Precise Airborne GPS Positioning Alternatives for the Aerial Mapping Practice

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SUMMARY

Positioning information derived from GPS measurements has become a reliable component of many of today's aerial mapping systems. However, one of the logistical limitations commonly faced when using GPS for airborne mapping is the need for continuous data collected by a GPS receiver at one or more base stations in the area of the survey (e.g. having a station within 30-50 km of the aircraft at all times). While the use of such data is a means of meeting the accuracy requirements of today's most demanding large-scale aerial survey applications, establishing a base station is often a difficult task when surveys take place over remote or inaccessible terrain. Further, even when dedicated base stations are established, the continuity of the data is not always guaranteed as a result of environmental effects, receiver error, or human error. With these points in mind, the objective of this paper is to evaluate the potential of deriving reliable and accurate estimates of the position of a survey aircraft without the establishment of dedicated GPS base stations. Three approaches have been used here. The first approach is to make use of data available from existing Continuously Operating Reference Stations (CORS) networks to estimate the position of the aircraft. While such stations are often at a considerable distance from the survey area (e.g. 50 to 500 km), they are often large in number and their data is usually freely available. The second approach is using the IGS products, where the precise orbits and the satellite clock corrections are obtained after the fact and used in a single point positioning mode. The third approach is using the satellite-based differential corrections available in real-time. A number of real data sets from real mapping missions that took place in the last three years in the USA and Japan have been used in this analysis. Preliminary test results and analyses are presented and discussed in some detail. Immediate benefits of these approaches include precise positioning for aerial survey applications such as GPS-assisted aerotriangulation, and the generation of Exterior Orientation parameters for direct georeferencing for aerial film or digital cameras, LIDAR, and SAR.

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1. INTRODUCTION

Aerial surveyors have been using airborne GPS as a standard tool to assist in the production of maps for the past decade. More recently, GPS-aided inertial systems such as Applanix POS AV™ have been successfully used to provide the full resolution of trajectory parameters; namely position, velocity, and attitude. The data acquisition procedure plays a key role in the success of these methods. Separation between the airborne and base station GPS receivers, satellite geometry as reflected by the Position Dilution of Precision (PDOP), signal multipath and many other parameters must be considered in order to achieve the maximum possible GPS positioning accuracy. On many occasions it is difficult or impractical to optimize these parameters. For example, because the sun angle required for aerial photography and the PDOP required for a strong geometry when positioning by GPS do not necessarily occur at the same time, aerial flight missions sometime inadvertently compromise the GPS PDOP in order to get a good sun angle. Careful mission planning is therefore mandatory for high accuracy mapping applications where the highest GPS positioning accuracy is required. A usual outcome of this is the requirement that a series of GPS base stations be deployed in order to support the project.

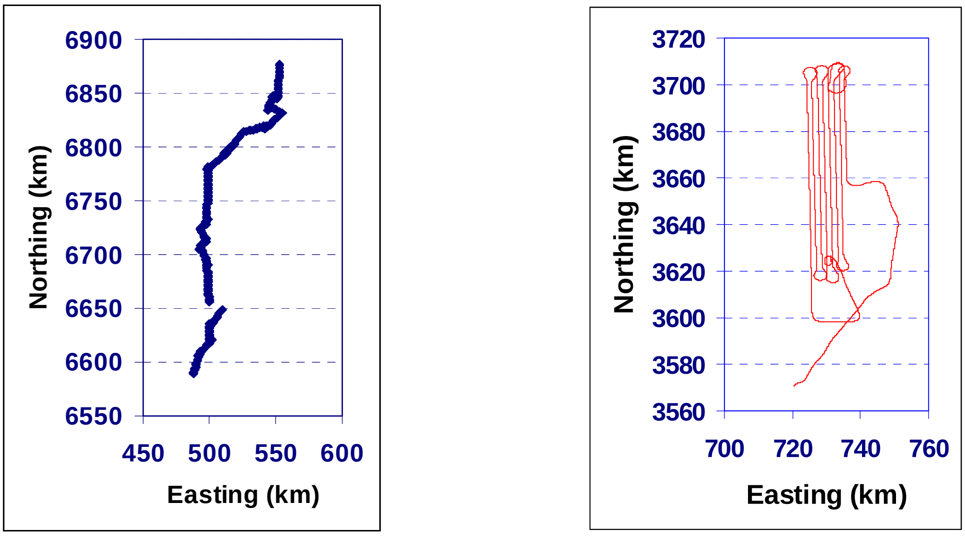

Figure 1: Typical Aerial Mapping Trajectories for Corridor Mapping (left) and Topographic Mapping (right)

This can be very difficult in physically inaccessible regions. In applications where the accessibility is typically good and the positional accuracy requirements are often relaxed, a major problem is the cost of laying out base stations at regular intervals along the corridor. As shown on the left side of Figure 1, an example of this is corridor surveying where surveys can extend for thousands of kilometres. Similar situations often occur in large aerial mapping projects, as shown in the right side of Figure 1. On other occasions, the GPS base station data may simply be lost due to equipment problems or human error.

2. HIGH PRECISION AIRBORNE GPS POSITIONING

There are two steps required by every GPS processing engine in order to achieve high positioning accuracy form aerial GPS surveys. The first step is to reduce or eliminate the dominant GPS errors using modeling and differencing techniques (c.f. Parkinson and Spilker, 1996). The second step is ambiguity resolution, which is beyond the scope of this paper. For a detailed discussion, see Parkinson and Spilker (1996). To eliminate or reduce the GPS errors, a number of currently available technologies can be used. These are treated in the following sub-sections.

2.1 The IGS Precise Orbits, Satellite Clock Corrections, and Atmospheric Information

Among a number of GPS and geodetic products, the International GPS Service for Geodesy and Geodynamics (IGS) produces high accuracy GPS satellite ephemeris, satellite clock corrections, and ionospheric and tropospheric information. These products can be used in airborne surveys to refine the GPS data. GPS data refinement can be done on different levels. Firstly, if airborne GPS is operated in DGPS mode while the base station is more than 100 km away from the mapping area, using the IGS data minimizes orbital and atmospheric errors and, therefore, improves the positioning accuracy. Secondly, airborne GPS can be operated in single point positioning mode (no base station). In this case, using the IGS data improves the positioning accuracy down to a decimetre level and makes it possible to use GPS without a base station in some mapping applications, especially after the S/A was turned off.

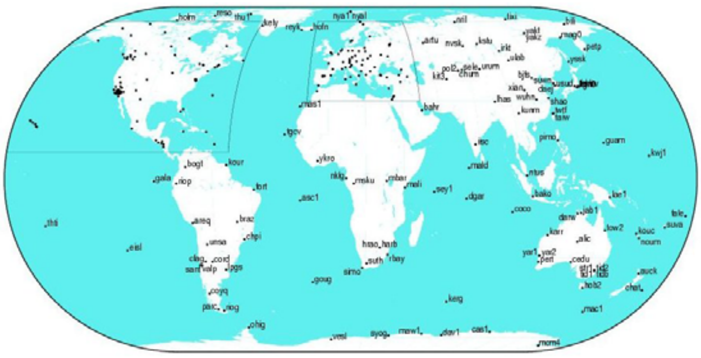

Figure 2: Worldwide IGS Tracking Network of GPS Stations (Courtesy of IGS website)

The IGS accomplishes its mission through continuous GPS tracking stations as shown in Figure 2, data centres, and analysis centres. Network stations are currently some 250 globally distributed stations continuously collecting GPS data using quality dual-frequency receivers. The data centres are responsible for collecting data from tracking stations, reformatting and archiving data, and submission of data to analysis centres. Analysis centres are responsible for data processing and analysis. These products are then delivered to the Global Data Centres using designated standards on a regular basis. The IGS products are available after different periods of time and with different accuracy. Table 2 shows the IGS products, their precision and their timelines. Quality control of the data is however questionable. This topic has not been studied although it is crucial in the aerial mapping field since the entire mapping mission depends on the quality of the GPS data. Therefore, it is strongly recommended to study the quality control aspects when implementing the IGS products for aerial mapping applications.

Table 1: IGS Combined Product Precision and Timelines (courtesy of IGS website)

Product		Accuracy	Latency	Updates	Sample Interval
Broadcast	orbits	~200 cm	real time		daily
	Sat. clocks	~7 ns			
Ultra-Rapid (predicted half)	orbits	~10 cm	real time	Four times daily	15 min
	Sat. clocks	~5 ns			
Ultra-Rapid (observed half)	orbits	<5 cm	3 hours	Four times daily	15 min
	Sat. clocks	~ 0.2 ns			
Rapid	orbits	<5 cm	17 hours	daily	15 min
	Sat. & Stn. clocks	0.1 ns			5 min
Final	orbits	<5 cm	~13 days	weekly	15 min

2.2 Differential Airborne GPS Positioning Using Dedicated Base Stations

Generally, Differential GPS (DGPS) reduces atmospheric (ionospheric and tropospheric) and orbital errors, eliminates satellite and receiver clock errors, and increases the single receiver noise. Atmospheric and orbital errors are correlated with distance; the shorter the separation baseline between receivers, the greater the correlation between these errors at each receiver. These errors are almost the same at two receivers separated by short baselines (1 to 30 km), so that differential processing of the receiver data will affect the almost complete cancellation of the errors. Since these errors also distort phase data used in kinematic ambiguity resolution, the reliability of ambiguity resolution on short baselines is much better than on longer baselines. For an overview on the subject, see Lachapelle (1995) Langley (1997), Parkinson and Spilker (1996), and Shi, 1994.
Table 2 briefly describes the DGPS remaining errors while Table 3 shows a summary for typical errors for GPS airborne differential positioning by carrier phase signal.

Table 2: Differential GPS Residual Error Characteristics

Error	Error Characteristics
Orbital	• Correlated between satellites • Significantly reduced by between-satellite differencing (DGPS) • Using precise orbits and satellite clock corrections improves positioning accuracy for long baselines
Ionospheric	• Frequency-dependent, thus, dual frequency data eliminates the error for long baselines. • Broadcast model reduces the error by 50% • In double difference airborne kinematic case error is typically 1-2 PPM for mid-latitudes between sunspot highs
Tropospheric	• Frequency-independent, thus, cannot be removed by dual-frequency data • Dry component can be modeled and removed • Wet component needs meteorological data and more difficult to model because of the variable nature of water vapour • Over long baselines the wet component effect on positioning can be estimated for airborne applications
Multipath	• Site-dependent and, thus, cannot be removed using differential GPS • In kinematic applications, the multipath signature has a strong correlation with vehicle speed. Therefore, multipath gets random (and less) for higher speed

Table 3: Typical Airborne DGPS Positioning Errors

GPS Error Source	Typical Relative Positioning Error (PPM)	Positioning Error For a 50 km baseline (m)
Orbital (SA is on)	1	0.05
Ionospheric	1-10	0.05 to ***0.50***
Tropospheric	2	0.10
Signal Multipath	0.01	0.05
Receiver Noise	0.001	< 0.025
Total Error	2.5 – 10.25	0.1 - *0.5*

2.3 Airborne DGPS Using Satellite Broadcasted Correction/Observables

Differential GPS can be implemented in either real-time or in post-mission. In real time, either the corrections or the raw observables are sent via radio-link or satellites to the airplane. Real-time processing of raw satellite GPS signals together with the received corrections/observables then takes place to apply the differential positioning technique. For details, see for example www.omnistar.com and www.navcomtech.com. OmniSTAR and NavCom are examples of wide-area differential GPS services using satellite broadcast techniques.

Data from many widely spaced reference stations is used in a multi-site solution to achieve sub-meter positioning over most land areas worldwide. An example of these systems is The NavCom concept shown in Figure 3.

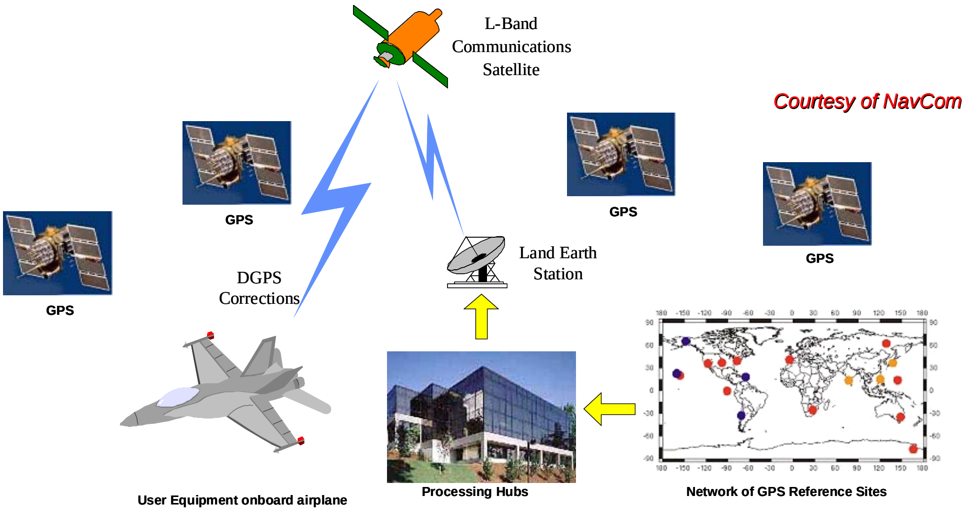

Figure 3: Real time GPS Using the NavCom Concept

2.4 Airborne DGPS Using Continuously Operating Reference Stations (CORS)

The CORS (continuously operating reference station) system is run by The US National Geodetic Survey (NGS). CORS comprises a network of 350 sites (Soler et al, 2003), containing geodetic quality GPS receivers. This network is currently growing at a rate of about 4-8 sites per month. The US NGS collects, processes, and distributes data from these sites in support of high-accuracy 3D positioning activities throughout the United States and its territories. For details about CORS, see Soler et al (2003), Snay (2000). Figure 4 shows a map of the CORS stations in The USA. For more details on CORS, see www.ngs.noaa.gov.

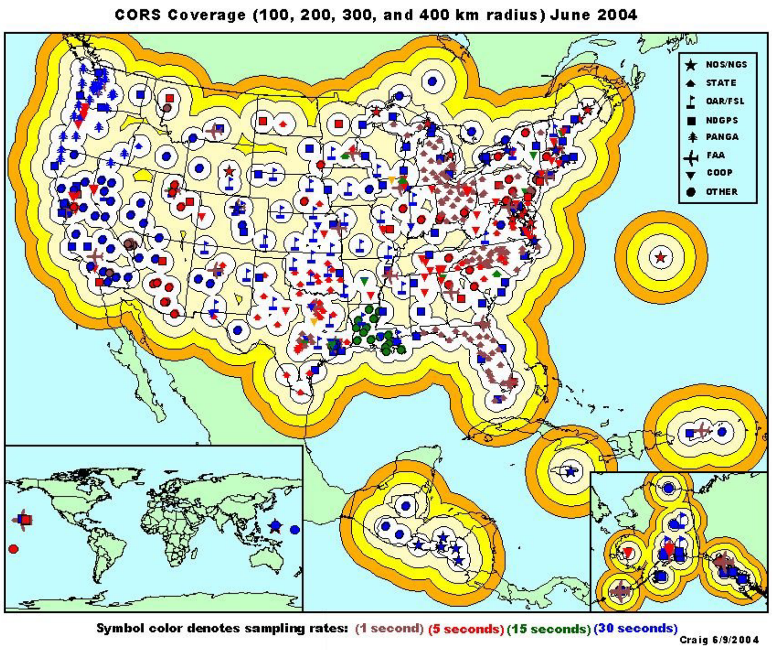

Figure 4: CORS Stations in The United States (courtesy of CORS web site)

3. CONCLUSION

In this paper, an overview of the precision of airborne GPS using different techniques is summarized, airborne GPS error sources and their contribution to the final accuracy is presented, and data test results and analysis from two different projects are presented. The advantage of a multiple-base station processing technique on the final airborne GPS accuracy is shown using the US NGS CORS stations. Further, the effect of the sampling rate of the CORS data on the accuracy of the aircraft position is presented.

It is shown that the longer sampling intervals used by some of the reference stations (greater than 5 seconds) will cause the positioning accuracy of the aircraft to deteriorated by about 0.03 m RMS compared to a 1 second sampling, with maximum errors of about 0.1m. Although accuracy deterioration of that magnitude will not affect small scale mapping applications, it will adversely affect large-scale mapping projects when using aerotriangulation or direct georeferencing methods of mapping.

So far, the use of the US NGS CORS stations in the airborne mapping process has proven to be quite viable, especially as a means to augment dedicated base stations for QA/QC purposes. The ease of accessing the CORS data on the Internet and the increasing number of stations around the USA makes it one of the most attractive methods of airborne GPS positioning in the USA. While more experience and results are required to make a definitive statement about using CORS data without at least 1 dedicated bases station, certainly the potential is there. Similarly, other countries have implemented the permanent tracking network approach for geodetic purposes. From the international airborne surveying perspective, it is strongly recommended to test the same concept of CORS in other parts of the world such as Australia and Western Europe.

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