Return to session menu

DYNAMIC POSITIONING CONFERENCE
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SENSORS I SESSION

Integrating INS and GNSS Sensors to Provide Reliable Surface Positioning

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ABSTRACT

The ideal surface positioning system will provide a constant, stable, accurate and repeatable position in real-time which is essential to safe and productive operations. In perfect conditions, GNSS along with augmentation data can deliver this performance and with the modernization of existing constellations and the imminent arrival of new satellite constellations the performance and availability of GNSS should improve. However, while additional observations will be available, the satellite signals are still susceptible to effects of ionosphere scintillation and interference whether intentional or un-intentional plus signal blockage can occur when working close to platforms and this will result in degraded positioning.

Inertial Navigation involves determining a position through dead reckoning using gyros and accelerometers to calculate changes in position, velocity and attitude. Inertial Navigation Systems (INS) are completely self contained and inherently robust providing output with exceptional good short term accuracy but the position accuracy will drift with time.

INS and GNSS are complementary sensors and when combined can deliver constant, stable, accurate and repeatable positioning. The integration of GNSS and inertial technologies exploits the long term accuracy and precision characteristics of GNSS positioning with the continuous availability and fast update rate of inertial sensors. The resulting integrated system can bridge GNSS disruptions (e.g. ionospheric scintillation, physical obstructions, etc.) as well as detecting position outliers due to common mode failures which can affect vessel GNSS systems simultaneously which is particularly advantageous for DP operations.

This paper will present a high level overview on the integration of GNSS and INS sensors required to deliver an integrated position solution considering the different options and also examining the benefits and weaknesses of the different solution options.

Results from real-world trials will be presented showing the performance of a loosely-coupled INS and high-accuracy GNSS position solution. In particular, several scenarios were tested to simulate the degradation of the GNSS data to look at the performance of the integrated solution which highlights the advantages of combining the two different sensors. The testing scenarios also considered a complete failure of the GNSS solution to monitor how quickly the position accuracy degraded when only the INS sensor was available.

Finally, the real-world operational implementation of an integrated system will also be considered as this will be different depending on whether the system is being used for DP operations or survey operations.

INTRODUCTION

The ideal surface positioning system will provide a constant, stable, accurate and repeatable position in real-time which is essential to safe and productive operations. INS and GNSS are complementary sensors and when combined can deliver constant, stable, accurate and repeatable positioning.

This paper will present a high level overview on the integration of GNSS and INS sensors required to deliver an integrated position solution considering the different options and also examining the benefits and weaknesses of the different solution options. In addition, the paper will look at the operational implementation of an integrated system along with some results from trials conducted.

GNSS Technology

GPS satellites are approximately 20,000KM above the Earth's surface and only transmit at 50W or less meaning that the signal is relatively weak by the time it arrives at the GNSS antenna. It also makes the signal susceptible to degradation through interference or as the signal propagates through the atmosphere. Also the antenna requires line-of-sight so obstructions like offshore platforms will mask the signal and so fewer satellites will be visible potential leading to un-reliable positioning.

Solar Cycle 24 is currently nearing its peak (Figure 1) with the increase in the number of sunspots visible on the sun. This makes the ionosphere more active and affecting the GNSS signals as they pass through it.

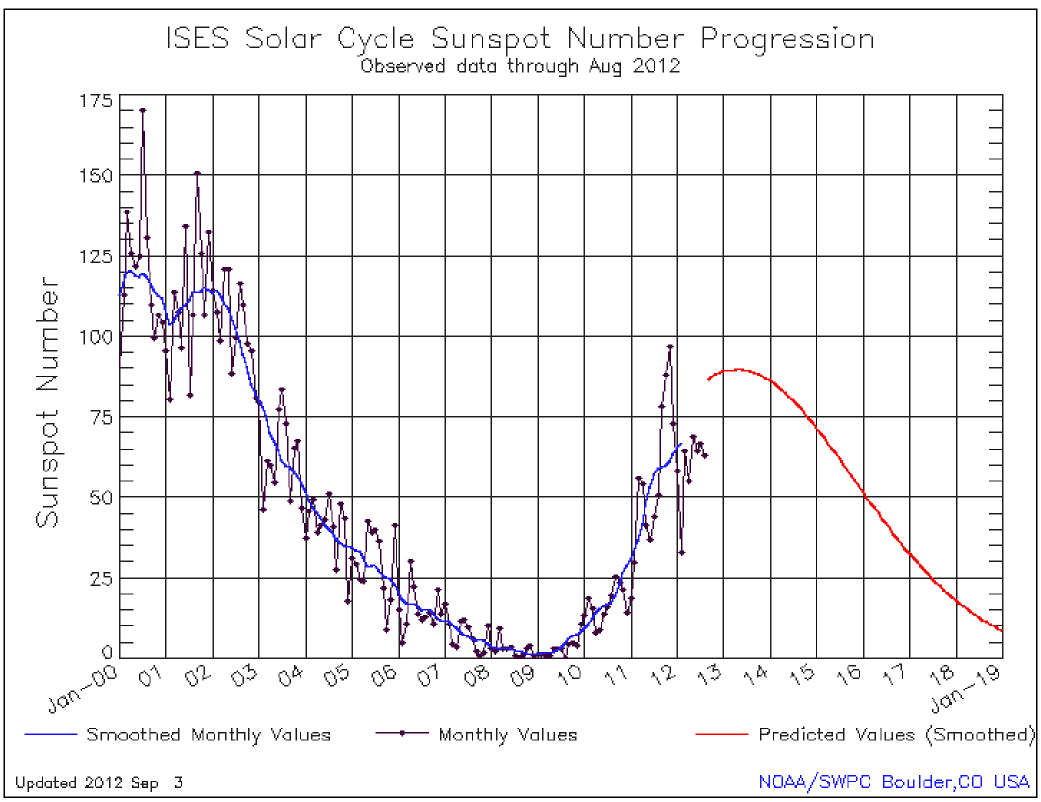

Figure 1 - Solar Cycle 24 Progression

Figure 2 indicates the Total Electron Content (TEC) of the ionosphere which is the number of free electrons along the path from the satellite to the receiver. TEC is linked to solar activity and other geomagnetic disturbances.

A high TEC value will result in errors in the GNSS range measurements as the signal is delayed as it passes through the ionosphere. One TEC unit is equal to a 16cm error on the GPS L1 range signal which will introduce large errors or biases in the position. Fortunately, using dual frequency (L1 and L2) the ionosphere delay can be computed and a correction applied to the range measurements to minimize the error.

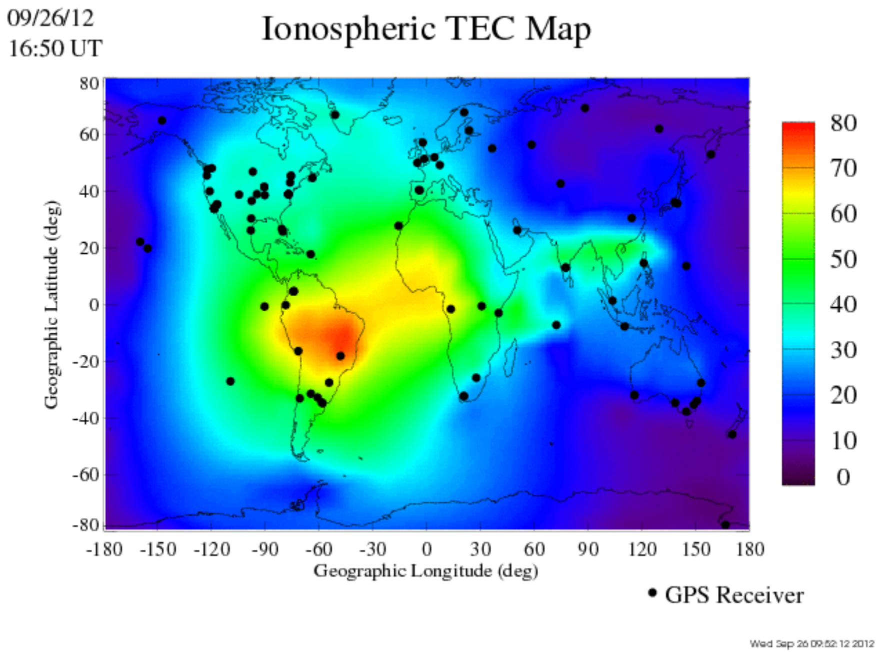

Figure 2 - Total Electron Content Map

Also present with the increase in ionosphere activity is scintillation which is more problematic for GNSS signals. It causes rapid fluctuations in the phase and amplitude of the L-band satellite signal as it passes through small-scale irregularities in the ionosphere. The effects of scintillation appear in different localized regions of the sky and thus only affect certain satellites at a time.

Amplitude scintillations can lead to periods of reduced signal levels at the GNSS antenna which results in an increase in the measurement noise within the code and carrier tracking loops of the receiver. Phase scintillations increase the dynamic stress on the carrier tracking loops which results in additional phase measurement jitter. Both effects result in an increase in range measurement errors and under extreme conditions can lead to complete loss of signal lock.

Scintillation typically occurs after sunset and can last several hours. The reason for this is that during the ionosphere rises due to solar heating but as it cools after sunset it cools and falls under its own weight. This results in small scale irregularities known as plasma bubbles which cause the scintillation effects on the GNSS signals.

The graphs in Figure 3 show the result of a scintillation monitor [1] for the Brazilian National Institute for Space Research including the error on the position when compared against the coordinates of the known point. It uses an index known as S4 [2] which provides a measure of scintillation. The graph clearly indicates the presence of scintillation in the hours after sunset which degrade the position solution.

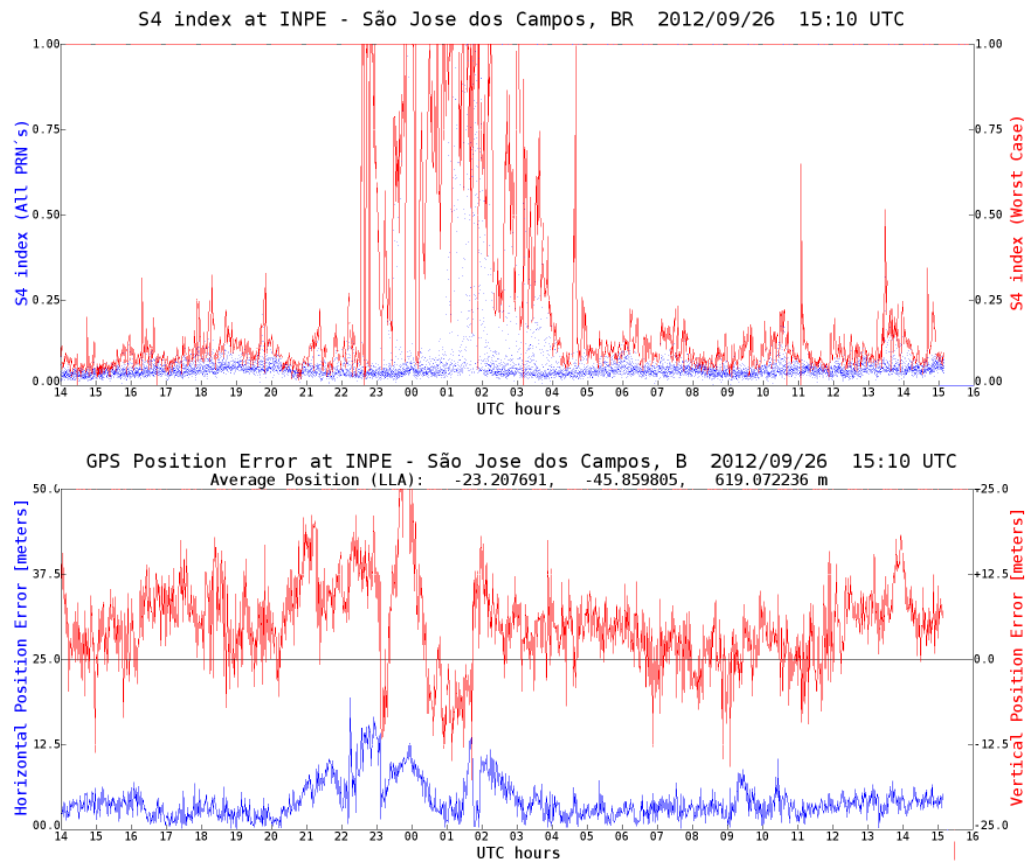

Figure 3 – L1 GPS Scintillation Monitor in Brazil showing S4 index and Positioning Performance (Cornell University)

GNSS interference which is something that is gaining more press coverage with stories about the availability of low-cost jammers and wireless broadband networks and the impact on GNSS. The radio frequency spectrum is very crowded and as the GNSS satellite signals are very weak they are susceptible to both in-band and out-band interference. This can results in the loss of signal which can impact the positioning performance.

Other issues affecting signal reception is masking through blockage such as platforms. Figure 4 shows a vessel working close to a platform inside the 500m zone during which signal blockage occurred. One remedy is to use additional satellite constellations to provide additional observations to improve redundancy and maintain positioning. Working close to structures can also cause a loss of the L-band signal delivering augmentation data from geo-stationary satellites which could impact positioning.

Figure 4 - Vessel Working Close to Platform

Despite all these issues, GNSS technology can provide reliable positioning most of the time and is almost universally used positioning in dynamic positioning (DP) systems. Other positioning sensors are used but the perception is that there is an over-reliance on GNSS

In the future GNSS will have more satellites and signals available to the user. Current GNSS (GPS and GLONASS) are being modernized and additional constellations being added through COMPASS and Galileo. However, the new signals will still be susceptible the same issue currently faced with radio signals broadcast from space.

Inertial Technology

The core component of any INS (Inertial Navigation System) system is the Inertial Measurement Unit (IMU). The IMU block is made up of three accelerometers and three gyroscope sensors. Each sensor is mounted orthogonally to each other such that the acceleration and angular rate can be measured is the X, Y and Z axis.

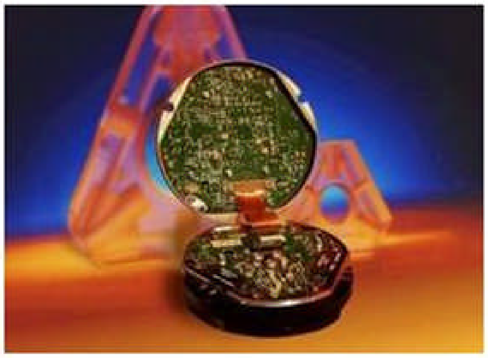

Figure 5 - Ring Laser Gyro

There are different types of IMU sensors available; Ring Laser Gyro (RLG) (see Figure 5), Fiber Optic Gyro (FOG) and Micromechanically Engineered Machine Systems (MEMS).

An INS (Figure 6 and 7) is an IMU which processes acceleration and angular rate data to estimate position, velocity, and attitude. The primary advantage of an INS is that it requires no external references in order to determine its position, velocity or attitude once it has been aligned. It computes it own position and velocity by integrating data received from the gyros and accelerometers.

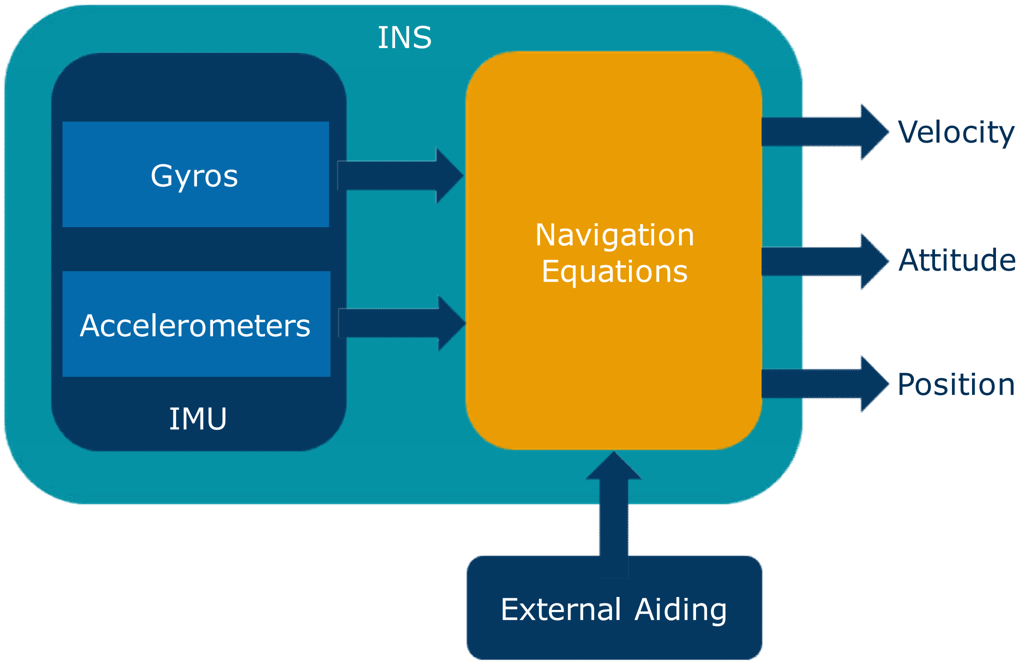

Figure 6 – Simplified INS Block Diagram

However, the INS will exhibit drift due to noise in the measurements of the accelerometers and gyros. The magnitude of drift will depend on the quality of sensor selected with a cost increase for the better quality sensors. High end sensors may also have export restrictions under the International Traffic in Arms Regulations (ITAR) limiting the countries where the technology can be used.

Integration with external sensors such as acoustic (e.g. USBL) or GNSS can help constrain the drift of the INS allowing position accuracy to be maintained.

Figure 7 – Surface INS System

Integration

INS and GNSS are complementary sensors and when combined can deliver constant, stable, accurate and repeatable positioning. The integration of GNSS and inertial technologies exploits the long term accuracy and precision characteristics of GNSS positioning with the continuous availability and fast update rate of inertial sensors. The resulting integrated system can bridge GNSS disruptions (e.g. ionosphere scintillation, physical obstructions, etc.) as well as detecting position outliers due to common mode failures which can affect vessel GNSS systems simultaneously which are particularly advantageous for DP operations.

There are different levels or types of integration that can be done to achieve an integrated INS/GNSS solution. Typically there are three levels of integration:

- Loose: integration of the navigation solutions (position domain)
- Tight: integration at the measurement level (measurement domain)
- Deep: integration at the signal processing level

Figure 8 shows the three levels of integration indicating the fact that going from no integration to deep integration improves the performance and robustness of the navigation solution but the complexity of the solution/system also increases.

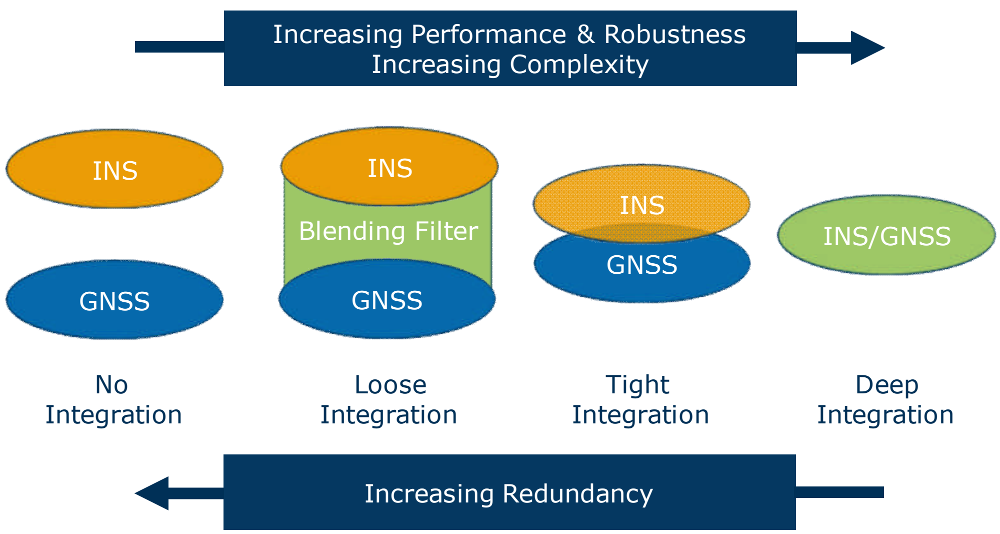

Figure 8 - INS-GNSS Integration

It can also be argued that moving to deep integration reduces the redundancy in the sensors due to the fact that they are so tightly coupled that they could be considered a single same sensor. However, integrating the two sensors is complementary providing a good solution to provide reliable and robust positioning.

Operational Implementation

VERIPOS has been working in conjunction with Sonardyne to develop an integrated INS-GNSS system for use in DP operations.

At the core of the system is the Sonardyne Lodestar, a solid state IMO approved INS which can output precise position, velocity and attitude in dynamic conditions. The high grade gyroscopes have been specifically selected to optimize performance and ease of use whilst remaining ITAR free. The North seeking capability of the system makes it easy to install as no external heading aiding is required. VERIPOS GNSS positioning solutions complement the inertial sensor outputs, which are combined mathematically to compute position with the best possible accuracy and integrity for a surface navigation system. The input of GNSS observation data corrects any potential degradation over time in the inertial position solution. At the same time the loosely coupled system can help bridges any problems with the GNSS systems as outlined earlier in the paper.

Figure 9 demonstrates the typical vessel setup with position and QC information on the position being passed from the GNSS system to the INS which then computes an integrated solution. Providing the QC information allows the INS to properly weight the GNSS position in the Kalman filter of the navigation solution.

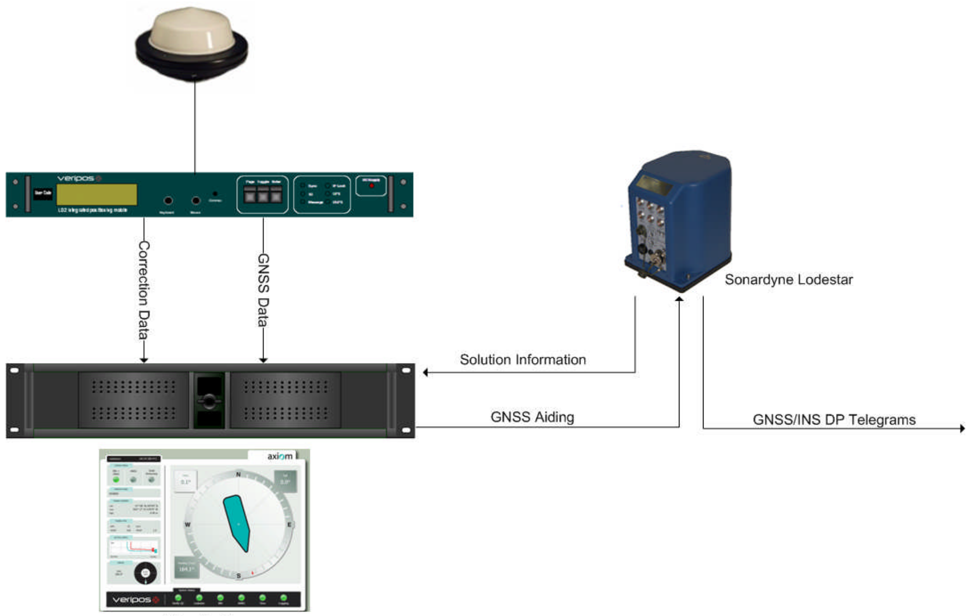

Figure 9 - Equipment Setup on Vessel

The subsequently position calculated in the INS is output in industry standard output telegrams to the DP system which can accept is as another PME. At the same time the Lodestar INS provides information back to the GNSS system on the integrated solution to allow for visualization of the position solution providing the operator with an intuitive status and basic quality metrics.

Figure 10 - Axiom User Interface

Figure 10 shows the visualization screen which provides information on whether the solution is an integrated solution or a GNSS only or INS only. This allows the operator to know that there is a potential degradation in the solution that may affect the position feeding the DP system.

System Validation

An important aspect is the system validation that needs to be conducted to validate the performance of the system to ensure that the integrated INS and GNSS solution can provide reliable surface positioning. Trials are currently continuing with clients to validate the system offshore not just from a positional perspective point of view but also from an operational implementation perspective.

Additional trials are in the process of being conducted to simulate various scenarios where the GNSS solution is degraded caused by a loss of correction data, loss of GNSS measurements and satellite masking in one half of the sky simulating blockage.

Figure 11 shows the horizontal error where the GNSS measurements were lost at 14:40 UTC. This helps determine the drift in the INS only solution which demonstrates the quality of the sensors within the INS. After five minutes the position error has degraded to 6m and the error is 10m after approximately six and a half minutes.

When the GNSS measurements become available again the integrated solution is quickly back to the position accuracy it was at the start of the test.

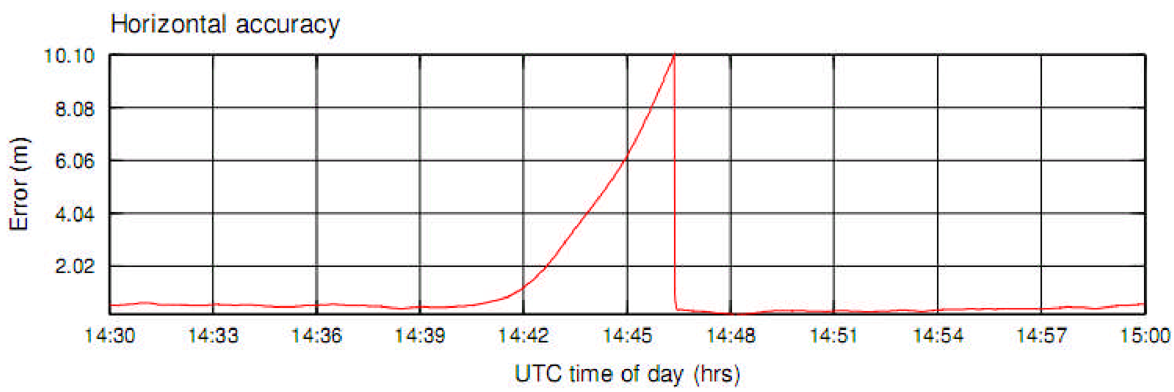

Figure 11 - Loss of GNSS Measurements

Figure 12a shows the performance of the GNSS only solution where the position solution transitions from a high accuracy precise point position (PPP) solution to a DGPS solution where the horizontal accuracy changes from approximately 0.1m to 0.6m. Also there is a 0.5m position jump in the solution is evident just after 14:06 UTC.

The corresponding position plot for the integrated INS-GNSS solution is shown in Figure 12a where the position jump has been eliminated demonstrating the clear benefit of the integrated solution. It is worth noting that the y-scales on both graphs are different.

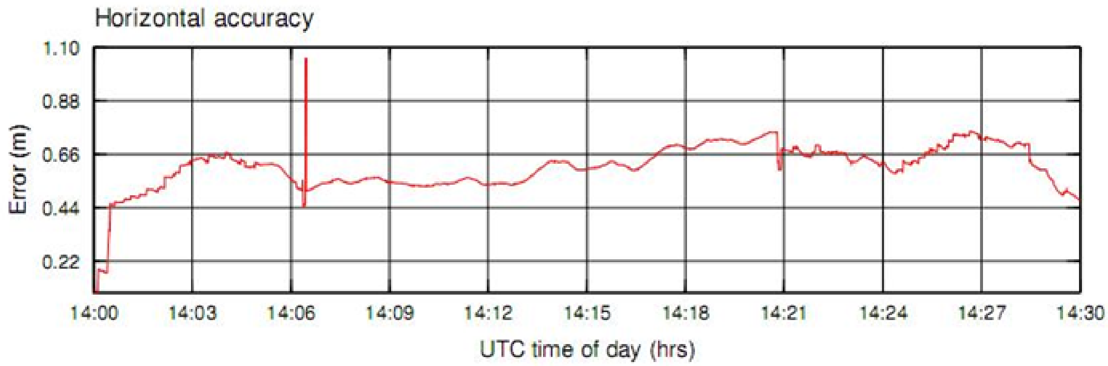

Figure 12a - GNSS Only Position Solution

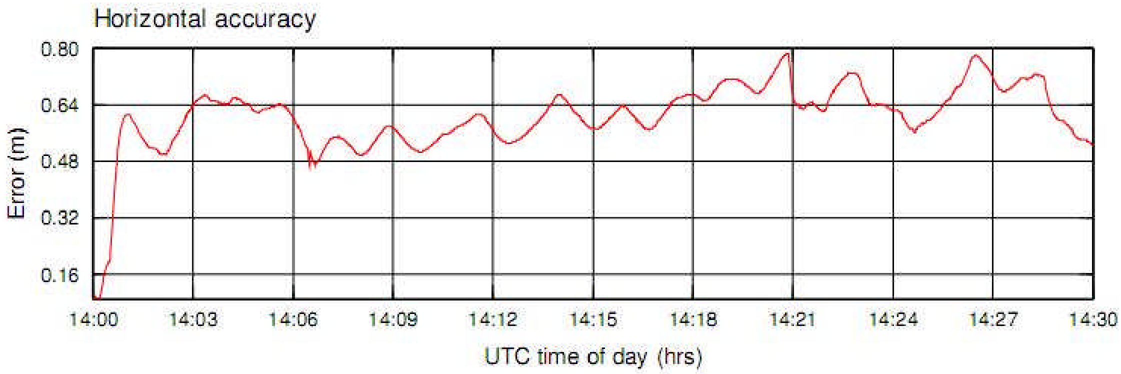

Figure 13b - Integrated INS-GNSS Solution

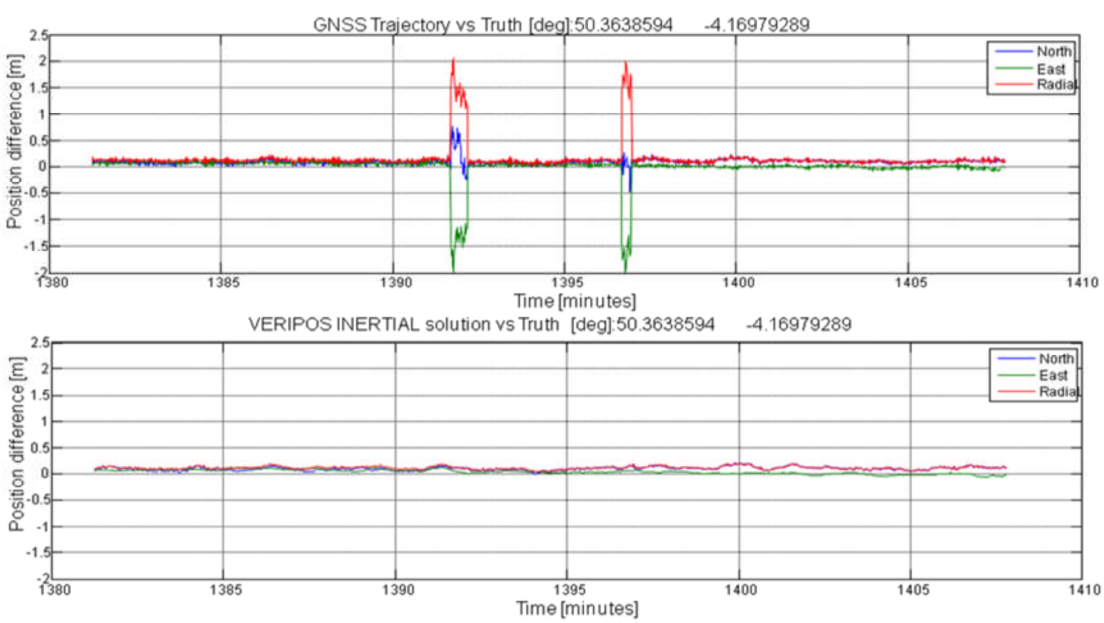

Figure 13 - Dynamic Vessel Trial Data

Figure 13 shows the performance of the GNSS and also the INS-GNSS solution in a dynamic environment compared against a 'truth' position generated using a RTK position. The top graph shows the performance of the GNSS only solution and two events where the position degrades when the correction information is lost. This results in a position jump of a couple of meters.

The bottom graph shows the performance of the integrated INS-GNSS solution where the integrated solution bridges the issues with the GNSS providing a stable and continuous position without any jumps. The other noticeable aspect is that the integrated solution generates a far smoother position removing the short term noise that is apparent in the GNSS only solution. This again highlights the advantage of integrating both GNSS and INS to provide reliable and robust surface positioning.

Future Work

Further work is continuing to look in to the quality information provided by the GNSS to the INS to allow better weighting in the integrated solution and subsequently providing a better integrated position solution. Work is also being conducted into developing a tightly coupled solution to further maximize the robustness of the integrated solution.

Additional work will need to be conducted into developing appropriate interface standards so that we can unlock the full potential of an integrated solution and ensure compatibility between all systems and the provision of appropriate information the DP operator.

REFERENCES

[1] Aquino, M., et al., 2005. *Implications of Ionospheric Scintillation for GNSS Users in Northern Europe.* Journal of Navigation, Volume58, Issue02, May 2005, pp 241-256.

[2] INPE, 2012. *Real Time Ionospheric Scintillation*. INPE Website, http://www.inpe.br/scintec/status?id=sjc (Accessed 26 September 2012).