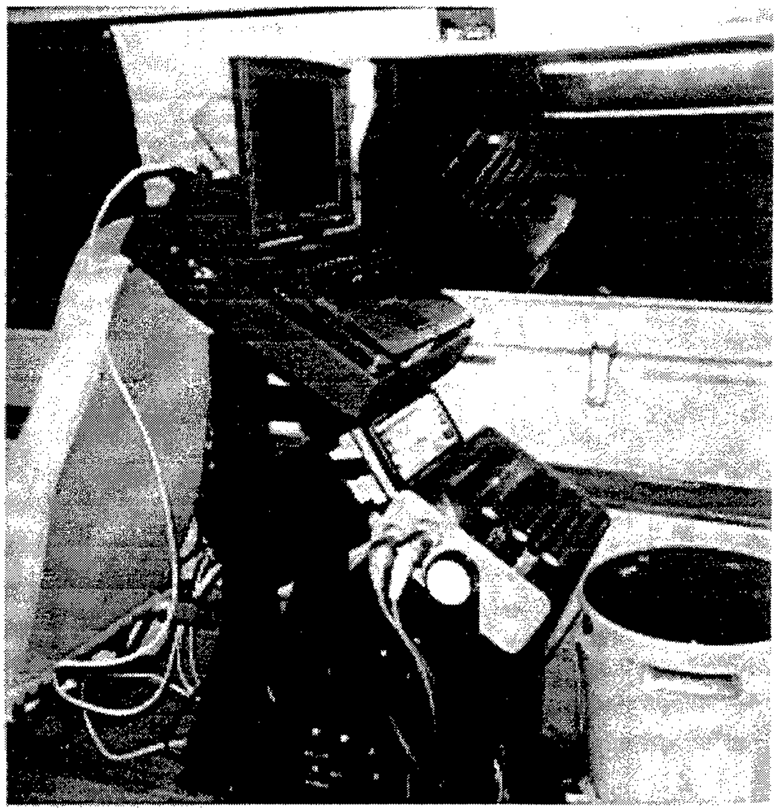

Figure 3.2 Photo-Nav Equipment as Seen from Entry Door

3.2 Software

Software was developed to serve the planning and GPS receiver uploading functions. Existing software developed by the NGS was integrated into these programs. Details of developed software are found in Appendix A.

3.2.1 Planning

The selection of waypoints, representing the beginning and end of individual flight lines, forms the basis of flight mission planning. To facilitate this step, the program "WAYPREP" was developed. It accepts data in two modes; either batch or keyboard entry.

The batch mode uses previously developed waypoint files. Such files may be either from previous missions or developed by direct measurements on appropriate digital files such as digital orthophotographs or digital maps. The description and data format for input batch files are presented in Appendix A.

The keyboard entry mode requires individual points to be manually entered as they are selected. This mode is useful, given the readily available, low cost data from such sources as DeLorme. The program provides means for automatically transferring flight line end waypoints to beginning waypoints for subsequent flight lines at the discretion of the planner. In the event a photo block is to be flown, the program will automatically compute waypoint coordinates for all subsequent lines. The program requires only the beginning and ending points for the first flight line. If it is indicated that the plan is for a block of photos, the planner is asked for the number of flight lines, altitude above ground level, direction of turn, and percent side-lap required. Given this, the program computes all waypoints by means of a standard geodetic position computation. Results are filed in a format suitable for uploading into the Trimble GPS receiver and airborne computer.

3.2.2 File Uploading

The program to upload waypoint files to the airborne computer named "WAYPOINT" was developed by NGS. Beginning with the waypoint data files developed during planning, the program allows viewing files both new and those remaining in the Trimble receiver. The files are viewed by means of the airborne computer. The files may then be uploaded to the GPS receiver in preparation for flight.

4. RESULTS

To operate the system, navigation information is first loaded into the receiver. Information required is the latitude and longitude of the starting and ending points, termed *waypoints,* on any given flight line. This information, compiled in the office, may consist of up to 99 waypoints, sufficient for a number of missions.

4.1 Pre-Flight

Before the flight mission, a series of checks are conducted with the aid of a check list. The charge level of the battery is maintained on the ground by a taper charge device especially adapted to the system. At full charge, the battery will provide more than enough power for both the computer and receiver for the duration of collection. A flight duration of 5 1/2 hours has been successfully completed, limited only by receiver data capacity. A battery charger and battery charge level indicator are built into the battery box.

The receiver is turned on and a series of pre-flight checks are made including collection rate, mask angle, baud rate, and position and navigation messages turned on. The aircraft can then be taxied to an appropriate location for establishing the initial position of the aircraft antenna with respect to a ground based GPS receiver (base station). As an alternative, "on-the-fly" technology may be used obviating the initial static data collection step.

During the initial collection period, the computer is turned on and the images of the map background and the icon representing the aircraft are brought up on the colored monitor. In addition to the aircraft icon, the elevation of the aircraft in meters and the PDOP (measure of satellite spatial configuration geometry) are displayed.

After initial conditions have been established, the aircraft is taxied to a run-up area, the usual checks of the aircraft completed, and take-off begun. During this time, the photo-nav system indicates position both graphically by the computer and numerically by the receiver.

4.2 During Flight

Once the GPS and computer have been initialized on the ground, the computer monitor continuously displays the aircraft icon superimposed on the colored map background along with indications of altitude and PDOP. The update rate is equal to the receiver collection rate, usually one second rate.

The display of cross-course corrections, range to the end waypoint, and ground speed are displayed on the front face of the GPS receiver for the selected flight line. Flight lines are selected by the operator by a simple toggling operation.

In summary, during the photo flight, the computer displays the aircraft on a color map background and the receiver displays flight line details and course corrections. A relay of flight line course correction information to the pilot is possible but was not implemented.

4.3 Post-Flight

After photo collection is complete, the computer may be turned off. The GPS receiver normally continues to collect data. After landing, the aircraft returns to the initial point on the airport and stops while continuing to collect data. After stopping the aircraft and with engines off, the receiver continues to collect data for approximately ten minutes. This static period establishes the ending baseline for purposes of closing the traverse. As confidence in airborne GPS-controlled methods improve, and the ability of modern GPS receivers and software to recover ambiguity on the fly is assured, the need for pre-flight and post-flight collections in a static condition will be mitigated and eventually abolished.

At this point, options exist for down-loading the receiver for subsequent processing. The primary method is to download the receiver to the airborne computer and process to produce a position file. This is based on the broadcast ephemeris, but is of sufficient value to give a field indication of the success of the flight mission. Subsequently, the data may be downloaded to other storage devices to facilitate transfer to office computers for final processing and storage.

After the receiver and computer have been secured, the battery charger is connected and left indefinitely to maintain charge.

4.4 Accuracy

At this time, the US Geological Survey maps at one to 24,000 scale are the highest accuracy, general coverage maps of Ohio. Digital orthophotos at a one to 12,000 scale are planned for Ohio and should prove to be ideal for purposes of waypoint selection both from accuracy and efficiency points of view. Although the accuracy of the one to 24,000 series is somewhat better than the real-time accuracy supplied by GPS, indications are that the combined map and uncorrected GPS real-time errors do not produce significant navigation errors. Further experience using airborne GPS for navigation may indicate that improved real-time accuracy would be useful. In that event, a correction message (RTCM) may be used. This was not attempted during this program.

4.5 Implementation

At the conclusion of the photo-nav development, demonstrations of the mission planning function were conducted for appropriate ODOT personnel. In addition, demonstrations of pre-flight, flight and post-flight operations of the photo-nav system were conducted.

5. CONCLUSIONS AND RECOMMENDATIONS

During the course of this development program, many changes occurred in components of both the airborne and ground based elements of the ODOT photo collection system. It was advisable to anticipate these changes which occurred primarily due to the rapid pace of development of computer and GPS technology. As a consequence, the current photo-nav system functions with the ODOT photo collection system as presently configured and remains reasonably adaptable to forthcoming changes.

To assure adequate accuracy for navigation purposes, it is recommended that the spatial accuracy results of the photo-nav system be evaluated as the system is used in production operations.

Finally, it is recommended that provisions for graphically indicating to the pilot the necessary cross-track corrections and distance to flight line end be developed. The current indications are presented on the face of the GPS receiver which is either not in the view of the pilot or is not large enough or graphical enough for use by the pilot during photo flight operations.

APPENDIX A. PROGRAM WAYPREP

The program "WAYPREP" is described in Section 3.2.1 providing purpose , description of equipment and method of operation. In the batch mode, the program requires a data file indicating beginning and ending waypoints for all flight lines. The following describes the records and formats for these pre-batch waypoint files.

Record 1. Format: (2X,A20,15X,F4.0,F3.0,F6.3,4X,F4.0,F3.0,F6.3)

photo scale number in units of 1000	col. 4
flight line number	col. 6
indication of start of flight line location relative to the mission site	col. 8
longitude of line beginning in degrees (- if west)	col. 38-41
minutes of beginning longitude	col. 42-44
seconds of beginning longitude	col. 45-50
latitude of line beginning in degrees	col. 56-58
minutes of beginning latitude	col. 59-61
seconds of beginning latitude	col. 62-67

Record 2. Format: (37X,F4.0,F3.0,F6.3,4X,F4.0,F3.0,F6.3)

longitude of line ending in degrees (- if west)	col. 38-41
minutes of ending longitude	col. 42-44
seconds of ending longitude	col. 45-50
latitude of line ending in degrees	col. 56-58
minutes of ending latitude	col. 59-61
seconds of ending latitude	col. 62-67

Note: Paired records continue for each flight line for remaining lines of mission.

An example of the pre-batch file is presented in Table A1.

4 1 N	-83.31.28.000	39.59.00.000
	-83.31.28.000	39.56.25.000
4 2 E	-83.26.20.000	39.56.25.000
	-83.31.28.000	39.56.25.000
4 3 S	-83.31.28.000	39.54.00.000
	-83.31.28.000	39.56.25.000
4 4 W	-83.36.19.000	39.56.25.000
	-83.31.28.000	39.56.25.000

Table A1. Typical Pre-Batch Flight Plan Data File for a Four Line Mission

APPENDIX B. HARDWARE

The major components of the system hardware consist of:

CAMERA: Zeiss LMK-2000 153 mm lens with 230 mm square image format, forward motion compensation and installed on a stabilized mount. The camera generates a mid-exposure TTL pulse for coordination with the record of GPS epochs.

GPS RECEIVER: Trimble 4000 SSE Geodetic Receiver capable of 1 Hz rate of positioning and equipped with:

- external event marker reception
- 5 meg. RAM
- 18 channels
- carrier phase processing
- RT survey data
- local datums
- fast measurement rate
- navigation package
- kinematic mode

COMPUTER: Laptop type "WINBOOK XP" with a 486 DX processor running at 100 MHz, keyboard mouse, Windows 3.1, 10.4 inch active matrix color VGA display fit to a docking station with CD-drive.

REFERENCES

Conners, Peter M. (1993) "Photo-Flight Navigation Using Moving Map Displays", Proceedings of the ACSM/ASPRS Annual Convention and Exposition, New Orleans, Vol. 3, p 72-78; Feb. 1993