Spaceborne GPS Receiver Assessment

S. B. Bisnath and R. B. Langley.

The GPS receiver model used for the GPS Meteorology (GPS/Met) mission was investigated for use in orbit determination of a future CSA micro/small satellite. The GPS/Met experiment utilizes an Allen Osborne Associations, Inc. TurboStar receiver to compute the precise orbit of the MicroLab-1 satellite (the vehicle hosting the experiment) in a post-processing mode. The receiver also collects carrier phase observations from GPS satellites being occulted by the earth's atmosphere for atmospheric limb sounding.

In carrying out our assesement, we conducted a survey of past, current, and future space missions whose spacecraft systems include GPS receivers and identified approximately seventy such missions (see the Spaceborne GPS Information Site: <http://gauss.gge.unb.ca/grads/sunil/sgps.htm>). Spaceborne GPS presents two problems for GPS receivers designed primarily for terrestrial applications: the space environment requires space qualifying of receiver hardware and the high dynamics of spacecraft requires incorporation of more robust algorithms in the receiver.

In addition to an assessment of the TurboStar's physical characteristics, we performed several position accuracy tests. For example, as a test of the MicroLab-1 precise orbit determination (POD) consistency, overlaps of adjacent orbital arc solutions for twelve days of data were differenced. The results showed a mean error of 81 centimetres three-dimensional (3d) root-sum-square (r.s.s.). An analysis of the precision of the real-time, on-orbit, receiver navigation solution compared to the POD solution showed a 3d r.s.s. mean error of 46.2 metres and a standard deviation of 28.5 metres.

We concluded that the TurboStar receiver is a good candidate for use on a future CSA mission but that other options should be considered including a receiver development partnership with another space agency. We also recommended that the CSA should take advantage of the many benefits that GPS offers when planning future space missions, not only for orbit determination but also for attitude determination and control, clock synchronization, and atmospheric studies. (**Canadian Space Agency)**

Specifications Development and Feasibility Study for Spaceborne GPS Receivers on the Proposed BOLAS Spacecraft

S. B. Bisnath, D. Gerrits, and R. B. Langley.

The proposed Bistatic Observations with Low Altitude Satellites (BOLAS) space mission is designed to study ionospheric phenomena in the auroral region. The space segment would consist of two approximately 75 kg subsatellites separated by a one hundred metre tether, rotating in a cartwheel-fashion in the orbital plane. It was proposed that GPS be used to synchronize the time and frequency signals required by the high frequency (HF) interferometry receiver in each subsatellite; for two-body attitude determination; and for precise orbit determination of each subsatellite in support of ionospheric limb sounding.

The requirements of the baseline TurboStar spaceborne receiver were determined and associated specifications developed. These included augmentation of the existing receiver to provide glitch-free frequency and time pulse output; investigation of the effects of the BOLAS cartwheel dynamics on the receiver performance; and the determination of data collection rate specifications.

A methodology was designed to provide the required ±20 ms timing coordination of the time standards involved in terrestrial pulse transmission and the reception of those pulses at the subsatellites. Also designed was a strategy to post-process the spaceborne GPS data to achieve the required phase coherence between the HF receivers. This strategy represents a novel procedure whereby on-the-fly kinematic relative subsatellite vector determination would be performed followed by the so-called geodetic method of time transfer to determine estimates of the differential GPS receiver clock offset with an accuracy of ±10 ns.

Associated GPS receiver investigations included studying the ionospheric occultation and tomography measurement requirements; developing specifications for the GPS receiver/phased antenna array interface; selecting an a posteriori precise orbit determination strategy; and refining the proposed GPS data collection scenarios. Also developed were future work plans involving algorithm development and receiver/antenna testing procedures. **(Bristol Aerospace Ltd.; Canadian Space Agency)**

GPS Multipath Assessment of the Hibernia Oil Platform

S. B. Bisnath, J. P. Collins, Y. Albrecht, and R. B. Langley.

The GPS multipath environment at the Hibernia Oil Platform was assessed in support of helicopter service. Three preferred sites for differential GPS (DGPS) station antennas were chosen on the platform, as well as a low-multipath site on the shore. Two days of dual frequency GPS receiver data were collected at these sites while construction and check-out of the platform was being completed in Bull Arm, Newfoundland. These data were processed in order to identify the potential magnitude of multipath induced error for a DGPS system to be located on the platform. Another goal of the project was to identify practical methods to mitigate the effects of this multipath.

The average root mean square (r.m.s.) pseudorange error for the three platform sites, determined from two 21- to 24-hour data sets, was computed to be approximately 5 m, 7 m, and 15 m; and the maximum range error to be 155 m, 200 m, and 300 m, respectively. To infer how these pseudorange errors would affect position determinations, baseline lengths between the shore site and the platform sites were determined. The mean r.m.s. baseline length error, due predominately to multipath, was computed to be approximately 3 m, 4 m, and 6.5 m at the three platform sites; and the maximum length error to be 54 m, 41.5 m, and 72 m, respectively.

From this analysis, as well as an analysis of the satellite sky distribution, one site was chosen as the optimal site for DGPS antenna placement. In addition, the use of new receiver processing technology and antenna chokerings and microwave absorbing material were recommended to reduce the multipath-induced error. Another recommendation was the use of an array of antennas to improve the integrity of the system.

Finally, it was recommended that a second study be contemplated with the platform in its final drilling location and orientation to re-assess the multipath induced errors at the preferred platform sites and to assess the residual multipath error of the installed DGPS system. (**Cougar Helicopters Inc.)**

GPS for Structural Deformation Surveying

J. P. Collins and R. B. Langley.

A preliminary investigation was carried out into the feasibility of using the Global Positioning System for monitoring the slow deformation of large structures such as dams. The intent was to identify the necessary processing and observing strategies required to reliably achieve centimetre to millimetre level relative coordinate accuracies. This would allow GPS to replace more conventional observing techniques.

The data used in this study were recorded at the U.S. National Geodetic Survey test network at Corbin, Virginia. Dual frequency Trimble receivers located at seven stations recorded data over a 48-hour period at a one-second sampling interval. The data were processed with UNB's DIPOP 3.0 software.

The results indicate that sub-centimetre coordinate accuracies are possible over small aperture networks with baseline lengths up to several hundred metres. However, this is contingent on having enough data to allow for the correct resolution of the carrier phase ambiguities. The limitation of achieving both this and the coordinate accuracy is provided by the existence of multipath at the observing stations. Further study is required into possible mititgation procedures to consistently achieve millimetre-level three-dimensional coordinate accuracies. **(U.S. Army Corps of Engineers)**

Reference Station Coordinates for U.K. Airport GPS Surveys

J. P. Collins and R. B. Langley.

We established three-dimensional Cartesian coordinates of three temporary active control stations in the United Kingdom for use in establishing GPS reference stations at various airports. A one-day subset of the dual-frequency Leica receiver data from the three active control stations was combined with data from three European stations in the International GPS Service (IGS) network and processed using UNB's DIPOP 3.0 software package. Data quality, including multipath, was first assessed using the UNAVCO QC software.

We processed the L3, ionosphere-free, linear combination of the carrier phases from the six stations. Any data below an elevation angle of 15 degrees was rejected. Standard atmosphere sea-level values of pressure, temperature, and relative humidity (1013.25 mbar, 288K, 50%) were used to drive the Saastamoinen tropospheric zenith delay model and Ifadis mapping functions. A residual delay for each station was estimated every three hours. This interval was chosen to avoid over-parameterizing the model. The integer ambiguities were not fixed. Precise orbits from the IGS combined solutions were used. The formal standard deviations of the resulting Cartesian coordinates of the active control stations were estimated to be less than 2 centimetres. **(SLC Associates)**

Modelling Tropospheric Propagation Delay Errors in GPS Airborne Navigation

J. P. Collins and R. B. Langley.

The use of GPS for airborne navigation provides a slightly different environment for modelling the GPS signal delay due to the neutral atmosphere. While ground stations can be provided with “real-time” measurements of pressure, temperature and relative humidity to help quantify the state of the atmosphere above the station, such measurements are usually not available to an aircraft’s receiver.

Hence, several models had been developed (e.g., Altshuler, NATO, initially proposed WAAS) that assume a basic model of the atmosphere in their algorithms to model the delay. These models are significantly less accurate than the more sophisticated models commonly used in space geodesy. In an effort to improve the delay modelling for airborne navigation, we have developed a new model that combines geodetic model algorithms with look-up tables of atmospheric parameters derived from the U.S. 1966 Standard Atmosphere Supplements.

Extensive tests with both kinematic GPS data recorded at an aircraft in flight and with ray-traced radiosonde data have demonstrated the improved accuracy of the new model (denoted UNB3) which has been adopted for use in the WAAS airborne GPS receiver. The focus of our current research has turned to investigating extreme atmospheric conditions that cause an unusually large signal delay, part of which cannot be accounted for by our model. The magnitude and frequency of the extremes are required to quantify the model errors. Knowledge of these errors will help ensure the accuracy and integrity of WAAS-derived aircraft positions. **(Nav Canada)**

Continuous GPS Monitoring of Crustal Deformation with the Western Canada Deformation Array: 1992-1995

X. Chen and R. B. Langley.

Data from high-precision, continuous GPS monitoring of the crustal deformation in the northern Cascadia subduction zone, which is located in southwestern British Columbia and known to be one of the most seismically active regions in North America, has been subjected to a rigorous analysis and deformation rates have been estimated.

Although conventional geodetic measurements were made in the past showing a consistent deformation pattern in the region, these measurements have relatively large uncertainties. In contrast, GPS, as a modern geodetic technique, provides the best means for deformation monitoring: higher accuracy, lower cost, more efficient, and near-real time. The Western Canada Deformation Array (WCDA) is a GPS network designed to monitor the crustal deformation with high precision. It has been in operation since its establishment in the summer of 1992 and is still under development.

The daily data collected from the WCDA stations have been reduced using the CGPS22 software package and the precise orbits generated by Natural Resources Canada (NRCan) or the International GPS Service (IGS). A specific estimation strategy has been designed and different measurement models have been tested in order to achieve high accuracies. Based on the estimation strategy, 811 days of daily solutions spanning from September 1992 to April 1995 have been obtained and analyzed in particular.

Despite some problems with the data and software models, the precision assessment for the WCDA solutions shows long-term repeatabilities of 2 to 5 mm in horizontal components and 6 to 9 mm in vertical components for baseline lengths ranging from 302 to 627 km. Linear rates in each of the baseline components have been estimated by the Least Squares Spectral Analysis algorithm, along with offsets and periodic constituents. In general, these linear rates show a deformation pattern consistent with that obtained from previous conventional measurements. However, a higher resolution on the crustal deformation signals and a better separation of GPS measurement errors from the deformation signals would require a longer set of solutions and more effort on error handling. **(NSERC)**

Global Ionospheric Total Electron Content Mapping Using GPS

A. Komjathy and R. B. Langley.

Based on a modified version of UNB's DIPOP software package, we have developed a procedure to produce hourly global total electron content (TEC) maps from Global Positioning System (GPS) data. The software incorporates an algorithm that uses spatial linear approximation of the vertical TEC above each GPS station with stochastic parameters in a Kalman filter estimator to describe the local time and geomagnetic latitude dependence of the TEC. A shell model of the ionosphere with temporally and spatially varying height is used. Our hourly GPS-derived global TEC maps can be ingested directly into a modified version of the International Reference Ionosphere 1995 (IRI-95) model – augmented with a plasmaspheric electron content model – to update its coefficient sets. We have used the technique to provide improved IRI-95 predictions by using the modified model as a sophisticated interpolator between hourly GPS-derived TEC updates. The updated IRI-95 coefficient sets will make it possible to provide ionospheric delay corrections for various applications including single frequency spaceborne radar altimeter missions such as Geosat Follow-On. **(NSERC)**

DGPS Marine Radionavigation Beacon Receiver Testing

P. Lathion and R. B. Langley.

Testing of a CSI DGPS marine radionavigation beacon receiver was carried out in the Fredericton area to assess the quality of reception of signals from the Canadian Coast Guard's DGPS beacon network and the performance of the CSI receiver. **(NSERC)**

Neutral-Atmosphere Propagation Delay Modeling in Space Geodesy Applications

V. B. Mendes and R. B. Langley.

The principal limiting error source in the Global Positioning System and other modern space geodesy techniques, such as very long baseline interferometry, is the mismodeling of the delay experienced by radio waves in propagating through the electrically-neutral atmosphere, usually referred to as the tropospheric delay. A hydrostatic (or dry) and a wet component is generally considered. Each of these components can be expressed as the product of a corresponding delay at the zenith and a mapping function that models their dependence on the elevation angle of the signal raypath.

We have analyzed a large number of zenith delay prediction models and mapping functions that have been developed for geodetic applications or for airborne positioning over the past few decades. For our most recent study, we have ray-traced nearly 35,000 atmospheric profiles from 50 radiosonde stations around the world to obtain truth data against which we compared the performace of the zenith delay models and mapping functions.

We have used profiles from 100 radiosonde stations to better characterize the behaviour of tropopause height and temperature lapse rate and developed models that allow their determination using surface temperature information. With these models, we have improved the performance of mapping functions that use this information as an input.

We have also studied the relationship between the wet zenith delay and integrated precipitable water vapour based on ray tracing. The models we have developed constitute an improvement over those reported in the literature. **(Laboratório de Tectonofísica e Tectónica Experimental, Univ. of Lisbon; NSERC)**

Real-time Relative GPS Tests

V. Pechar and R. B. Langley.

To obtain a better understanding of real-time kinematic (RTK) differential GPS positioning, including its limitations in practical applications, a series of tests were carried out using Ashtech RTZ equipment. Diverse data sets were collected and analyzed to show the improvement in RTK positioning accuracy compared to code-based differential GPS as well as RTK positioning's shortcomings under certain conditions. Testing included zero-baseline set-ups, hardwire links with a variety of data transmission rates, and code and RTK differential tranmissions. **(Univerität Stuttgart; NSERC)**

Atmospheric Investigations for WAAS — The Ionosphere

P. Stewart and R. B. Langley.

On passing through the ionosphere, electromagnetic signals from satellites such as those of the Global Positioning System are subject to a phase advance and group delay. In order to properly utilize these signals for ranging purposes, these ionospheric effects must be accounted for. Fortunately, the magnitude of the advance and the delay is, to an excellent first approximation, inversely proportional to the square of the frequency of the carrier wave, and so dual frequency GPS observations may be used to estimate ionospheric delay values.

GPS receivers used in aviation are typically single frequency units, however, and are therefore not capable of correcting for the ionospheric effects with the technique described above. The Wide Area Augmentation System (WAAS), currently being developed under the sponsorship of the Federal Aviation Administration (FAA), aims to provide (amongst other corrections) a method for the single frequency GPS user to determine ionospheric delay from a set of grid node values interpolated from dual frequency data collected at a network of sites around North America.

Research currently being conducted at UNB, and funded by Nav Canada, concentrates on evaluating this method for use in Canadian airspace, and involves comparison of the WAAS grid model with various “truth” sources such as data from independent dual frequency GPS receivers, and also with alternative ionospheric models. Our alternative portrayals of the ionosphere will attempt to take account of the highly dynamic nature of the ionosphere at northern latitudes, and will permit us to evaluate model features such as varying the height of the assumed ionospheric “shell”, and the use of more sophisticated mapping functions. Another important aspect of this work concerns the solar activity which drives the ionosphere. This activity fluctuates on an approximately 11 year cycle, and with the next maximum forecast to occur around March of 2000, predictions of the impact of increased ionization on WAAS are required. (**Nav Canada)**