PPVRS Rushes in a New Era for Hydrographic Surveying

This paper describes a technique for centimetric positioning in hydrographic surveying using a network of GPS base stations to determine ephemeris, clock and atmospheric errors at the rover location. This technique uses the GPS observations from a Virtual Reference Station to compute a tightly integrated GPS/Inertial solution, with minimum baselines of over 100km.<P>

Today's primary positioningtechnique for near-shore (within 100km) marine hydrography is based on the integration of GPS and inertial navigation systems (INS). The inertial measurement unit (IMU) aids in reducing GPS noise as well as providing high-bandwidth uninterrupted solutions during GPS outages. For high-precision surveys (5cm or better in X, Y and Z), the most common technique has been the post-processed inertially aided kinematic ambiguity resolution (IAKAR) mechanisation, which requires a reference station in the proximity of the survey area. The reference station helps to mitigate atmospheric and satellite biases and to resolve integer ambiguities (number of full cycles on the carrier signal wave). In these cases, the GPS rover position is required to be within 20km of the reference station. Otherwise, the atmospheric biases degrade the accuracy of the results, imposing significant limitations and increased survey costs. Here we describe the new Applanix SmartBaseTM software, released within Applanix POSPac, utilising the post-processed virtual reference station (PPVRS) technique and the tightly coupled inertially aided post-processed kinematic (IAPPK) techniques for marine hydrography.

PPVRS makes use of GPS network stations to determine atmospheric biases at the rover positions. POSPac integrates GPS with inertial data to provide continuous, high-precision navigation solutions with minimum reference station baselines of up to 100km. Unlike the traditional loosely coupled GPS-inertial integration, tight integration maintains an accurate position fix even if there are less than five satellites in view. Even after a complete GPS outage, the tight integration works to re-establish fixed integer ambiguities almost immediately after satellites are reacquired, thus reducing the effect of a signal loss.

POSPac not only allows for the post-processing of position and orientation data, but also for processing in both the forward and backward directions. This results in a 'smoothing' effect on GPS outages, producing an accurate solution even if signal loss occurs.

The Applanix SmartBase Workflow

A standard NOAA hydrographic survey was performed in the Chesapeake Bay to test the work flow. Data acquisition was conducted aboard NOAA Ship Rude (pronounced 'Rudy') on 18 October 2007 as part of the acquisition of a multibeam reference surface. The workflow started on the vessel where all raw positioning sensor data was logged for post processing. GPS reference station data were logged onshore for the same time period. For this test, actual continuously operating reference stations (CORS) data were used as provided on NOAA's National Geodetic Survey's website.?Post-mission processing began with an extraction of the vessel raw data files and a check for completeness and data integrity. The extracted data was formatted for use in downstream processing, in a directory structure suitable for standard desktop computers with average speed and storage capacity.

Reference Station Import

Once the extraction of the vessel data was complete, the reference station data was downloaded (or imported) into the processing package. The reference station download tool automatically retrieves the data for the coinciding time interval of the survey. In the case of an internet download using an existing set of permanent GPS reference stations, the software identifies those stations within a user-defined radius from the middle of the survey trajectory. A database of stations is maintained within the POSPac software along with an automated tool for FTP access to sites, making reference station data available for public use.

A minimum of four reference stations are required, although typically five–ten are used. A search radius of up to 200km is recommended, less if there are stations near the survey area. In order to maintain centimetric accuracy, at least one of the stations must be within 100km of the rover at all points of the survey (the closest station is allowed to change). In this survey, all stations were within 200km of the survey trajectory and 38 stations were within the recommended 200km search radius. For the final processing of data, seven stations were used.

Reference Station Quality Check

Once the reference station data is downloaded, a network adjustment is applied to check for accurate base station position and for reference station data integrity. The network adjustment uses GPS measurements, input base station coordinates and computed baselines in a least-squares adjustment. Twenty-four hours of reference station data are required for this quality check in order to ensure the most accurate validation of base station coordinates. The reference station data should be without cycle slips or data gaps. If a shorter time period is used, centimetric accuracy in the final rover position cannot be guaranteed.
The software automatically disables reference stations according to predetermined thresholds i.e. when the horizontal and vertical differences in computed coordinates vary from the input coordinates by more than 5cm, or when there is less than 24 hours of operational data with the time of the survey as the centre of the time window.
For the purposes of the network adjustment, the software automatically selects one station as the control station. The coordinates of this control station are fixed in the network adjustment, and it is usually the closest station to the survey. The user can overrule the control station selection.

Generate Corrections
The next step is correction generation, when the data from the network of reference stations is used to generate a single set of corrections for the rover. The station closest to the survey with the cleanest data is selected by the software as the primary station. The GPS observables from the primary station, together with atmospheric corrections computed from the network of GPS stations, are used as a basis to compute the VRS observables at the rover position. Correction generation, guaranteed to meet specifications if the rover survey trajectory is inside the area circumscribed by the network of reference stations, relies on consistency in the reference data. Data gaps and cycle slips are continuously checked for. If the operator chooses to use a station with gaps, the station is used when available and the remaining stations are used when it is not. The operator report is shown in Figure 1.

Tightly Integrated Inertial Navigator
The final step in the workflow is computing the tightly integrated position and orientation solution using the observations and the raw GPS and inertial data extracted at the beginning of the workflow. The data are processed in both the forward and backward directions, smoothing the effect of GPS outages and other irregularities in the data. This smoothing results in the best possible position and orientation solution for a given dataset, maintaining centimetric accuracy for significantly more time and at longer distances from shore than would be possible with traditional GPS processing. The output from this process is referred to as the smoothed best estimate of trajectory or SBET. A quality check using a suite of statistical checks on the final solution is also performed.

Results
The result of tightly integrating the SmartBase data, vessel GPS and inertial observations in the inertial navigator are displayed in Figure 2. The RMS results show that all data (with the exception of the start and end of line) are below 10cm with the majority of the data accurate to better than 5cm in X, Y and Z. It should be reiterated that this was accomplished with no user installed base stations, using only CORS found on the NGS website.

The reason for these excellent results is found by examining the display of the processing mode, where Mode 0 is equal to fixed integer narrow lane. In other words, all cycle ambiguities were resolved for all GPS epochs. It is worth noting that the forward/backward smoother is effective in providing fixed integer mode in both the forward and backward direction.
The distance to the closest station is an important statistic for illustrating one of the key advantages of this technology. In the example above, centimetric accuracy is successfully maintained throughout the entire dataset, even although the nearest base station in continuous use is at least 65km away (with a maximum of up to 72km distance in certain parts of the survey).

Data Quality
A code-based real-time position and orientation solution was computed for this case study (using the Applanix POS MVTM package) with typical accuracy of about 1m. As an additional quality check, the operator compared the results of various survey processing ‘runs’. The difference graph in Figure 3 shows the difference in positions for the real-time and post-processed solutions. As might be expected, differences of up to 2m are evident, which serves to further underline the accuracy improvement inherent in the post-processed solution.

Quality Assurance statistics can be plotted in POSPac. Some of the more relevant statistics and plots available include:
• smoothed best estimate of trajectory;
• performance metrics, RMS for
- position in X, Y and Z;
- heading;
- roll;
- pitch; and
- velocity;
• smoothed error estimates including
- accelerometer biases; and
- gyro biases;
• solution status including
- number of SVs;
- PDOP; and
- processing mode.

Each of these statistics may be examined to ensure they fall within prescribed limits. This ensures a statistically robust solution and smoothed best estimate of trajectory.

The Bathymetry Results
The gridded bathymetry produced onboard the Rude shows that results from the tightly integrated inertially aided SmartBase technique using ellipsoidal altitude are superior to the tidally referenced bathymetry. Positional accuracies are greater by at least an order of magnitude, and loading, dynamic draft and tide effects are negated since the vessel’s vertical position is being accurately measured. The improved handling of dynamic draft can be seen in the difference surface where linear artefacts are present due to subtle changes in ship’s speed as shown in Figure 4. Figure 5 (left) is an image of the sand waves seen in the reference surface acquired by Rude using SmartBase and Figure 5 (right) is an image of the exact same location from an identical angle created using the traditional method. Close examination reveals greater detail in the left image on the small objects within the survey areas, as a result of the improved accuracy.

Conclusions
The PPVRS and IAPPK methodologies available in the Applanix POSPac software, and the associated workflow, provide a logistically simple method for achieving tremendous accuracy without the need to install and maintain dedicated base stations. The overall process is simple and can be easily added to existing hydrographic data processing workflows without asignificant loss of processing productivity.