Should One Consider Combining Kinematic GPS with Aerial Photogrammetry?

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ABSTRACT: The potential application of kinematic GPS in conjunction with aerial photogrammetry has been reported in several papers. This paper investigates from a practical point of view when it should be applied with aerial photogrammetry.

INTRODUCTION

TRADITIONALLY, AERIAL PHOTOGRAMMETRY has been applied to many tasks such as topographic mapping and three-dimensional control densification. The second aspect is often referred to as aerotriangulation. It provides not only photo-control points for use in subsequent mapping, but also ground control points.

In order to reduce the necessary ground control for aerotriangulation, so called "auxiliary data"-obtained from such devices as the statoscope, altimeter, radar profile, and Shoran-controlled air-stations—have been of interest to photogrammetrists. An extensive review can be found in Brandenberger (1959). Although most of these approaches have become outdated and were never widely applied, the statoscope has received worldwide attention and is still considered practical.

GPS, on the other hand, has proved useful in photogrammetric and surveying applications. For ground control extension, Chong (1987), Collins (1987), and Reilly (1988) have analyzed the cost factors for mainly static positioning. An example shows that a $50,000 receiver will be amortized over three years at 12 percent interest. Logan (1988) described the demands and tests for terrestrial relative kinematic GPS. Ackermann (1984, 1986), Friess (1987), and Lucas (1987) have reported on the benefits of applying kinematic GPS in aerotriangulation from the accuracy point of view. With the drastic price reduction for receivers, the practicality and efficiency of many surveying tasks has been improved.

Kinematic GPS uses a static GPS system at one station (master) while another GPS system (rover) is moved from one station to the next until all stations have been occupied. This procedure is still under development; however, preliminary studies have shown that centimetre accuracy can be expected (Remondi, 1985; Mader, 1986). A recent study by Eschenbach *et al.* (1988) reported that, with kinematic GPS, 50 points can be surveyed to centimetre level accuracy during a three-hour GPS survey session. Although the same accuracy level has been achieved with an airborne laser ranging system (Degnan *et al.*, 1983), the low cost potential makes GPS extremely attractive.

It seems to become necessary to query why we may need kinematic GPS, when and where we need it, and under which circumstances. These questions are addressed in view of accuracy and reliability, monumentation (legal aspects), economic considerations, and operational restrictions.

ACCURACY AND RELIABILITY

With centimetre (cm), even decimetre (dm) accuracy from GPS, both the reliability and accuracy of estimated parameters in aerotriangulation can be significantly improved. Because of the multi-bundle intersection for ground points, the accuracy of ground coordinates is essentially better than that of the camera station coordinates (Figures 1 and 2).

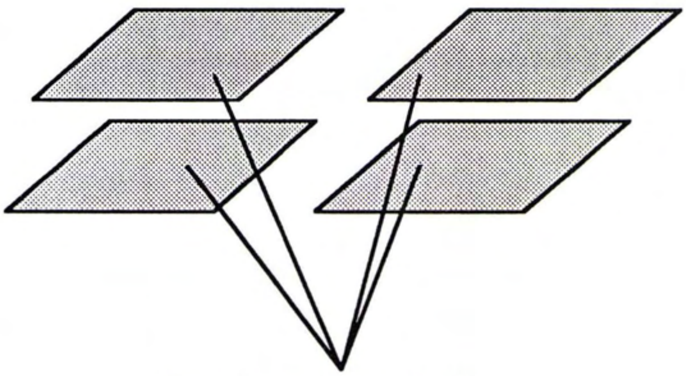

FIG. 1. The intersection of bundles.

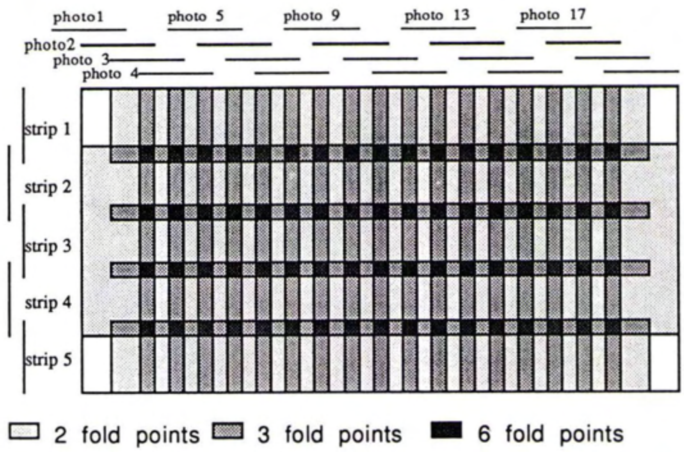

FIG. 2. Distribution of multiple images of points (20 percent sidelap, 60 percent overlap).

Because the observations introduced from kinematic GPS are associated with the camera stations, the geometric configuration is homogeneous and strong, and the error propagation is direct. This is particularly significant for elevations. Vertical ground control points in the center of a block can be removed if the positions of the camera stations have been determined with kinematic GPS to a sufficient accuracy.

Lucas (1987) reported 10-cm accuracy for heights, which, depending on the photo scale, is approaching the image resolution. This kind of accuracy may be necessary for certain situations.

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Mapping specifications, however, require that 95 percent of all elevations lie within one half of the contour interval, which for a 1:5,000-scale map is typically 5 or 10 metres. We should therefore be able to produce a 1:200-scale plan applying the accuracy reported by Lucas (1987). However, in such a case, the information content of the photography becomes the limiting factor (Masry *et al.*, 1980). Hakkarainen (1986) reported that among 47 tests, only 18 of them achieved resolving power higher than 50 line pairs per mm, and none of them exceeded 60 line pairs per mm.

A GPS receiver can basically provide only two types of measurements: pseudo-range and carrier beat phase. While psuedo-range measurements utilize the time shift required to line up a replica of the code generated in the receiver with the received code from the satellite, multiplied by the speed of light, the carrier beat phase measurements use the phase of the signal which remains when the incoming Doppler-shifted satellite carrier is differenced (beat) with the constant frequency generated by the receiver (Wells, 1986). Because the wavelength of the carrier is much shorter than the wavelength of either the P-code or C/A code, carrier beat phase measurements provide much better resolution. However, the initial cycle ambiguity has to be resolved and the lock on the satellite signal has to be maintained. In the kinematic case, the initial cycle ambiguity is resolved before the rover is moving. Due to many possible reasons, the lock may be lost, and cycle slips can occur.

Although, at some time in the future, kinematic GPS will be free from most systematic errors, it is not expected that cyclic slips, etc., will become reliably under control. Therefore, Ackermann (1984) stated that "ground control points can only be deleted completely when constant or systematic errors of the auxiliary data are negligible or are calibrated otherwise."

It may thus be stated that

- kinematic GPS is expected to provide much higher accuracy than that which is required for mapping; and
- the use of ground control points cannot be totally avoided unless systematic errors from GPS are completely eliminated and the system is operationally reliable, although the amount of ground surveying effort can be reduced.

MONUMENTATION

Traditionally, surveying authority is demonstrated by survey monuments on the ground, their associated coordinate values, and their legal stature. GPS provides a means to determine the coordinates of monuments in an efficient and accurate way.

In the previous section it was noted that kinematic GPS has high potential for control densification. However, survey monuments will remain important to society. If ground monumentation is retained, terrestrial GPS surveys seem to be better suited than kinematic GPS in conjunction with aerotriangulation. In fact, in almost all control point densification projects, point signalization is required. This requires visitation of all points by a field crew, which – instead of signalizing the points – might as well coordinate them using terrestrial GPS.

The datum problem also has to be considered. Coordinates computed from GPS observations are obtained initially in the geocentric coordinate system or World Geodetic System of 1984 (WGS 84, see Defense Mapping Agency (1987)). The planimetric coordinates can be obtained by transformations from WGS 84 to local coordinate systems, which are normally defined by a local spheroid or ellipsoid. However, the transformation of heights requires knowledge of a specific geoid and its undulations, because a geoid represents a commonly used reference vertical datum. Hintz and Zhoa (1988) proposed to use GPS for planimetric control and signalized ground control points for heights. Compared with this scheme, conventional aerotriangulation with terrestrial GPS measurements appears to be much more economical.

ECONOMIC CONSIDERATIONS

When looking at the economics of an approach, the major aspects are costs associated with instrumentation, operation, and software.

In reference to instrumentation costs, we must realize that not all GPS receivers can be utilzied for airborne kinematic purposes. More exactly, the GPS receiver and data logging equipment, as well as the recording device, have to be specifically designed for kinematic operation on a fast moving platform. Design features should include

- the data log time interval has to be small enough and recorded fast enough;
- the tracking bandwidth has to be wide enough to tolerate the acceleration; and
- the instant of photographic exposure has to be recorded.

Thus, agencies which already have GPS receivers may have to consider further investment for airborne kinematic operation. In addition, traditional photogrammetric instruments have to be available for aerotriangulation with kinematic GPS.

From an operational point of view, flying over an area with GPS would take far less time. But, if monumentation is required, this relative advantage is drastically reduced. Moreover, image digitization and computation consume personnel resources. A final conclusion can be drawn only after a careful cost/benefit evaluation.

The observations from airborne kinematic GPS are related to the camera station by an off-set (Figure 3). The components of its influence are functions of the camera station orientation, more specifically the rotations ϕ, ω, and κ. Therefore, a rigorous adjustment cannot be performed with weighted constraints. The functional constraint model, or the additional observation model as utilized in El-Hakim (1979), should be implemented. It is as follows:

$$F(X_1, X_2, L) = 0;$$
$$G(X_1, L_G, L_{\text{off-set}}) = 0.$$

X_1: unknown parameter group 1, bundle orientation parameters;
X_2: unknown parameter group 2, e.g., ground coordinates;
L: observations, including image coordinates, ground coordinates, and other;
L_G: GPS observations; and
$L_{\text{off-set}}$: off-set value between GPS measurements and the camera perspective center.

This clearly indicates that further photogrammetric software investment is also required. While this might perhaps be trivial in an academic environment, it could also be expensive, especially for industrial users of this technology.

OPERATIONAL RESTRICTIONS

Generally, GPS has all-weather characteristics. As long as there are sufficient satellite passes, it can be operated on a cloudy day, or at night. However, for kinematic GPS with aerotriangulation, both the photogrammetric conditions on weather and vegetation (i.e., season) and GPS conditions such as the number

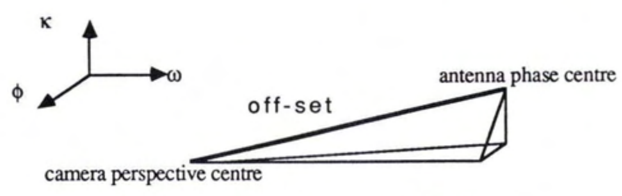

FIG. 3. The GPS persepctive center off-set.

and geometry of available satellites at the site, have to be suitable. Lucas and Mader (1988) reported on two experiments conducted in Texas and in Washington State. Although centimetre-level accuracy was achieved, problems arising from the mounting of the GPS antenna, the calibration for off-set, and others, are also addressed. Besides the restriction from the narrow window of suitable satellite geometry, flight restrictions also exist. In order to ensure that clear paths from all satellites to the antenna would not be interrupted by the aircraft wings, all turns had to be made with minimum bank angles (Lucas and Mader, 1988). Meanwhile, if loss of the signal lock happens during flight and resulting cycle slips cannot be resolved, the flight has to be repeated. All these operational restrictions point to a higher logistic cost. The full 18 + 3 satellite constellation is expected to provide much improvement in the future, which will reduce the problem, but not remove it.

Perhaps kinematic GPS with aerotriangulation would be advantageous for remote areas where ground monumentation is neither available, nor needed, and where it is difficult and very expensive to send ground personnel. However, for most of these cases, a high accuracy is also not required. Therefore, statoscope use would be sufficient for vertical control, and planimetric control could be simplified by either extending the coverage to include control points outside the object area or else by placing some GPS ground control at the perimeter (Brown, 1979). Other auxiliary information, such as lake surfaces, will be helpful as well.

CONCLUSIONS

Kinematic GPS in conjunction with aerotriangulation potentially provides a powerful, yet rather theoretical, alternative to traditional approaches. It can be applied when the price is suitable, the technique reliable, and when no or minimal ground monumentation is required.

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