Integration of Local Surveys into the Canadian Spatial Reference System

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Presented at the Public Works and Government Services Canada (PWGSC) Survey Contracting and CACS Seminar, Edmonton, Alberta, February 24, 1998.
Revised May 25, 1998.

Introduction

Local surveys can be integrated into the Canadian Spatial Reference System (CSRS)* and its NAD83(CSRS) datum in basically two ways. The traditional approach is based on measurements (or connections) to existing control points with known positions in the NAD83(CSRS) datum. The NAD83 positions of the local survey are determined indirectly from the known NAD83 positions of the control points. The other method of integration is based on precise GPS point positioning using the precise GPS ephemerides and clock corrections as determined by the CACS tracking network. In this case, the satellites effectively serve as the known control points. Each of these methods will be discussed here.

Whatever method of integration is used, it should be evaluated through testing (such as a GPS validation survey) to ensure it is capable of providing the required accuracy. In addition, a sufficient level of redundancy should be incorporated into the method to verify the achieved accuracy.

Integration via Precise Point Positioning

GPS point positioning using pseudo-ranges is the most common method of GPS positioning. Although it provides positions in real-time, the normal accuracy of this standard mode of operation is only about 100 m horizontal and 150 m vertical at the 95% confidence level. However, by using precise GPS ephemerides and clock corrections from the Canadian Active Control System (CACS), much greater accuracy can be obtained. In low multipath environments and under good satellite geometry (GDOP $\leq$ 5), individual point positions can be obtained with an accuracy of better than 2 m horizontally at the 95% confidence region.

The point positioning accuracy is mainly limited by ionospheric, tropospheric and multipath effects as well as the accuracy of the satellite ephemerides and the resolution of the pseudo-range measurements of the GPS receiver. The following steps can be taken by the user to minimize the effects of these error sources:

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- Accuracy of ephemerides and clock corrections: Precise ephemerides and clock corrections should be used in order to achieve metre level accuracy. Although precise ephemerides are available from some organizations participating in the International GPS Service for Geodynamics (IGS), only a few provide the necessary clock corrections for precise point positioning. Care must be also exercised to ensure the resulting positions are in the required coordinate system or datum (i.e., NAD83).

  Note: The Geodetic Survey Division (GSD) makes available precise ephemerides in both NAD83(CSRS) and the International Terrestrial Reference Frame (compatible with WGS84), as well as precise clock corrections. The precise ephemerides and clock corrections can be applied using the GPSPACE software (also available from GSD as part of its CACS product line). A few other commercial GPS software packages are also capable of using this information to perform precise point positioning.

- Ionospheric effects: This effect varies with sunspot activity and is more pronounced at northern latitudes and the equator. Currently, the only reliable way of minimizing this effect is to use dual frequency GPS receivers to correct for the bulk of the error. Strong ionospheric effects can also cause loss of “lock” on the GPS signals for which there is no remedy. It is always advisable to monitor the ionospheric prediction bulletins and avoid periods of high ionospheric activity .

- Tropospheric effects: Standard tropospheric models can reduce the bulk of this effect. Testing indicates that the remaining residual errors are typically less than about a decimetre. If necessary, the residual errors can be randomized by over long observing periods or by multiple occupations at different times of the day and on different days.

- Multipath effects: This effect is a function of the geometry of the observed satellite configuration. Because the geometry changes systematically over time, the error can be randomized and “averaged out” over time. However, the length of averaging time needed depends on the local multipath conditions and is difficult to predict in advance. It is best to avoid potential multipath environments and to average over multiple occupations at different times.

- Measurement resolution: This error is small and considered random. If necessary, it can be reduced by averaging over time.

Local surveys can be integrated into NAD83(CSRS) using estimated point positions as position observations, weighted by their estimated standard deviations, in an over-constrained network adjustment. In order to provide checks on the presence of the above systematic effects and obtain realistic estimates of the standard deviations of the estimated point positions, a sufficient level of redundancy should be incorporated into the method of integration. Generally, this involves multiple occupations of multiple stations in the local network. For example, a minimum of three stations is usually sufficient to provide independent checks on an error in the point position of any one station, while independent reoccupations of stations made at different times of the day can be used to randomize potential systematic errors (e.g., multipath) and obtain more realistic accuracy estimates. Tests have shown that realistic accuracy estimates can usually be obtained with 2 hrs. of data.

The local survey may also be used to verify the relative accuracy of the estimated point positions for different points in the project. The coordinate differences between the point positions should be statistically compatible with the coordinate differences from the local survey. The compatibility can be assessed by comparing the estimated point positions to those derived from a minimally constrained adjustment of the local survey with one of the point positions fixed. Any statistically incompatible discrepancies should also be revealed as "outliers" in a combined (over-constrained) adjustment of the local survey and the estimated point positions. Significant outliers or discrepancies may be due to errors in the estimated point positions, errors in the local survey or incorrect weighting of the point positions or the local survey.

Integration via Direct Connections to Control Points

The traditional method of integrating local surveys into NAD83 is to directly connect them to existing control points with known coordinates in the NAD83 datum. Positions for the local survey are determined indirectly from the known positions of the control points. Care must be taken, however, to ensure that the control points are in the correct reference system and of sufficient accuracy.

Although it may be possible to physically occupy control points nearby, these may not be of sufficient accuracy (particularly in remote areas) or even in the correct reference system. It is often more convenient and accurate to compute GPS baselines directly to the continuously operating CACS stations using their GPS carrier phase observations. The carrier phase data for all CACS stations is available from GSD in RINEX format at a 30 sec. data rate. Although the positioning accuracy of this method is generally much better than precise point positioning, it is limited mainly by the same effects as for point positioning, as well as the accuracy of the known control. The following steps can be taken by the user to minimize the effects of these error sources:

- Orbit errors: The effect on baseline vectors of errors in the current broadcast GPS ephemerides can generally be reduced to the decimetre level through "double difference" carrier phase processing. More accurate results can be achieved using precise ephemerides, such as those available from GSD.

  Note: It is important to ensure the computed baseline vectors are in the required coordinate system (i.e., NAD83). Most GPS software compute baseline vectors in the coordinate system of the satellite ephemerides. Thus, if broadcast ephemerides are used, the computed baselines will be in the WGS84 reference system . Depending on the length, orientation and location of the baseline and accuracy required, it may be necessary to transform the computed baselines to NAD83. For example, in the far north where baselines to CACS stations can be over 2000 km long, the differences between baselines in NAD83(CSRS) and WGS84/ITRF94 may reach the few decimetre level. It is generally more convenient to instead use precise ephemerides expressed in the NAD83(CSRS) reference system. In this case the baselines are computed directly in NAD83 and no transformation will be required. GSD provides precise ephemerides in both NAD83(CSRS) and ITRF. For those using ephemerides in WGS84 or ITRF, GSD can also provide parameters for transforming the resulting baselines to NAD83(CSRS).

- Ionospheric effects: As for point positioning, the only reliable way of minimizing the effects of the ionosphere is to use dual frequency GPS receivers to correct for the bulk of the error. It is also advisable to monitor the ionospheric prediction bulletins and avoid periods of high ionospheric activity .

- Tropospheric effects: Over baselines less than about 30-50 km, much of the tropospheric effect can be reduced through double difference carrier phase processing. Over longer baselines the effect can become significant, depending on weather conditions, but is generally small and not likely to be of much consequence for integration purposes. If necessary, the residual error may be partially randomized and averaged out though multiple occupations of points at different times of the day.

- Multipath effects: As for point positioning, it is best to avoid potential multipath environments and to try to average out part of the effect by collecting baseline data over a longer period of time and at different times of the day.

- Measurement resolution: For geodetic quality GPS receivers, the carrier phase measurement error is generally considered random and insignificant (mm level) in comparison to the systematic errors above.

- Ambiguity resolution: For baseline less than about 30-100 km it is common practice to try to resolve and fix the unknown integer carrier phase ambiguities in order to improve the precision of the estimated baseline vector. Different GPS survey techniques (e.g., rapid static, kinematic, static) use different methods to reliably and accurately determine the ambiguities. The particular technique used should be adequately evaluated in a GPS validation survey. Over longer lines up to about 100 km, only the static technique can generally be used to resolve and fix the integer ambiguities. For even longer lines (e.g., to CACS stations), it is not recommended to try to fix the ambiguities to integer values.

- Accuracy of known control: The accuracy of the positions for the known control points depends primarily on the quality of the existing control network. Traditional horizontal control networks suffer from the accumulation of errors in the hundreds of thousands of measurements needed to construct conventional national and regional networks. For example, the national NAD83 horizontal networks is now known to contain errors of the order of 0.25 to more than a few metres in remote areas such as the far north. It is strongly recommended to use instead the more modern 3D control networks comprising the CSRS, which utilize high accuracy GPS techniques over longer lines to reduce the accumulation of errors and greatly improve accuracy. These 3D networks include the CACS, Canadian Base Network (CBN) and provincial/regional high precision networks (HPNs). For example, the positional accuracy of the CACS network is about 1 cm, while that for the CBN is about 2-5 cm. Regional HPNs are expected to have positional accuracies of about 5-10 cm.

Local surveys can be integrated into NAD83(CSRS) by combining them with baselines to control stations in an over-constrained adjustment, using the published positions of the control stations and their standard deviations as position observations (constraints). However, care must be taken to ensure there is a sufficient level of redundancy to provide checks on these baselines and that they are weighted appropriately with respect to those in the local survey. As for the point positioning method, this generally involves baselines from multiple stations in the local network to multiple control points made at different times of the day. For example, a minimum of three points in the local survey each connected to at least 3 known control points in NAD83(CSRS) is usually sufficient to detect any error in one of the baselines to the control. Computing baselines to CACS stations is generally the most convenient method of connecting a local survey to NAD83(CSRS). In this case a minimum of only 2 CACS connections from each of the local survey points may be needed because of the greater reliability of CACS data and positions, providing there are redundant connections to CACS from other points in the local network. Testing has indicated that decimetre level accuracy can be achieved on baselines to CACS stations up to a couple of thousand km. away using the static carrier phase processing technique with 1 hr. of data.

The local survey may also be used to verify the accuracy of the baseline connections to the control points if there is a sufficient number of redundant connections to the control network. Any statistical incompatibility between the local survey and the connections to the control network should be revealed as "outliers" in the baseline residuals from either a minimally constrained and over-constrained adjustment of all the baselines. Significant outliers may be due to errors in the baselines to the control points, errors in the local survey or incorrect weighting of the baselines. Care should be taken to ensure the baselines to the control points are correctly weighted relative to those in the local survey during the over-constrained adjustment. Weights derived from standard deviations or covariance matrices that are too optimistic may distort the local network.

Combined Approach

The two methods of integration described above are not mutually exclusive. In fact, because they are based on different observables (pseudo-ranges versus carrier phases), absolute point positions can be used together with baselines to control points to provide checks on each other and improve redundancy without any additional cost in terms of observations.

Validation of Integration Method

Whatever method of integration is used, it should be thoroughly tested and evaluated on a network with known, accurate positions in NAD83(CSRS) to ensure it is capable of providing sufficient accuracy and reliability. This should normally be done during the validation of the local survey methodology. It is very important that the testing be carried out under similar conditions to which the integration is to be used in practice. For example, the distances from the local survey to the known control points (e.g., CACS stations) should be typical of what will be expected during the actual survey.

Further Information

For further information about the CSRS, CACS products or network integration issues, contact the Geodetic Survey Division of Geomatics Canada. These recommendations are also being continually revised to reflect current technology and test results. Users should contact GSD for the latest revisions.

Acknowledgments

This document was based on an earlier version entitled "Application of Canadian Active Control System Products for the Integration of Local Survey Networks" by Robert Duval and Susan Blackie, April 1995.