GPS Navigation for Large-Scale Photography

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ABSTRACT: A navigation system for large-scale 70-mm aerial photography using a lap-top computer and a GPS (Global Positioning System) is described. The system is able to direct the pilot along flight lines, fire cameras on a fixed distance interval, and record the coordinates of every photograph. The GPS has unlimited range and is relatively inexpensive to run, with no ground stations to maintain. In the first year of operation, approximately 90 percent of the photo-locations were found to be within 100 m of the position mapped from the GPS data. Discrepancies greater than this were usually associated with photography under sub-optimum satellite coverage.

LARGE-SCALE (>1:5000) 70-mm and 35-mm photography have become important tools for foresters and land managers during the past 20 or 30 years. Major applications have been estimation of timber volumes (Spencer and Hall, 1988; Hagan and Smith, 1986), assessment of forest regeneration (Hall, 1984), and detection of forest pests and diseases (e.g., Heller *et al.*, 1959; McCarthy *et al.*, 1982).

The techniques required for each of these applications have been developed through experimental trials but various factors have hindered their implementation in operational programs. One of the major difficulties has been the accurate determination of the location covered by each photograph. This is because many forestry operations take place over remote or poorly accessed terrain which is deficient in ground control. Location of large-scale, small-format photographs in these regions is difficult because each frame covers a very small area. However, the location of each photograph is often critical. An area identified as being afflicted by some pest or disease must be located to allow control measures or salvage. Areas of inadequate regeneration need replanting, and some sample plots need to be located on the ground for detail measurements.

One solution has been microwave navigation. Bradshaw and Chandler (1978) and Bradshaw (1979) used microwave tracking systems to locate the 1:4500-scale, 70-mm photography used for mapping jarrah dieback disease in Western Australia. While these systems were very precise (± 3 m for the Motorola MRS III), they used ground based transponder stations which had a limited range of approximately 80 km and were expensive to install and maintain. Annual maintenance costs for the transponder stations and on-board equipment were approximately $35,000 (Department of Conservation & Land Management records).

A recent application of large-scale photography in Western Australia produced a cheaper and more modern solution to the problem. The photography was used for estimating timber volumes in eucalypt forest and was obtained with twin 70-mm cameras mounted on a helicopter (Lyons, 1966). An area of 1.2 million hectares was to be sampled over a period of three years. Sample plots consisted of photo-pairs at 500-m intervals on flight-lines located 1000 m apart. Each photo-pair covered only 55 m by 55 m. The location of each sample plot had to be known accurately to allow the timber volume estimates to be combined with other map information and for some to be relocated for detailed ground measurement.

To meet these requirements, a navigation system was developed using a commercial GPS (Global Positioning System) navigation instrument. GPS navigators use signals from the constellation of NAVSTAR satellites to calculate once every second the position, speed, and direction of a vehicle and can direct the user over a specified course. The precision of the instantaneous positions is around ± 25 m and the range is unlimited while satellites are available. Other GPS instruments for precise survey work can calculate positions to centimetre precision over a period of about one hour (Scherrer, 1985) but are not suitable for this application. Detailed information about global positioning systems may be found in Canadian GPS Associates (1986) and Institute of Navigation (1980).

This paper contains a description of the system for in-flight navigation, camera control, and position recording which was developed for large-scale 70-mm photography.

DESCRIPTION OF THE EQUIPMENT

The navigation system consisted of a GPS navigator connected to a lap-top computer by means of an interface unit. The interface also connected the computer to a radar altimeter and to the two cameras (Figure 1). The antenna for the GPS was mounted

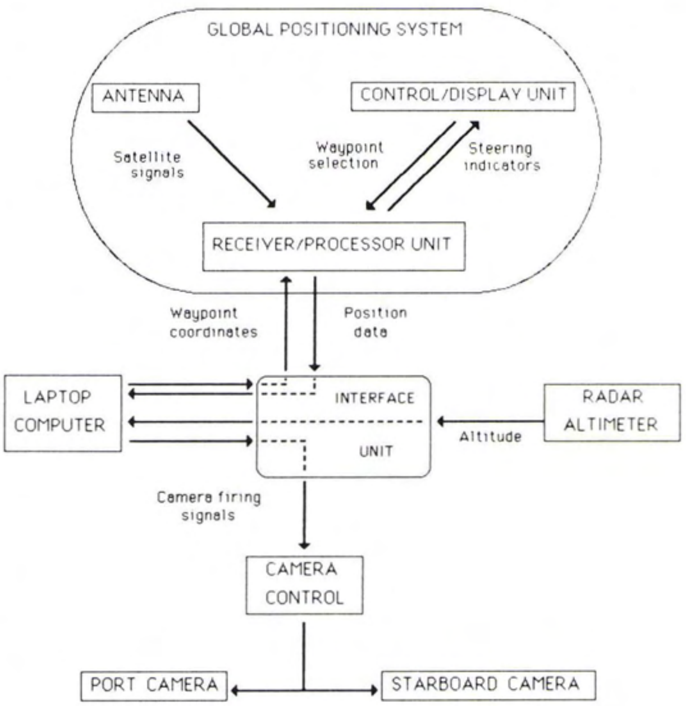

FIG. 1. Components of the navigation system.

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on one of the camera pods to remove it as far as possible from the shielding effect of the rotors. The remainder of the equipment was installed inside the helicopoter (Figure 2). The specifications of the equipment are given in Table 1.

In use, the GPS provided visual steering indicators for the pilot and instanteous positions at a rate of one per second to the computer. The computer used the position data to fire the cameras on a fixed distance interval and simultaneously recorded the time, position, altitude, and frame number of every photo-pair onto a floppy diskette. The altitude data were obtained from a standard radar altimeter which, unlike the "foliage penetrating" altimeters described by Nielsen (1974), reflected off both the ground and tree crowns. For this reason, the altitude data were only used as a backup for the calculation of scale from the fixed air-base (Lyons, 1966).

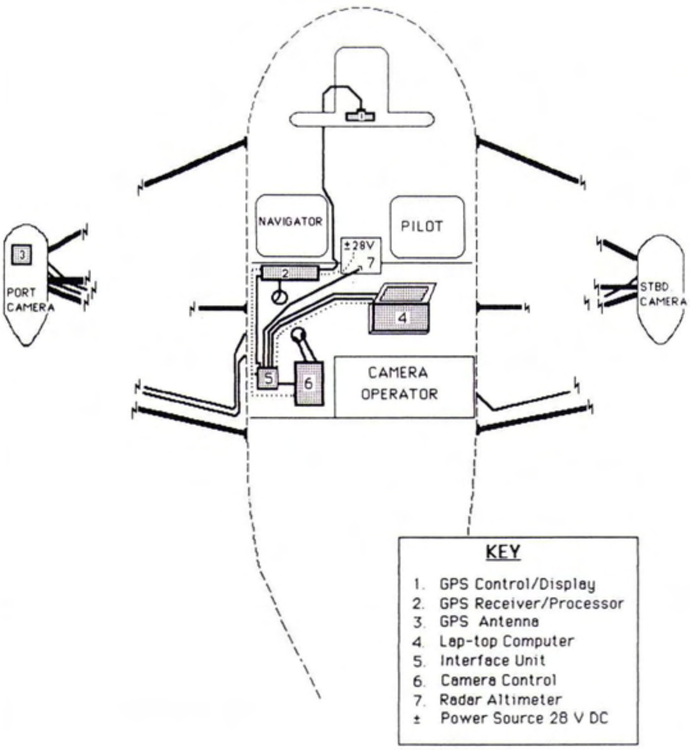

FIG. 2. Positions of the equipment in the helicopter.

METHOD OF OPERATION

The system was operated according to the following procedure:

GPS SETUP

- The waypoints for the photography mission were loaded in bulk into the GPS receiver from a diskette by means of the lap-top computer.
- The GPS receiver was programmed to display steering indicators on a repeating cycle, while flying between waypoints. The indicators included
  COURSE OVER GROUND
  COURSE TO DESTINATION
  CROSS TRACK ERROR
- The GPS receiver was also set to provide data through the communications port (once per second, the shortest interval available):
  TIME, POSITION, SATELLITE STATUS, PRECISION FACTOR

PHOTOGRAPHY

- The GPS display was used to navigate to the start of the first flight line (Waypoint 1).
- Photography commenced at the start of the flight line by keying in a command on the lap-top computer and by entering the initial frame number.
- The pilot navigated the helicopter to the next waypoint at an altitude of approximately 100 m using the GPS display and radar altimeter gauge.
- The lap-top computer fired the cameras at a fixed distance interval

TABLE 1. SPECIFICATIONS OF THE EQUIPMENT USED.

Component	Model	Specifications	Cost
Global Positioning System	Trimble 10X	* Low profile antenna * RS-422 input/output * Separate control/display unit	$840 / wk ($12 000) (purchase)
Laptop Computer	NEC Multispeed	* 640 k memory * 2 × 3.5" diskdrives * Serial & parallel ports	$2900
Interface Unit	Custom built (Protek Eng.)	* Connects computer RS-232 to TRIMBLE 10X RS-422 * Converts analogue radar altimeter output to digital * Closes circuit on camera control on command from computer	$5000
Radar Altimeter	Bonzer	* Not specifically foliage penetrating	n.a.
Camera control	Custom built (Quantum Eng.)	* Fires the cameras simultaneously on command * Adjusts aperture on cameras	n.a.
Computer mapping facility	Intergraph	* Host: Microvax 250	n.a.

Brand names are given only for illustration and do not imply endorsement. All costs are in Australian dollars, 1988.
n.a., not applicable, the costs are independent of the navigation system.

(500 ± 15 m) using the position data from the GPS receiver. The position of each photo-pair was recorded on diskette, along with the time, satellite status, and precision factor from the GPS. The altitude from the radar altimeter and the frame number generated by the computer were also recorded. The computer provided a screen display, refreshed every second, of the altitude and satellite status and indicated when each photograph was taken.

- The photography was paused at the end of the flight line by means of the computer keyboard and was continued at the beginning of the next line by entering a new starting frame number.

Post Flight Processing

- At the end of the mission, the photo-location data were transferred from the lap-top computer to a computer mapping facility. Photo-location maps were produced at two scales 1:25,000 for ground navigation and 1:250,000 for planning and administration. The maps were created plotting the photo locations onto tracing paper and overlaying these on existing base maps (Figure 3).
- A proportion of photo-pairs (10 percent) were selected for detailed ground measurement. Ground crews used a hip-chain and compass and distances and bearings scaled from the 1:25,000 maps to locate the approximate sample locations. At these positions, a pocket stereoscope and a perspex light board were used to determine the exact center of the sample plot marked on the photographs (Figure 4).

EVALUATION OF THE NAVIGATION SYSTEM

The critical test of the system's performance was the ability to relocate the sample photographs on the ground. A precision of ±75 m was expected, allowing ± 25 m for the GPS, ±25 m for the precision of the topographic base map, and ±25 m for errors in overlaying the base map with the photo-point map. Additional variation was expected due to the limitations of the hip-chain and compass survey, which was only designed to find the approximate sample locations.

Two hundred sample plots were examined to determine the average distances between the expected positions (from the hip-chain and compass survey) and the actual positions (located from the photographs). The mean distance was found to be 50 m, with 80 percent of the samples within 75 m and 90 percent within 100 m. Samples within this range were quickly found by reference to the photographs.

This was very encouraging but still left 10 percent of plots up to 300 m out of position. Some of these were due to errors in

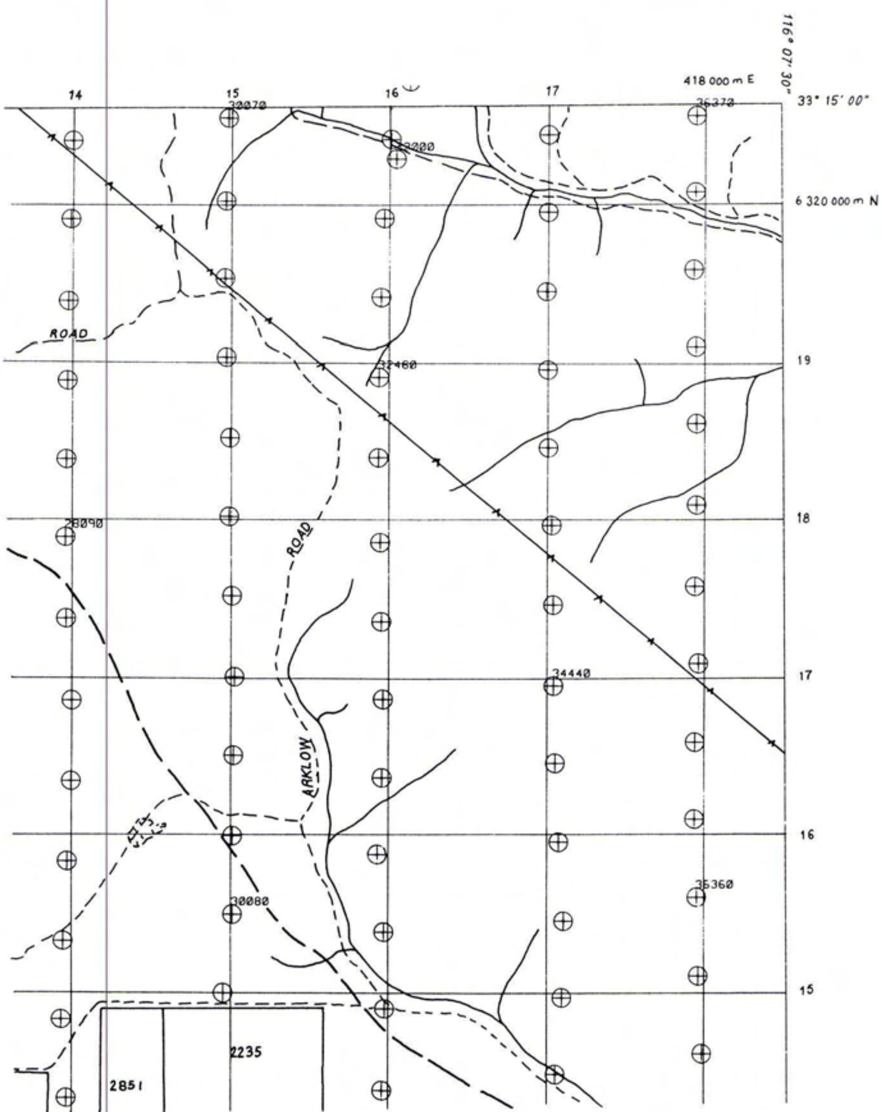

FIG. 3. A portion of a flight line map produced by the Intergraph mapping facility and overlaid on a 1:25,000-scale base map. The reference grid is the 1000-m Australian Map Grid.

FIG. 4. A pocket stereoscope and perspex light-board were used to view the photo-pairs in order to determine the exact center of the sample plot.

the ground survey or in the base maps, but it was found that the majority were associated with photography taken during periods of the day with substandard GPS satellite coverage. This was caused by the incomplete constellation of satellites present during the development phase of GPS.

Seven satellites are now in orbit, giving a "window" during each day when at least four satellites are available for calculating accurate locations. The window is approximately five and a half hours long and occurs during daylight hours during summer in south-west Australia. For approximately one hour either side of the window, three satellites can be used to determine position, assuming that the height above sea level is held constant or can be input from another source.

Some photographs were taken during the three satellite period in an effort to finish high priority areas, but the height above sea level varied as the aircraft followed the terrain, causing potentially significant errors in the calculated position. This situation could be detected by referring to the record of satellite status from the GPS and taking care in locating doubtful photographs, but the best solution was to avoid photography during sub-optimal satellite coverage. The problem should disappear after 1990 once the full constellation of 18 satellites is in place (Scherrer and Fricker, undated).

FLIGHT NAVIGATION AND PHOTOGRAPHY

The GPS receiver fulfilled all requirements for navigation along flight lines. It had unlimited range and was not affected by terrain during the window of full satellite coverage. Using the steering indicators, the pilot was able to fly accurate lines, ensuring an even sample distribution. The system of camera control was also successful, giving a regular spacing of photo-samples along the flight line irrespective of the speed over ground. These attributes would also aid in the maintenance of the correct overlap with smaller scale, timed interval photography.

MAPPING

The photo location data were transferred from the lap-top computer disks to the computer mapping facility easily and quickly. This allowed the rapid production of photo location maps, facilitating the earliest measurement of the sample plots. This rapid production of flight-line maps may also be useful for other aerial photography applications.

Sample plot data were linked to the photo location information using a geographic information system. Because the plot locations were already in digital form, this task was achieved without additional manual input. Timber volumes can now be estimated for any part of the sampled area by selecting relevant plots from the data base by their location and passing those plot data to statistical software.

COSTS

Most components of the system were purchased for a total cost of A$ 7900, but the GPS receiver was hired at A$ 840 per week for the five weeks of the photography season (Table 1). The total cost of the system, over the first three years of photography is expected to be A$22,000, disregarding the camera control and the computer mapping facility which were already owned and used for other tasks. Much of this expense is offset by the more efficient use of the helicopter through good navigation, and compares very favorably with the alternative microwave systems. Furthermore, no additional ground staff are needed to install and maintain transponder stations.

CONCLUSIONS

The combination of a GPS navigator and a lap-top computer has proven to be an excellent navigation system for large-scale photography. It can fire the cameras on a distance interval and record the position of each photograph to a nominal ± 25 m. Additional errors are introduced during the production of photo location maps so that the precision of the whole system is closer to ± 75 m. 90 percent of photo samples were found within 100 m of chain and compass survey in this study.

The benefits to large-scale photography outlined here may apply equally to other aerial photography applications. The total cost of the system is low and there are no ground stations to maintain. The performance of GPS systems is expected to improve as more satellites are deployed but, until then, the status of the local satellite coverage should be checked before planning to use this system.

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REFERENCES

Bradshaw, F. J., 1979. Low level aerial photography. *Proc. Seminar on Land-Use Planning, Recent Advances, Prospect 2000 Conference*, Univ. Western Australia, pp. 16–24

Bradshaw, F. J., and R. J. Chandler, 1978. Full coverage at large scale. *Proc. Amer. Soc. Photogramm. Symp. on Remote Sensing for Vegetation Damage Assessment*, Seattle, Washington, pp. 267–290

Canadian GPS Associates, 1986. *Guide to GPS Positioning*, University of New Brunswick, Fredericton, N. B., Canada

Hagan, G. F., and J. L. Smith, 1986. Predicting tree groundline diameter from crown measurements made on 35-mm aerial photography. *Photogrammetric Engineering and Remote Sensing* 52(5): 687–690

Hall, R. J., 1984. *Use of Large-Scale Aerial Photographs in Regeneration Assessments*. Can. For. Serv., North. For. Res. Cent., Inf. Rep. NOR-X-264

Heller, R. C., R. C. Aldrich, and W. F. Bailey, 1959. Evaluation of several camera systems for sampling forest insect damage at low altitude. *Photogrammetric Engineering and Remote Sensing* 25: 137–144

Institute of Navigation, 1980. Global Positioning System. Papers published in *Navigation*, 3 volumes, reprinted by The Institute of Navigation, Washington, D. C.

Lyons, E. H., 1966. Fixed air-base 70 mm photography, a new tool for forest sampling. *Forestry Chronicle* 42(4): 420–431

McCarthy, J., C. E. Olsen, and J. A. Witter, 1982. Evaluation of spruce-fir forests using small-format photographs. *Photogrammetric Engineering and Remote Sensing* 48(5):771–778

Nielsen, U., 1974. *Description and Performance of the Forestry Radar Altimeter*. Canadian For. Serv. Inf. Rep. FMR-X-59

Scherrer, R., 1985. *The WM GPS Primer*. Wild Magnavox Satellite Company.

Scherrer, R., and P. Fricker, undated. GPS the surveying system of the future. *Wild Reporter* 24: 3–7, Wild Heerbrugg, Switzerland.

Spencer, R. D., and R. J. Hall, 1988. Canadian large-scale aerial photographic systems (LSP). *Photogrammetric Engineering and Remote Sensing* 54(4):475–482

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