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Accuracy is addictive – new techniques for high accuracy positioning offshore

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ABSTRACT

Position accuracy is addictive. As a DGNSS service provider operating world-wide, Fugro continually strives for ways to meet our customers expectations for increased performance. This paper focuses on techniques for providing high accuracy positioning in offshore regions hundreds of kilometres from land.

In the offshore environment, the approach to improving accuracy must be different to the approach on land. One cannot always add local reference stations or establish an RTK (Real Time Kinematic) system. The reasons are obvious, there are limited options for reference station locations and limited infrastructure for broadcasting the correction data to marine users. While, the seas and oceans are covered by satellite communication systems, there is a limit to the data bandwidth usage that is practical for technical and economical reasons. On the other hand, the open seas offer a near ideal environment for GNSS signal tracking. The antenna generally has a clear line-of-sight to all satellites above the horizon and GNSS receivers on board a ship experience few cycle-slips.

This paper presents technologies for high accuracy positioning far from land. A particular solution developed by Fugro is discussed and test results are presented. Emphasis is made both on the accuracy and the integrity of this approach. In addition to reviewing this state-of-the-art technology, a vision for what to expect in the future is also provided.

CODE BASED 1m POSITIONING

Code based DGNSS (Differential Global Navigation Satellite System) is a well-established technique to improve the accuracy of GPS or GLONASS. It is simple, robust and has well defined data transmission format, which ensures equipment interoperability. However, there is a limit to the accuracy of code based DGNSS. On shorter baselines, using high-end receiver equipment, it is possible to get down to the sub-meter level, but improving on that is practically impossible.

The reason behind the accuracy limitation of present DGNSS is the code measurement accuracy. As a rule-of-thumb for radio-systems, it is possible to measure a radio-wave with an accuracy of about 1% of the wavelength. The C/A code in GPS is 1.023 Mbits/s that gives a chip-length or wavelength of 293 m. This indicates an expected measurement accuracy at the 3 meter-level. Thanks to the wider bandwidth of the GPS satellites (20 MHz) and improved receiver tracking technology (Narrow Correlator), high-end receivers actually measure with a few decimeter accuracy. Still these state-of-the-art receivers suffer from multi-path. Multi-path are reflected signals that do not follow the shortest signal-path between the satellite and the receiver antenna. Further the number of satellites in view, and their inter-geometry affects the accuracy. Consequently, a 1m position accuracy is the expected performance level of high-end code based DGNSS equipment over medium length baselines.

On longer baselines (100 – 2000 km) there are also other error sources that come into effect. The satellite signal travel-path to rover and base is not precisely the same, and spatial changes in the atmosphere affects the differential measurements. Thus, to some extent the troposphere, and certainly the ionosphere becomes an error source for long baseline DGNSS. Dual-frequency receivers can be used to determine and eliminate the effect of different ionospheric travel paths on the measurements. On very long baselines, errors in the broadcast orbits can also influence the differential position accuracy because the satellites are viewed from slightly different angles. However, satellites clock errors are always completely removed in differential positioning independently of baseline length. The global Fugro DGNNS technology uses a combination of reference stations to take advantage of the reference network geometry to reduce these longer baseline error sources.

CARRIER-PHASE HIGH ACCURACY POSITIONING

For very short baselines, a technique called RTK (Real-Time Kinematic) provides the highest level of accuracy achievable with GNSS in real-time. The RTK approach uses the carrier-phase measurements in addition to the code measurements mentioned above. The GPS carrier-phase has a wavelength of 19 cm on the L1 frequency and 24 cm on the L2 frequency. Using the same 1% rule-of-thumb, this indicates a measurement accuracy of a few millimeters. The challenge in measuring the carrier-phase is that it is a continuous wave with no time-stamp information in it. Therefore it is impossible for a GNSS receiver to know which carrier-cycle it is measuring with millimeter-level accuracy. The carrier-phase measurement has an ambiguity of plus or minus an integer number of wavelengths.

The RTK technique uses the redundancy in the number of satellites and repeated measurements over time to determine the correct ambiguities for each satellite. Statistical methods maximize the likelihood that the selected ambiguities are correct. The residual differential errors have to be practically zero for RTK to work. During conditions of ionospheric instability, the maximum baseline length of the standard RTK systems is the 10-50 km range. In any case RTK is not an option for reliable high accuracy offshore positioning at long ranges from land. Robust, cm-level RTK is not possible on such long baselines with today's processing techniques and only two available GNSS frequencies on each satellite.

However, the open seas provide an almost ideal environment for GNSS signal tracking. The GNSS antenna generally has a clear line-of-sight to all satellites above the horizon. This is important because the carrier-phase ambiguities have to be recalculated upon cycle-slips, and several satellites with cycle-slips will force the carrier-phase processing to reinitialize. Of course, mounting a GPS antenna above all other equipment on a ship is not trivial, but generally GNSS receivers on board ships experience few cycle-slips.

In order to address emerging applications that require higher precision, Fugro has developed a solution for high accuracy real-time positioning in the offshore regions hundreds of kilometers from land. The service is named Starfix HP (High Performance). The higher accuracy is achieved by exploiting the high precision of dual-frequency carrier-phase measurements. It corrects for the ionospheric delay by measuring the carrier-phase difference on the two GNSS signal frequencies. It uses a network of base stations to reduce the longer baseline error sources and to increase the robustness of the solution. The best possible carrier-phase ambiguities are estimated and a high accuracy position is calculated. Target accuracy for the Starfix HP service is 20 cm horizontal and 30 cm in height 95% of the time. The service is broadcast using geostationary satellite links to provide coverage over wide areas.

FUGRO DGNSS SERVICES

Fugro provides code based DGNSS services with world-wide coverage based on a network of more than 85 reference stations. The services are broadcast on a total of 10 geostationary communication satellites. This includes regional spot beams covering regions like the US, Europe and Australia, and global beams covering the world to70 degrees latitude North and South. The mobile equipment ranges from high-end systems with extensive user interaction and quality control capabilities for the offshore industry, to small and lightweight equipment for land applications that receives both GNSS satellites and the DGNSS broadcast with a single antenna. The Starfix HP service is a further development of the Fugro navigation and positioning services to meet new demands in accuracy.

HP RESULTS

The Starfix HP is operational in the Gulf of Mexico and the North Sea since May 2001.

Figure 4 shows data from the real time monitoring of the North Sea Network. The monitor is in Rogaland in South Norway and the solution uses 6 reference stations with ranges to stations from 300 km to 1100 km. During this 24 hour period the maximum horizontal radial error is 20 cm.

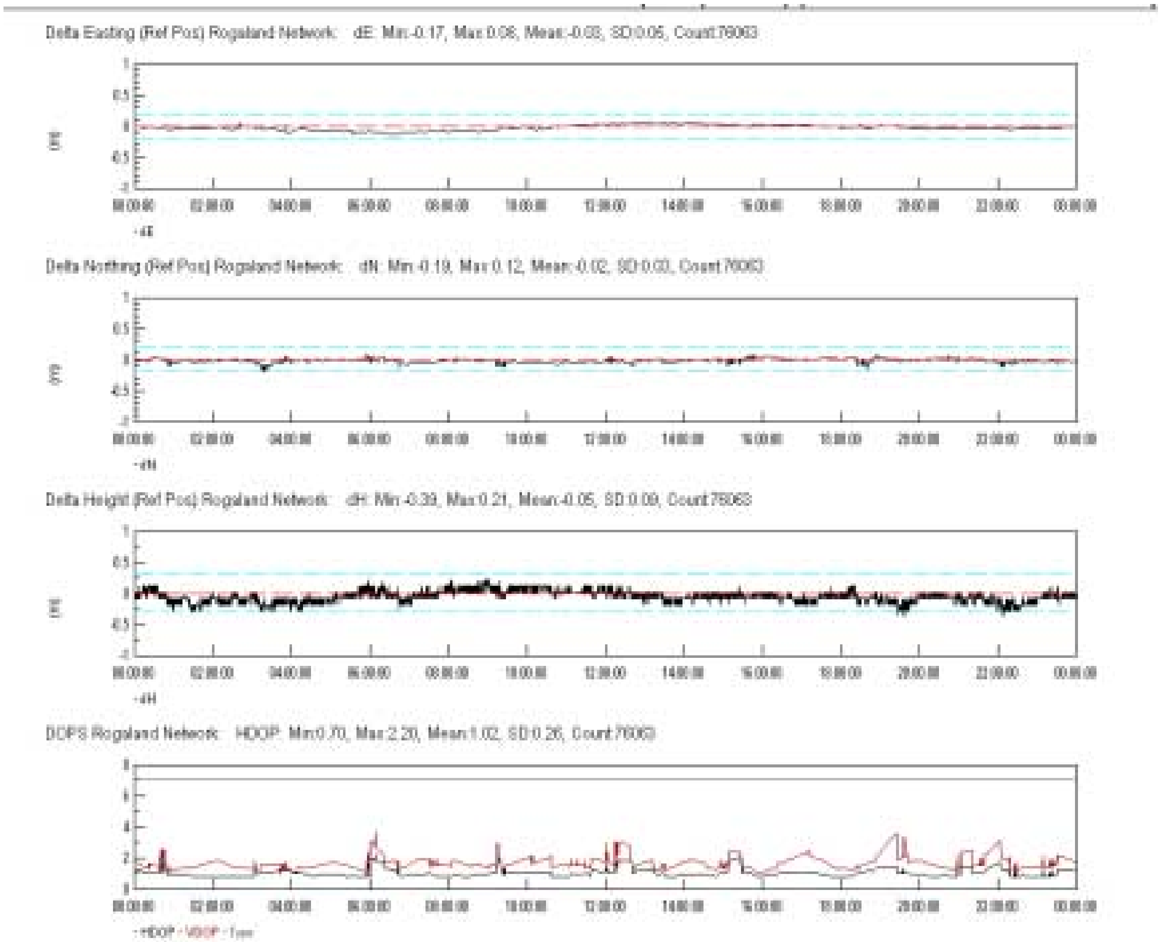


Figure 4: *Fugro Starfix HP monitoring data from the North Sea on 28 July 2001. The monitor is located in Rogaland (Norway) with distance to the 6 reference stations ranging from 300 to 1100 km.*

Figure 2 shows dynamic tests data from the Gulf of Mexico area. The mobile is on a vessel in Louisiana, and the distance to the four reference stations used ranges from 400 km to 1100 km. The Starfix HP data was compared to local a RTK system with range 10-35 km. The track followed by the vessel was a back and forth track at about 5 m/s speed, see figure 3.

The data was collected on 19 July 2001 and figure 2 shows the errors (from top) in latitude, longitude and height for a 10-hour period. It should be noted that the errors remain small during the 180 deg turns.

The results show that the target accuracy of 20 cm horizontal and 30 cm height 95% is met.

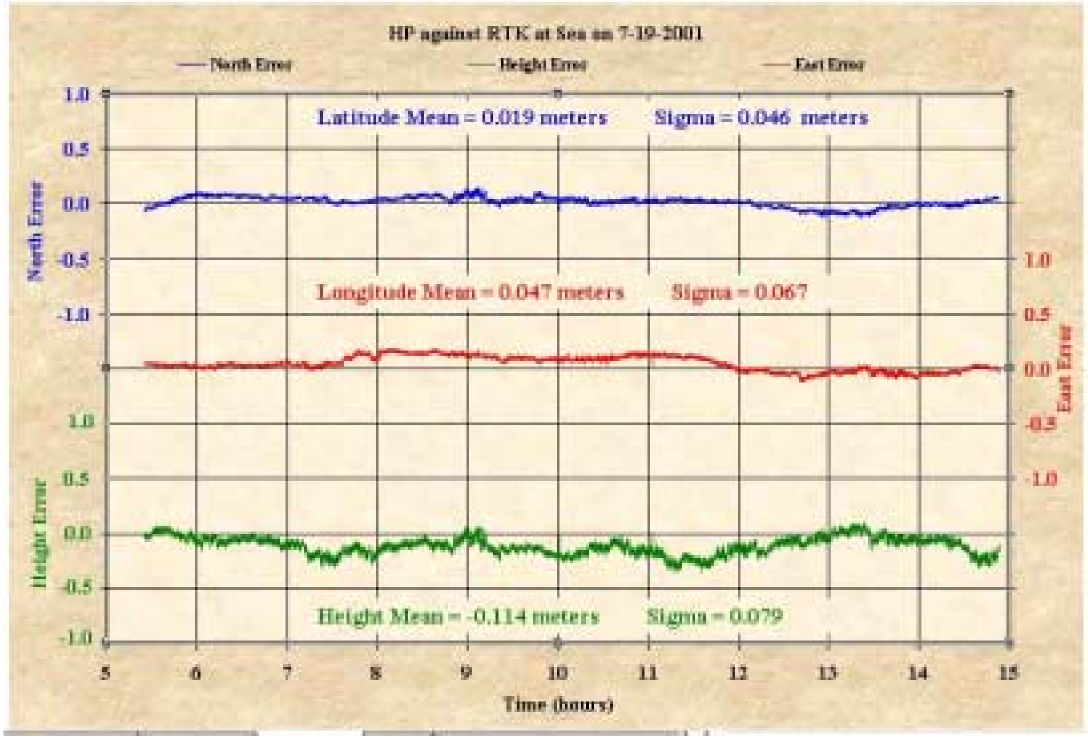


Figure 2: Position errors relative to short range RTK using multi-baseline solution in the Gulf of Mexico area with ranges to reference stations 400 – 1100 km.

Figure 3: Speed and heading during comparison testing with RTK in the Gulf of Mexico area

Dynamic tests have also been conducted in the North Sea, close to the UK coast using the Fugro vessel Geo Scanner on a cable route survey. In order to illustrate the capabilities and potential of the system, examples of height determination using the Starfix HP system is shown.

Figure 4 shows the height determined using Starfix HP as the dark blue line for 12 hours on 19th September 2000. What look like noise in the plot are actually wave movements. The yellow line is tidal height determined from sea bottom pressure measurements in the area (not corrected for atmospheric pressure). As the mean sea level was not known, this curve has been shifted in height. This close correlation shows the potential of the Starfix HP system to determine the height of a vessel performing a survey without depending on a known mean sea level and external tide measurements. The height is directly available in ellipsoid height referenced to an earth fixed reference frame.

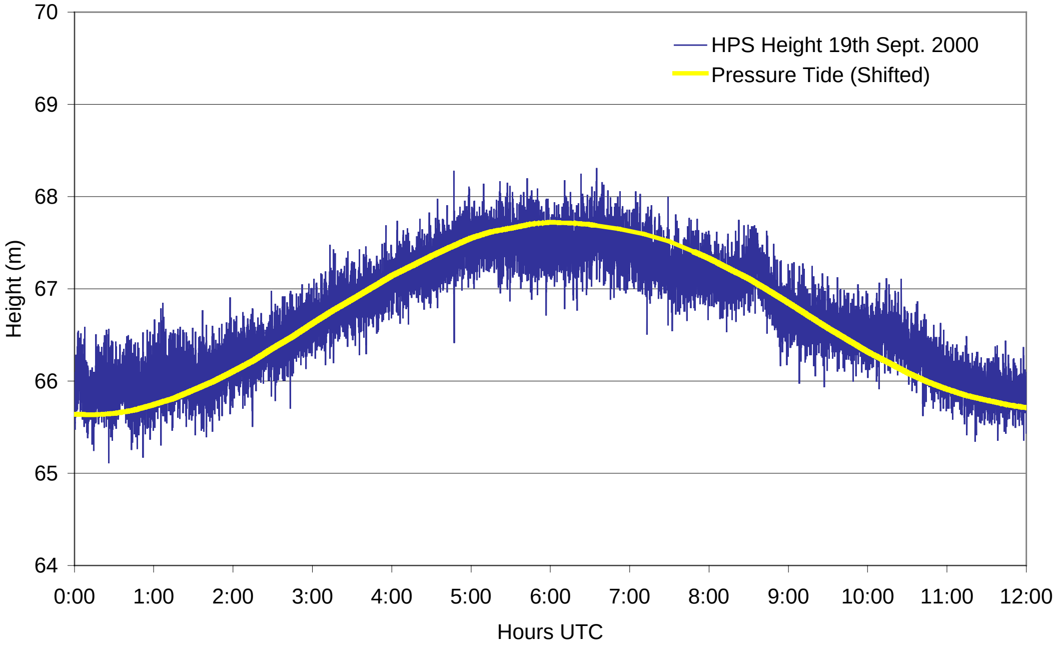
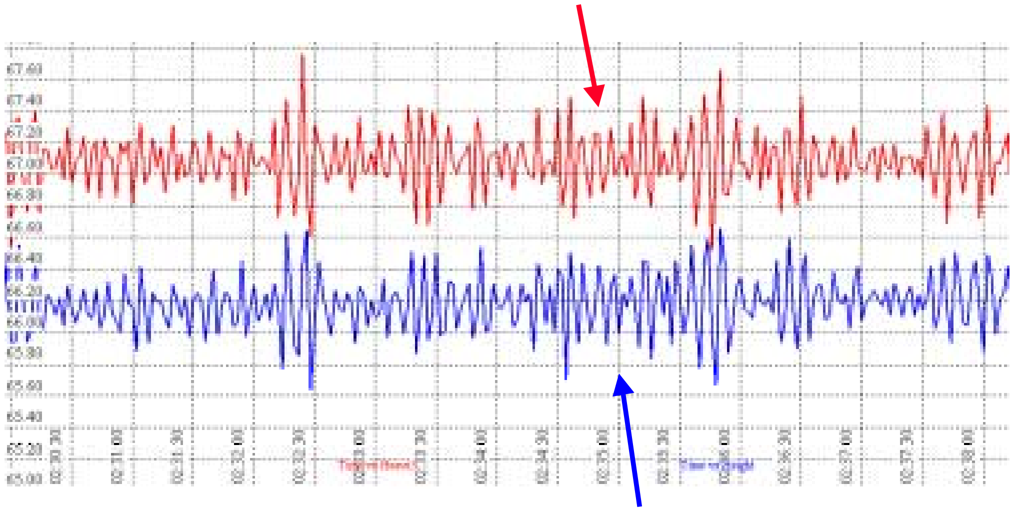


Figure 4: Height data collected on the vessel Geo Scanner19th September 2000 from 00:00 to 12:00 UTC. The smooth curve is derived from tidal pressure measurements.

Heave from analogue TSS Heave Sensor (below deck)



Heave from Fugro Starfix High Performance Service (antenna in mast)

Figure 5: Height data collected on the vessel Geo Scanner19th September 2000 02:30 to 02:38 UTC. Top curve is from an analogue heave sensor mounted below deck, and bottom curve is from the Fugro Starfix HP service with antenna in the mast.

Figure 5 shows an 8 minute part of the same time series as in Figure 2 from 02:30 to 02:38. The lower time series is the Starfix HP height of the antenna in the mast, while the upper curve shows the wave movements as tracked by an analogue heave sensor below deck (shifted for clarity). Close correlation can be seen in spite of the measurements not being referenced to the same location on the vessel. This shows that data from the Starfix HP system can be used to determine the heave of the vessel. The Starfix HP measurements can be used stand-alone or in combination with an analogue heave sensor to increase the performance in terms of accuracy and robustness.

SUMMARY AND EXPECTATIONS

The Starfix HP carrier-phase based technology for high accuracy positioning far from land has been discussed. Results from both static and dynamic tests, in the Gulf of Mexico and the North Sea, have been presented. The tests show that the 20 cm horizontal and 30 cm height accuracy requirement is met 95% of the time. And results from two promising applications namely tidal height determination and heave measurements have been presented.

Robust cm level RTK is currently not possible on baselines of several hundreds of kilometers. There are two main developments that may change this situation. The first is the planned development is that the Galileo satellite system bringing the total number of GNSS (GPS, GLONASS and Galileo) satellites is doubled to around 50-60 plus. The second development is that both GPS and Galileo will transmit on three radio frequencies, and this will open new possibilities for carrier-phase ambiguity resolution techniques with high accuracy on long baselines.

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