Hydrographic Surveying on the Ellipsoid with Inertially-Aided RTK

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ABSTRACT

Accurate heave measurements are a critical component of the measurement of a hydrographic survey vessel's vertical motion. With the use of RTK GPS, a survey vessel's vertical position can be measured as an altitude on the WGS-84 ellipsoid, with accuracy similar to that provided by the heave measurements. The Applanix POS MV system is a GPS-aided inertial navigation system which provides heave measurements and accurate altitude measurement on the WGS-84 ellipsoid in addition to a complete suite of position and orientation measurements. Applanix has been developing new techniques for providing robust real-time and post-processing methods of altitude measurements which span RTK outages.

INTRODUCTION

The ability to accurately compute heave measurements is a critical component in the successful acquisition of marine hydrographic surveys. A recent trend in hydrographic surveying is the production of vessel altitude measurements relative to the WGS-84 ellipsoid using either real-time kinematic (RTK) or post-processed kinematic (PPK) GPS positions.

An Inertially-Aided Real-Time Kinematic (IARTK) Position and Orientation System (POS) produces a very accurate estimate of the echosounder location on the ellipsoid over all vessel dynamics with data rates of up to 200 Hz. Recent work to look at vessel motion from sub-second periods to tens of hours was undertaken to develop new measurement products such as RTK-Heave and RTK-Tide (Sanders, 2003) and to develop new techniques to reduce the effects of GPS carrier phase cycle slips and long RTK outages.

The availability of carrier phase GPS signals for accurate positioning on the ellipsoid is limited to relatively short distances from shore. RTK-based positioning requires a real-time solution to the GPS-outage problem and an example is shown. PPK-based positioning allows the user to acquire raw navigation data and perform a recomputation of data based on carrier phase processing in post mission. At present the user needs to decide whether to install an RTK base-station and radio link and incur possible outages versus logging a gigabyte or more of raw inertial data for post-processing.

The data used for this analysis was collected on Lake Ontario in November 2003. Information on the survey location and the survey vessel's configuration can be found in Arumugam et al., 2004. Another dataset used for this analysis was collected off the coast of the Alaska Peninsula in July 2004.

BACKGROUND AND HISTORY

POS MV - Tightly-Coupled Inertially-Aided RTK

The POS MV system is a tightly-coupled inertial/GPS integrated system with IARTK. Figure 1 shows a photograph of the POS MV system which consists of a POS Computer System (PCS), the inertial measurement unit and two GPS antennas.

Figure 1 Applanix POS MV hardware components

The system block diagram is shown in Figure 2. The Inertial Navigator provides a very accurate estimate of the vessel's position (on the WGS-84 ellipsoid) and its pitch, roll and heading at rates up to 200 Hz. The POS MV system includes the GPS Azimuth Measurement Sub-system (GAMS) which uses two GPS antennas to provide accurate heading aiding for the inertial navigation system. The POS MV system also uses the Z-axis accelerometer channel to generate the heave and TrueHeave channel.

In the tightly-coupled POS system, the GPS receiver is used as a source of observables (pseudo-range, carrier phase and Doppler) only. The GPS observables are used to aid the inertial navigator even when fewer than four satellites are visible. With inertially-aided RTK, the POS system's Kalman filter also estimates the floated phase ambiguities. Integer ambiguities are fixed using an on-the-fly (OTF) ambiguity resolution algorithm (Scherzinger, 2002). After a full outage, RTK is typically recovered in 5 to 10 seconds and after a partial outage RTK may be recovered in as quickly as 1 second.

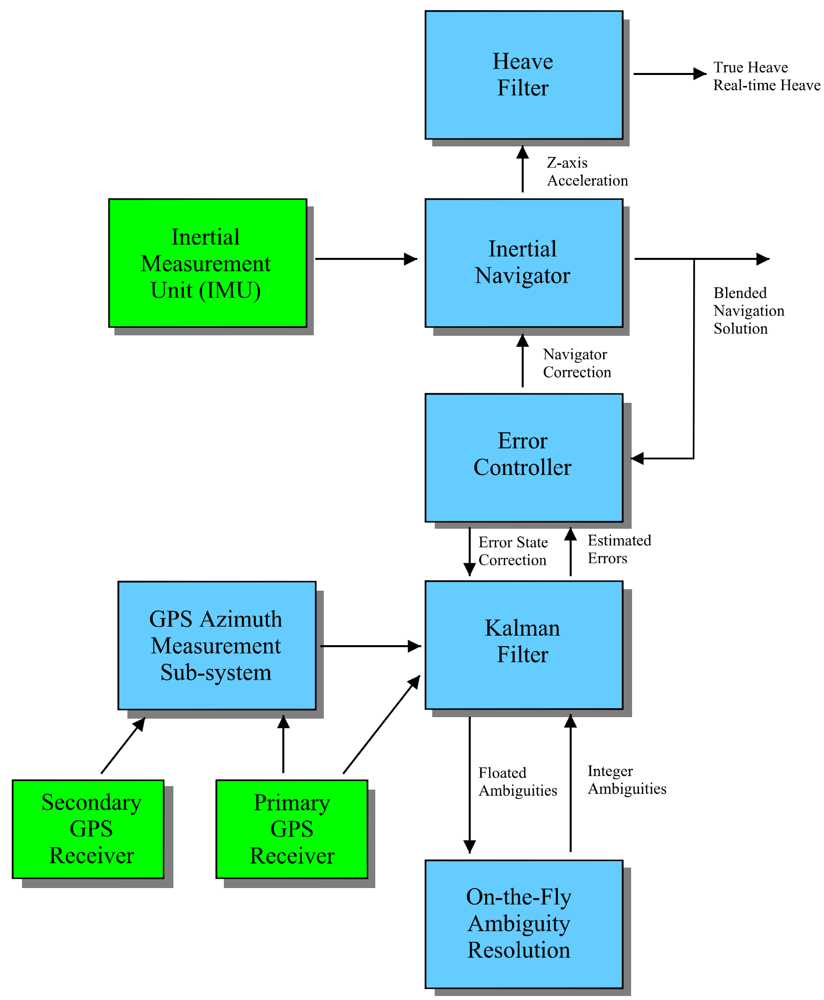


Figure 2 POS MV – Tightly-coupled Inertially-Aided RTK

The Heave Channel - Understanding Traditional Estimates of Vertical Positioning

Since multibeam echosounders first started using Position and Orientation Systems (POS), the heave channel was used to estimate a vessel's vertical motion. The heave channel is based on high-pass filtered double integrated vertical accelerations as depicted in Figure 3. With the recent introduction of the TrueHeave technique, the reliability of the heave solution from POS, under certain difficult dynamics and swell conditions, has increased dramatically (Canter and Corcoran, 2004)

Traditional heave estimates typically measure vessel motion over periods ranging from sub-seconds to 30 seconds. Nearby water level gauges can be used to measure tide effects with a period of half a day and seiche effects (seen in Lake Ontario) with a period of approximately 15 minutes (or less) to 1hour. Squat, settlement, dynamic draft and other long period vessel motion remain unaccounted for, as they are not included in the heave or water level gauge measurements. Figure 4 summarizes the changes in water level which the hydrographic surveyor needs to consider.

With RTK GPS measurements of vessel altitude, Applanix is looking to fill in the measurement gap between the heave measurements and the tide gauge measurements.

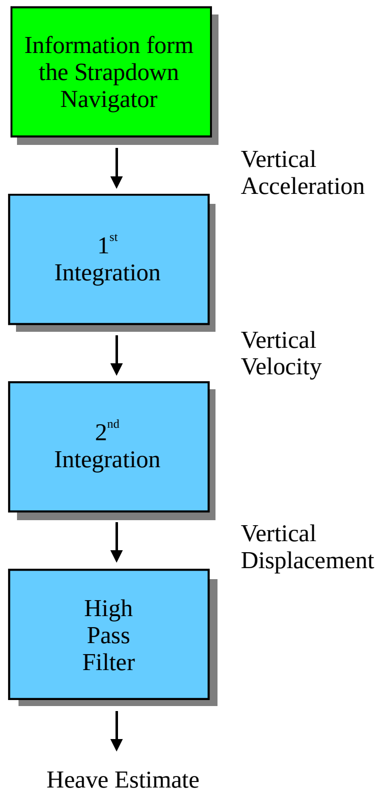


Figure 3 Double Integrated Vertical Acceleration = Heave

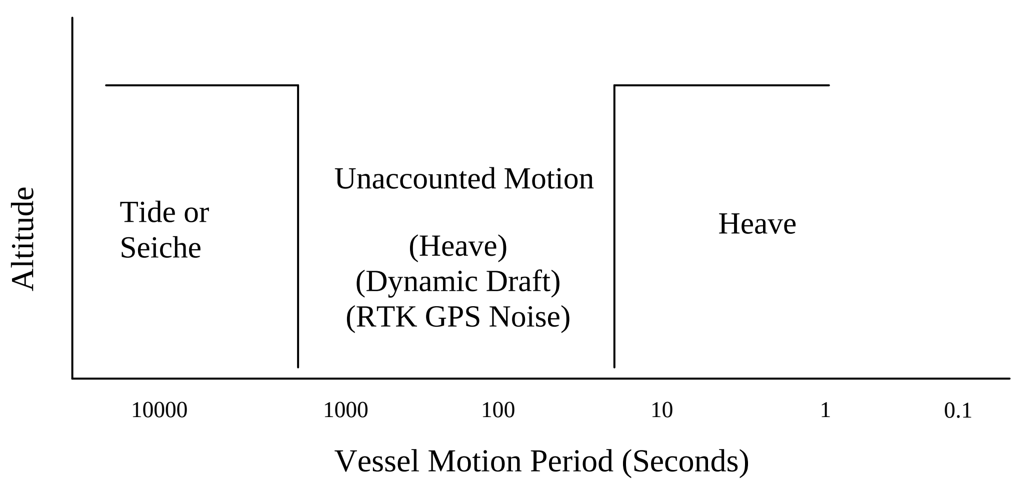


Figure 4 Vessel Motion Periods – Measured and Unmeasured

Long Period Vertical Motion – The Tide-Like Channel

Vessel vertical motion included in the heave channel includes motion with periods of 30 seconds or less. To observe vessel altitude motion over periods longer than those normally included in the heave channel we can subtract the heave channel from the POS altitude channel to take out short term motion. This produces a channel of the long term heave data which we have come to call the “Tide-Like Channel”.

Figure 5 shows a plot of the tide-like channel and the Toronto water level gauge measurements. The upper profile is the tide-like channel derived from the POS altitude channel after transformation to the IGLD85 datum. The lower profile is the water level gauge reading. In this plot, the seiche effect in Lake Ontario, which is the formation of standing waves, can be observed (Arumugam et al., 2004). The plot reminds us that the traditional heave channel does not measure all the changes in vessel altitude (or water level). This becomes apparent when we look at altitude referenced to the ellipsoid.

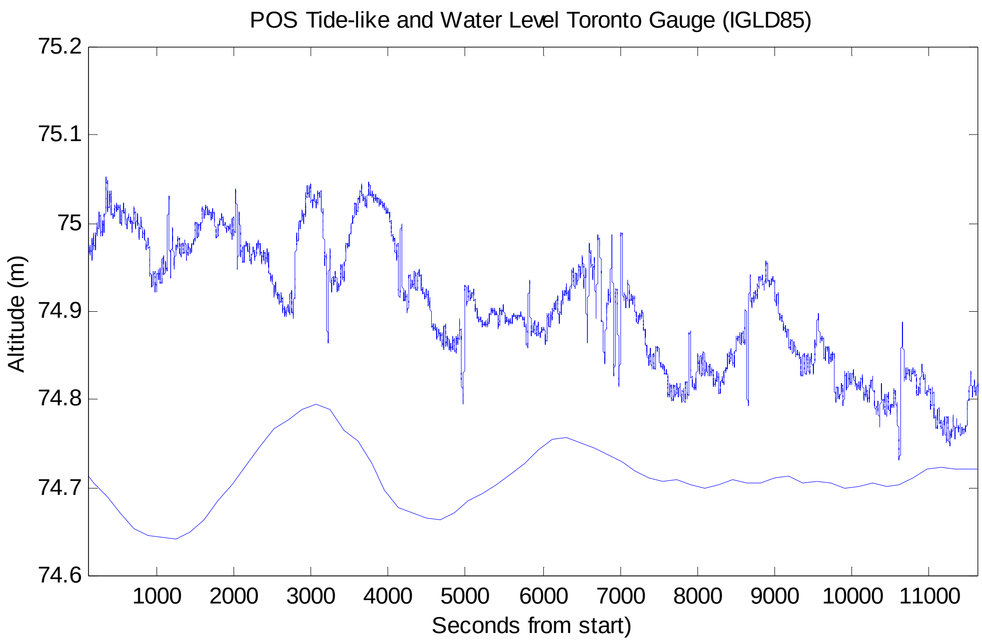
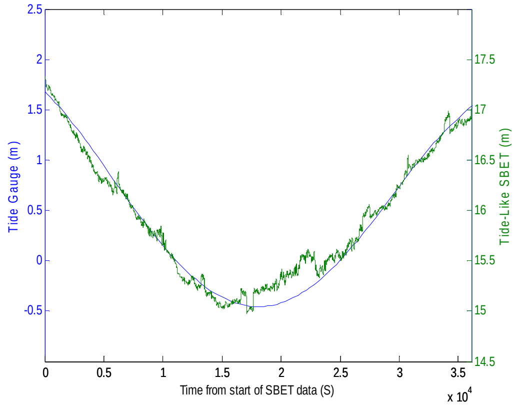


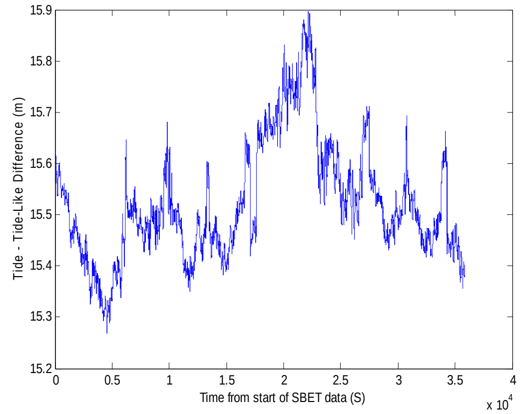
Figure 5 Seiche Effect in Lake Ontario - Measured By POS

The Toronto water level gauge is approximately 30km from the survey area and there is little correlation between the tide-like channel and the water level gauge. Use of the water gauge on the survey data set would therefore add error.

The Lake Ontario example is contrasted with a dataset collected off Alaska in July 2004. Figure 6 shows a comparison of the tide-like channel in the open sea with an overlay of a nearby tide gauge. Figure 6A) shows the tide gauge plotted in blue and the POS tide-like channel plotted in green. Figure 6B) shows the difference between the tide-like channel and the tide gauge measurement. The variation is approximately ±30cm over the 10-hour period shown in the figure. Most of the variation can be explained by changes in vessel speed and squat. This comparison leads us to believe that we are truly measuring the sea surface ellipsoidal height.



A) Plot of Tide-like channel from IARTK altitude data compared with Tide Gauge, limiting the x-axis to the IARTK data range. (Note the different y-axis ranges)



B) Plot of the difference between the Tide-like channel from IARTK altitude data and the Tide Gauge over the periods of the available IARTK data.

Figure 6 Tide and Tide-Like Channel Comparison – Alaska 2004

GPS OUTAGE IMMUNITY ANALYSIS

Since accurate measurement of vessel altitude on the ellipsoid requires RTK GPS, and given that RTK GPS suffers from outages, a technique is required to fill in the gaps to provide a robust measurement product. The previous section shows that there is unaccounted vessel motion (motion that is not measured within the heave channel or by tide gauges). As the heave channel provides a measure of vessel motion out to periods of 30 seconds, a technique which would use the heave data to fill in the gaps in the RTK coverage was investigated.

Comparing Inertially Aided Kinematic GPS Z and the Heave Channel

POS altitude (Z) and the heave channel can be compared by filtering the altitude channel to limit vessel motion to the same periods as the heave channel. Figure 7 shows a plot of the heave channel and a high-pass filtered POS altitude channel. The heave channel is plotted in blue and the filtered POS altitude is plotted in green. The results show a very close match with a maximum difference of 3cm over the time period shown in the plot (130 seconds). Over the whole time period used for the analysis (3 hours), the maximum difference observed was 5cm. This analysis supports the concept that limited GPS outages can be handled by augmenting the altitude from an inertially-aided kinematic solution with the heave channel.

RTK GPS Outage Handling

Most users face some sort of logistical problems when acquiring positioning data with RTK. The main challenge is to ensure that signals are always available. Modern radio link technology makes this possible with high reliability only when close to the RTK reference station and, even then, physical obstructions can and do cause signal blockage. This means that hydrographic surveys suffer occasional RTK outages.

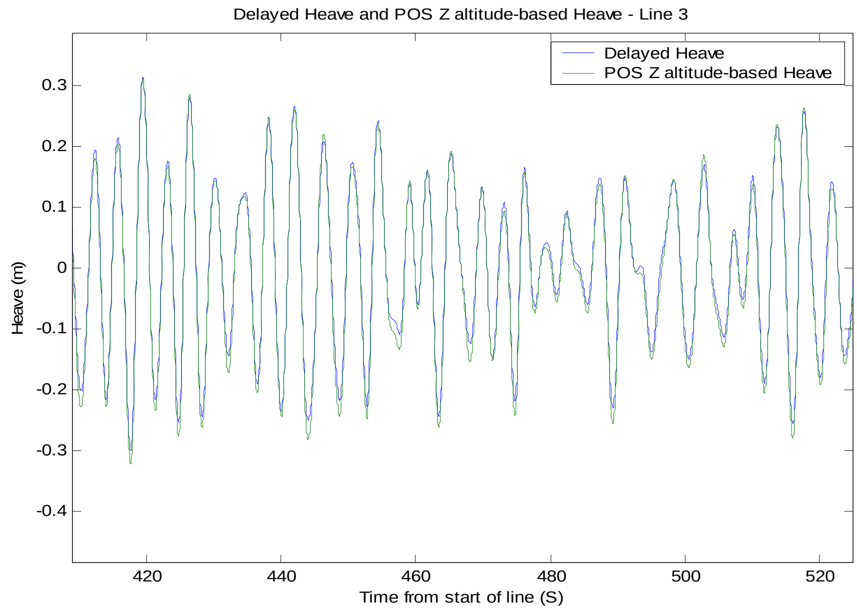


Figure 7 Inertially-Aided Kinematic GPS Z vs. the Heave Channel

There are two ways to create immunity to RTK correction or GPS outage. The first method is to combine the heave channel with Z from the inertial navigator. Figure 8 illustrates that outage immunity for 15 seconds is easily achieved if the heave channel is tied into the inertial navigator altitude. In this figure, the original POS altitude data is plotted in blue and the recovered altitude data is plotted in green. The recovered altitude data is created by sampling a single POS altitude value every 15 seconds (these points are marked with an 'x') and filling in the gaps with the heave data for that period. The slope of the line plotted in black shows the values used to align the zero-mean heave data with the ellipsoid reference.

The technique shown has the potential to span many real-time outages and permit post-processed outage handling without raw inertial data.

Post-Processing of Aided-Inertial Data

Improved results can be achieved by collecting a complete set of raw data for post-processing. Post-processing requires the user to acquire and store raw inertial and GPS data on the survey vessel and also to store GPS base-station data. A radio link is not required. A POS system configured for full raw data logging capability is required as is the POSPac™ post-processing software package.

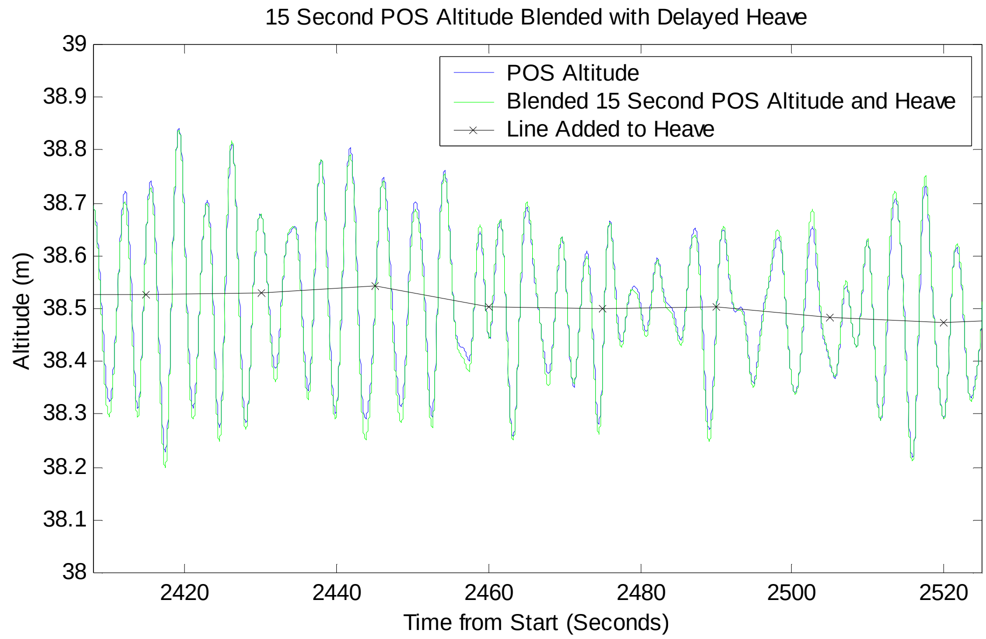


Figure 8 Outage Immunity for Vertical Positioning

The Applanix POSPac post-processing software package has the following key attributes:

- It provides an integrated suite of software tools
- It maximizes POS system accuracy using forward and reverse processing techniques
- It handles multiple GPS base-station processing
- It has automatic setup capability and straightforward operation

Figure 9 shows a diagram of the various post-processing modules available with the Applanix POSPac post-processing software package.

After recording data, a POSPac extraction utility is used to reformat and check for data integrity and completeness. POS system settings, status and performance through data collection are reported and can be analyzed. The POSGPS portion of POSPac is a differential GPS post-processing module that uses GPS roving and reference station data. POSGPS performs carrier phase ambiguity resolution for maximum accuracy. Multiple base-station data is supported. IMU and GPS are then used in the POSPac integrated inertial navigator. The computed solution includes 3D location, orientation angle, velocity, acceleration and angular rate, calculated at 200 times per second. The “smooth” process which follows, allows the smoothed best estimate of trajectory (SBET) to be computed by forward/backward processing. This improves GPS dropout immunity beyond that already provided by POS in real-time. In addition, the NAVDIF portion of POSPac is used for in-depth review of QA statistics.

CONCLUSIONS

The Applanix POS system altitude channel is a real-time, high-rate RTK-Heave measurement, but it may have outages due to radio link dropouts from the GPS base-station. A technique that blends the heave channel into the POS altitude channel has been demonstrated to provide a more robust RTK-Heave measurement.

Post-processing POS data along with the GPS base-station data also provides GPS dropout immunity. The user needs to decide between the complexity of the RTK infrastructure and possibly incurring GPS outages versus logging raw inertial data and post-processing after the survey is complete.

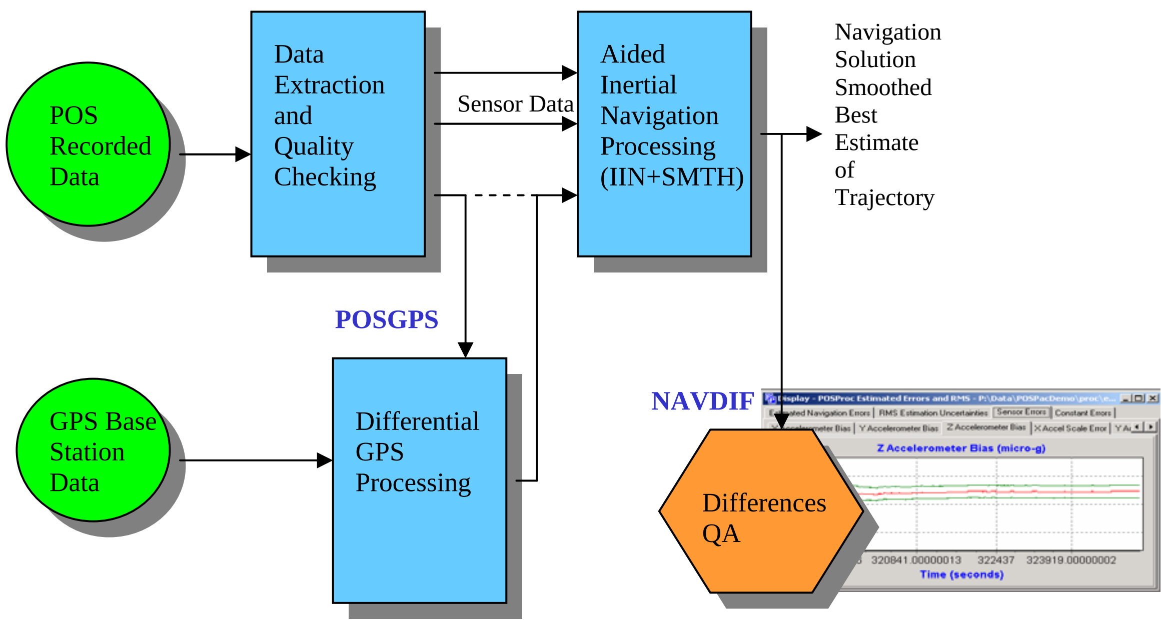


Figure 9 POS Post Processing Architecture

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REFERENCES

Arumugam, D., C. Lockhart, D. Lockhart, 2004, Application of Post-Processed Navigation, Motion and Tide Data to Multibeam Surveys Using Applanix POS/MV, Canadian Hydrographic Conference, May 24 - 27, 2004, Ottawa, Canada

Canter, P., R. Corcoran, 2004, New Generation of POS a Boost for Hydrographic Surveying, International Ocean Systems, September/October 2004, p 10-13

Sanders, P., 2003, RTK Tide Basics, Hydro International, December 2003, p 26-29

Scherzinger, B., 2002, Inertially Aided RTK Performance Evaluation, Proceedings of ION-GPS-2002, Portland, OR, September 24-26, 2002.