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DYNAMIC POSITIONING CONFERENCE
October 7 - 8, 2008

Sensors I

Integrating Other GNSS with GPS and its Implication for DP Positioning

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Abstract

With satellite navigation moving into a new era with more satellites in orbit than ever before, users are beginning to see the benefits such as better geometry, availability and new signals. This paper will look at the current status of all Global Navigation Satellite Systems (GNSS) and will present some early results from tracking of the European Galileo and Chinese Compass signals.

The main focus of the paper will look at the experience of integrating the GPS and GLONASS constellations to provide a combined position solution looking specifically at the issues, the benefits and the positional results. Experience gained will be fundamental to integrating the new Galileo and Compass constellations and new signals from the modernized GPS and GLONASS constellations.

While most people are aware that better accuracy and availability are the main benefits of the improvement to satellite navigation there are also other benefits that will assist users. These include stronger signal power which should help during increased ionosphere activity and better multipath mitigation which will make high accuracy positioning more robust. The paper will consider what users can expect from a multi-constellation system and also look at integrating other sensors.

Finally, the paper will examine the implications that all these changes will have for DP operators and manufacturers. With multiple constellations coupled with use of other sensors such as INS and acoustics there is clearly a benefit in terms of position robustness, accuracy and reliability. However, that means more information is available to the user and DP system and how this information is processed and used will need to be addressed. Another area that will impact the future is whether the regulatory bodies such the IMO can keep up with the pace of technological development. This could result in operators not being able to make use of new technology or techniques until the standards catch up.

Introduction

Global Navigation Satellite Systems (GNSS), particularly the Global Positioning System (GPS), are acknowledged for making positioning and navigation more accessible for all types of users. It is used extensively as a position reference within dynamic positioning (DP) systems to guide vessels involved in offshore survey and navigation operations.

Most people are aware that the current GNSS landscape is changing with the modernization of current systems and the addition of new satellite constellations. While it is recognized that the availability of addition satellites should make positioning more accurate and reliable, this paper will also look at some of the particular advantages that the new signals will bring and what they mean for the user.

The integration of multiple satellites constellations brings it own challenges including problems that must be overcome in order for reliable and accurate positioning. This paper will look at the experiences of integrating GPS and GLONASS to provide a combined position solution.

Global Navigation Satellite Systems

GNSS will remain as one of the main positioning references used within DP systems and will go through some significant changes over the next couple of decades. While this will see an increase in the number of satellites, it will bring better availability and accuracy through these extra satellites. However, it will also bring other benefits that will help the user, particularly in marginal conditions of satellite tracking such as when there is an increase in the solar activity which affects the ionospheric activity. The following sections outline the current situation with regards to each satellite constellation and highlight some of the additional benefits that the systems will bring to users.

GPS

At present there are 31 GPS satellites available to users and the modernization of the GPS constellation is underway. Currently there are four signals available to civilian users which are the C/A on L1, the L2C on L2 (a new signal) which are tracked using open codes and also the two encrypted P(Y) codes transmitted on both L1 and L2. The L2C signal is a recent addition presently available on six satellites.

The next GPS satellite to be launched will include the fifth civilian signal which will be broadcast at the L5 frequency (1176.45MHz) and in the future a new L1C signal will be broadcast from the GPSIII generation of satellites.

While additional signals are always welcome as they bring redundancy, they also bring other advantages in addition to improved accuracy and availability. The different chipping rates provides better signal tracking and also most robust and accurate signal tracking in the presence of multipath. Perhaps one of the major benefits of the new signals is the pilot signals transmitted which carry no data and allow better integration over longer periods which allow receivers to acquire the signals under weak conditions (such as in the presence of RF interference or ionosphere scintillation). The fact that it will be possible to track coded signals (as opposed to semi-codeless) higher signal to noise ratio of racking can be achieved making tracking more robust. The improvement is in the SNR is approximately 6dB which will help with tracking signals in noisy RF environments.

In July 2008, the US government through the US Coastguard sent a letter to the IMO affirming that the civil GPS service would be available for the foreseeable future on a continuous, worldwide basis and more importantly free of direct fees. It was also stated that the US Government would provide at least six years notice prior to any termination of GPS operations or service.

The US Air Force is now also looking at the GPS III program to follow on form the current Block II design of satellites. Improvement in GPS III will see better anti-jam, new L1C civil signal to replace the current C/A code.

GLONASS

Currently the GLONASS constellation consists of sixteen operational satellites with several under maintenance. In 2008, six satellites are scheduled for launch on the 25th of September and 25th December. By 2010 the constellation aims to have between 21 and 24 operational satellites which make GLONASS a viable alternative to the GPS system and not just an augmentation providing more satellites and redundancy for users. Figure 1 shows the launch schedule for the GLONASS system.

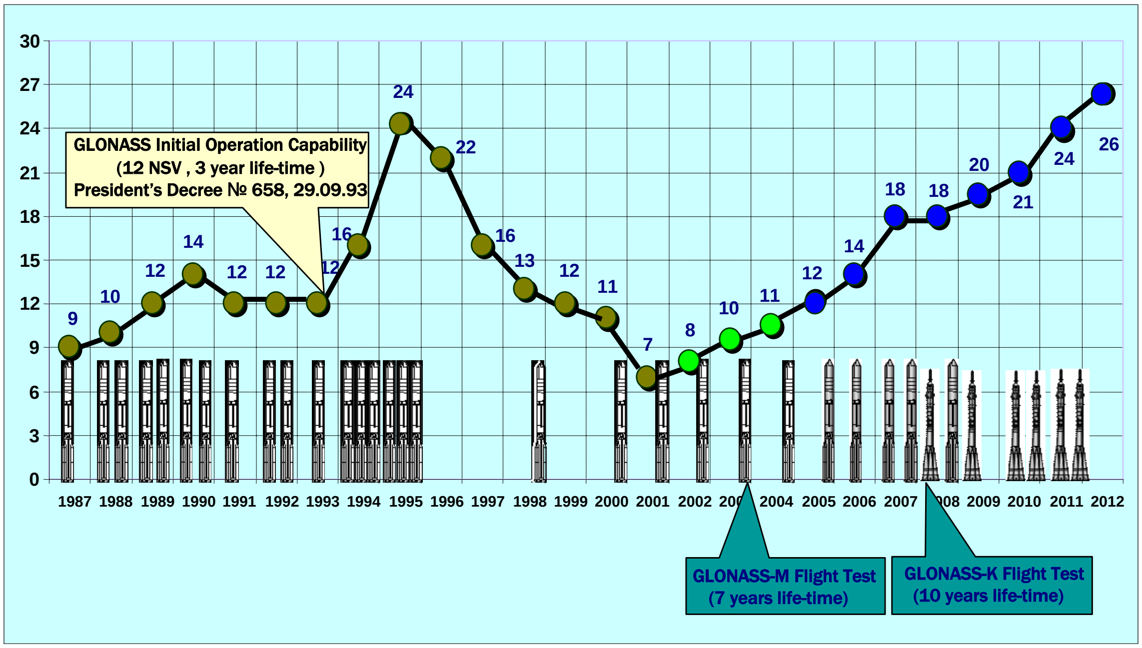


Figure 1 – GLONASS Launch Schedule

The generation of GLONASS satellites, designated M satellites, are being launched that include a civil L2 service with an improved 7 year design life (compared to previous 3 year for older generation). That means that the GLONASS constellation transmits three signals that correspond to the GPS C/A, L1 P(Y), L2 P(Y), although the frequencies at which the data transmitted is different to GPS – each satellite has its own unique frequency.

Other changes that have been undertaken have been modernizing the ground segment and improved ground measurement processing to improve the orbit and clock accuracy of the system. Also the implementation of improved geodetic reference frame (PZ-90.02) was completed in September 2007 which ties in better with the International Terrestrial Reference Frame (ITRF) that will aid high accuracy applications.

Looking to the future the next generation satellites (GLONASS-K) are being developed which have longer life spans and also a third civil signal. The modernization plan also includes looking to improve the standalone accuracy and there is ambitious plans looking to make two of the civil signals CDMA as opposed to FDMA making the signals compatible with the GPS and Galileo. No definitive plans or timescales have been released.

Galileo

Now that all the political wrangling regarding the funding model for Galileo have been resolved, the current status is that the European Space Agency (ESA) is looking to appoint a contractors for the implementation of the various work packages required to get Galileo to full operational capability (FOC). The various work packages include implementing the ground mission segment, ground control segment, the space segment and also the operations phase for Galileo. It is hoped that negotiations can be completed and contracts signed by the end of 2009. Based on the current timeline for the project, Galileo should reach FOC by 2013.

Presently, Galileo has two experimental satellites on orbit designated Giove-A and Giove-B with signals being successfully tracked and decoded. The Galileo spectrum, which consists of 4 frequency bands: E5a, E5b, E6 and L1. Although the principles of Galileo are quite similar to that of GPS, Galileo will offer a much greater variety of signals and services. The design of Galileo signal structure presents significant user advantages compared to the current GPS which include:

- The power of Galileo signals will be greater by a factor of 2, which will result in the reduction of tracking noise for both phase and code ranges.
- Each Galileo signal includes a pilot signal (a data-less component) which can be easily acquired independently, without the decoding of data bits. This helps with acquisition and re-acquisition of the signals.
- The modulation schemes for Galileo will result in significant reduction of both tracking and multipath noise for all code ranges resulting in better accuracy.
- The system also includes a more robust 3-step coding scheme for navigation bits which increase the reliability of navigation message decoding in the presence of interference or with low signal power.

The complex signal structure for Galileo, which includes as many as 10 signal components, will serve the needs of different positioning services offered by Galileo.

- Open Service(OS)
- Safety-of-Life (SoL)
- Commercial Service (CS)
- Publicly Regulated Service (PRS)

The list of Galileo observables, which shall be produced by Galileo receivers and used by most users, is presented in Table 1.

No	Observable	Carrier Frequency (MHz)	Notes
1	E5a	1176.45	= GPS L5
2	E5b	1207.14	
3	E5a+b (Alt-BOC)	1191.795	Low-noise signal
4	E6-A	1278.75	PRS
5	E6-BC	1278.75	CS
6	L1-A	1575.42	PRS
7	L1-BC	1575.42	= GPS L1

Table 1 – Galileo Observables

COMPASS

The new Chinese COMPASS (Beidou 2) system launched its first satellite in April 2007. There is very little published information on the system and no Interface Control Document (ICD) currently exists. Work has be done by researchers at Stamford University (Gao, G., et al, 2007) which successfully decoded the signals transmitted by the COMPASS system and could track the COMPASS satellite.

The current plan calls for 35 satellites (5 of which are geostationary) to provide navigation and positioning on a global basis. It will have three frequency structures that operate at similar frequencies to GPS and Galileo. At present there no timeline or launch schedule for the COMPASS system but it does appear that it is a viable system and more information is eagerly anticipated.

Integration of Multiple Satellite Systems

The different satellite systems operate in a similar fashion but the subtly of each system ensures that in order to develop an integrated solution there are different factors that need to be accounted for. VERIPOS has implemented and been using a full combined GPS and GLONASS multi-reference solution in its positioning algorithms. Presently, VERIPOS coverage for GLONASS includes Brazil, European, India and the Far East with all stations capable of being activated on demand.

The principle difference between GLONASS measurements and GPS measurements is the frequency of transmission. GPS L1 measurements are all transmitted at 1575.42MHz whereas equivalent GLONASS measurements have a base frequency of 1602MHz. Further complicating the issue each GLONASS satellite transmit on slightly different frequencies, these are all an integer number of 562.5KHz apart, the integer number representing the what is termed the channel number.

During the integration of the two constellations several areas need to be addressed in order to provide a reliable and accurate positioning solution. The first area that needs to be addressed is how to handle the satellite ephemeris and almanac data which is transmitted in a different format and reference frame to GPS. The integration of the ephemeris and almanac data is done in the GLONASS geodetic reference frame PZ-90. This is something that needs to be considered when integrating all satellite navigation systems.

GLONASS ephemerides are transmitted with respect to a reference time tb. The ephemerides typically update every half an hour with this reference time being 15 minutes ahead of the initial upload time. This tb is used in RTCM corrections to indicate the particular ephemeride that was used to generate the correction set. Unfortunately, it has been known for a new set of ephemeris parameters to be uploaded with the same tb value. Clearly this can cause difficulties when applying corrections. It should be noted that this problem has not been seen and it is not known if it continues to be an issue.

With respect to the calculation, the code carrier filter which is used to increase the precision of the pseudorange measurement (e.g. Hatch filter) needs to be slightly altered to handle GLONASS measurements. The only adjustment that is necessary is changing the frequency for each GLONASS satellite which is required for converting carrier measurements in cycles into equivalent distances in metres. This simple filter can be easily adapted for use with other GNSS signals.

Another area in the signal frequency calculation that needs to be accounted for is atmospheric delays (troposphere and ionosphere) to improve the accuracy of the position solution.

Troposphere delay occurs in the lower part of the atmosphere and is affected by the weather. However it is not affected by the frequency of the transmitted signal which means that it can be compensated using the same techniques and models as used in GPS.

Ionosphere delay is at a higher level of the atmosphere than the troposphere. GPS broadcasts a model, known as the Klobuchar model which is sued for estimating ionosphere delays. The parameters for the model are transmitted over GPS and are typically updated daily, and the delays are affected by frequency, so the Klobuchar derived delays are with respect to the GPS L1 frequency. However, for use within GLONASS these can be adjusted to the relevant GLONASS frequency by the use of a simple equation.

One area that is currently under investigation at VERIPOS is looking at using the second civil signal on GLONASS to determine the true iono-delay similar to that within GPS when using the L1 and L2 signals. This is something that will be particularly useful during the peak of the next solar cycle particularly if GLONASS has reached FOC and so can be used as an independent solution to GPS and also as a combined GNSS solution.

One are that is of particular importance is the geodetic reference frames that both systems use and is something that needs to be considered when integrating more that two satellite navigations systems. The question that needs to be addressed is what datum should be used as the main reference datum that all other satellite navigation systems need to be transformed into?

For GPS and GLONASS they both have independent geodetic datums or reference systems. GPS is referenced to WGS84 and GLONASS to PZ90. The standard form of transformation between the two datums is known as Helmert transformation using 7 parameters which is outlined below.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} DX \\ DY \\ DZ \end{bmatrix} + \begin{bmatrix} Scale & RZ & -RY \\ -RZ & Scale & RX \\ RY & -RX & Scale \end{bmatrix} * \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

This transforms ECEF coordinates in one datum to another. However, there no globally accepted set of parameters for the transformation which causes problems as the selection of the most appropriate set of parameters is left to the implementer.

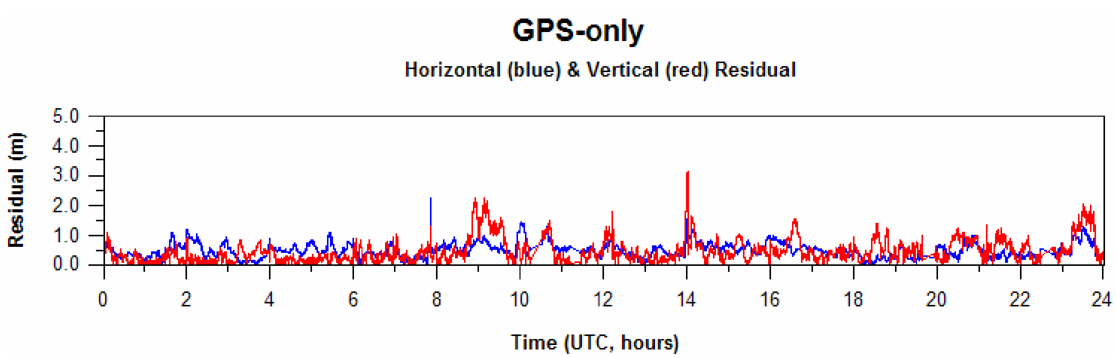
When forming corrections it is important to identify the set of ephemeris parameters used in generating them. While GPS has an ICD number, GLONASS has no such device. This has led to two forms of RTCM Type 31 messages: the original form uses tb as its reference and the later (tentative) form uses tk. Currently all received Type 31s use the tb value so the software can only employ these earlier corrections.
The tb value is the ephemeris reference time. The ephemeris normally updates every 30 minutes, with the tb value set to 15 minutes ahead of the time first transmitted. Under these circumstances the tb value is unique and works satisfactorily.

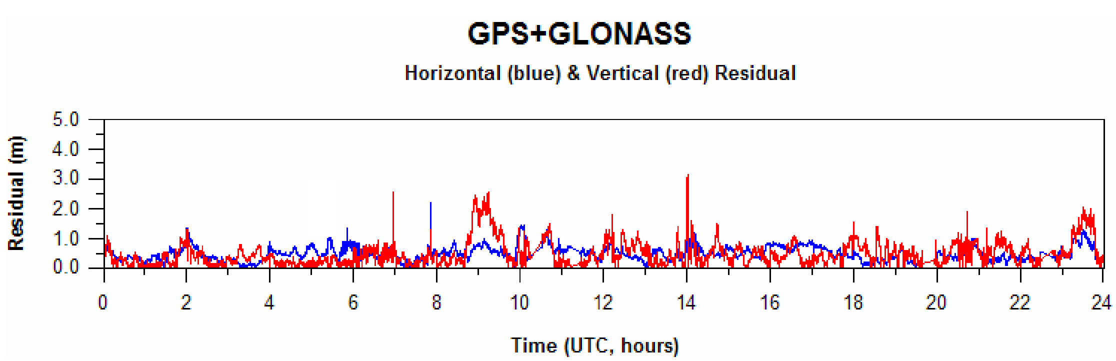
It has, however, it has been witnessed that a new set of ephemeris parameters can be uploaded with the same tb value as a previous set. For this reason a change flag was introduced so that a different ephemeris set can be identified.

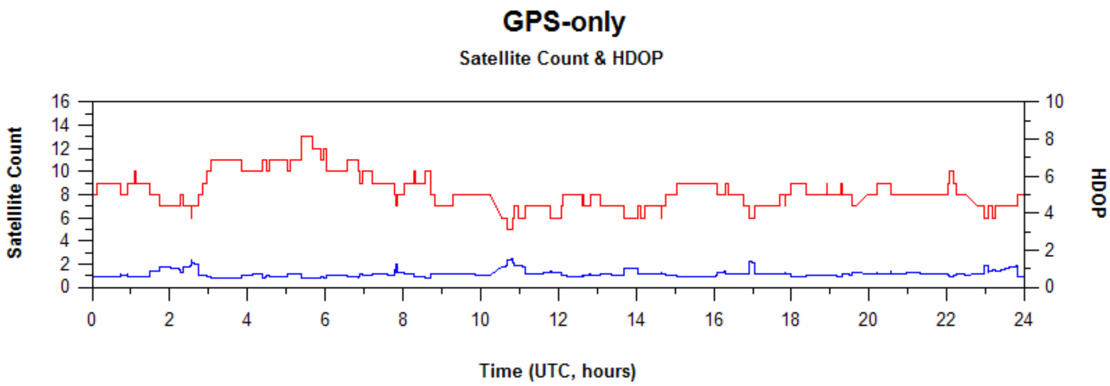
During the validation of the VERIPOS GPS-GLONASS combined differential solution it was noted that using different types of receivers from different manufacturers the transformations used where slightly different. This caused problems when using corrections from reference stations as this introduced biases into the solutions particularly over long base lines. The VERIPOS implementation uses the T3 and T32 data which is used to detect what shift has been applied in the system. At present the system can detect the shifts used by the Topcon, NovAtel, RTCM and local. It would be helpful if a global standard was adopted to minimize the implementation issues. This is something that future satellite navigation systems should consider.

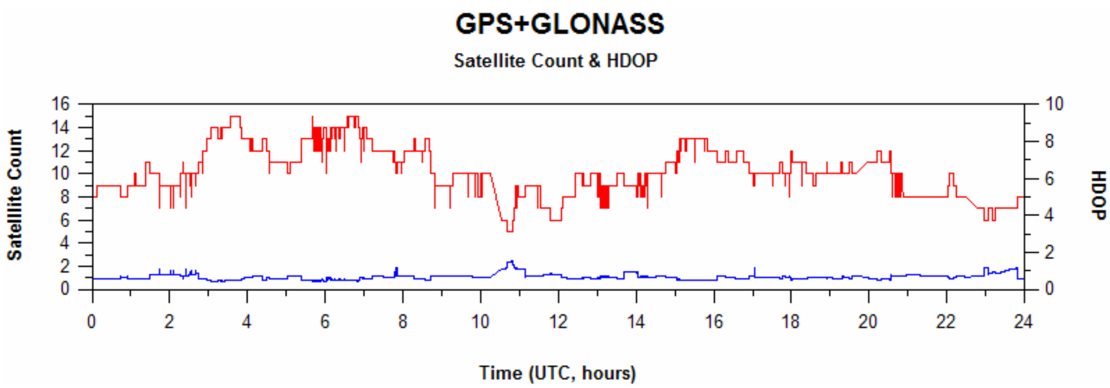
One other issue that was detected during the implementation was the shift of GLONASS frequencies to include negative slots numbers. This required an upgrade of the receiver firmware in all receivers in order to accommodate this.

Results from the combined solution indicate that it does bring a slight improvement to the accuracy but the main benefit is the additional satellites and observations that are available to the position solution. The following graphs present the data from the 27th February 2007 for a baseline in Brazil of 800km. The results show that the inclusion of GLONASS does not degrade the combined solution making it an excellent augmentation to the GPS solution.









Implications for DP Operators

GNSS is changing and will remain one of the main positioning references for DP systems. It is clear that the systems are modernising to meet the future needs of all satellite navigation users including the offshore oil and gas industry.

The advantages that the new and modernised systems will bring are better availability due to the number of increased satellites and signals that can be utilised. These additional signals will be help with accuracy and reliability as this will increase the redundancy of data allowing the processing to be more selective in what data to use. This means that questionable data can be eliminated through complex modelling and statistical testing without affecting the availability of the solution which should lead to more robust positioning.

By having multiple signals at different frequencies and with different characteristics should make solution more resilient to the effects of interference. It will also improve satellite geometry which will help with the convergence of high accuracy systems. Perhaps one useful feature of the having all these different constellations will be the ability to use each constellation independently and also integrated together. This could be an important aspect for safety critical operations.

One potential disadvantage of satellite navigation systems is the perception of Perception of GNSS today is that it is becoming a consumer technology (e.g. mobile telephone) whereby the systems are cheap, infallible providing positioning anytime and is always correct. Consequences of this perception are that inappropriate systems could be installed that could lead to loss or poor quality positioning. The result of this is that the vessel could be out of specification and unable to work.

With the potential for a multitude of different positioning services, there will be several factors that the operator will need to factor when selecting the most appropriate system. Factors such as cost, accuracy, reliability and whether the system allows a vessel to meet class has to be considered.

What about the weighting of references in the DP system itself? How will this be handled in the future when there is a potential for different solutions to made up of different signals and different constellation. Will the suppliers of positioning systems need to provide additional information on the position solution through improved output strings or better integration DP system through collaboration with the DP manufacturer. Is there a requirement for standardising the information (interface) that is provided to DP systems by positioning reference systems to allow this integration?

An area that will become more prominent in the future is the certification of the reference systems that are used in DP systems. At present there are no standards to cover satellite navigation position references that feed into DP systems. The only standard that covers positioning systems is the Marine Equipment Directive (MED) which is designed to enhance safety at sea and is driven by a number of specific resolutions issued by the IMO.

Some Notified Bodies have requested that the position references feeding into the DP system meet the MED. However, if only the vessel SOLAS approved GNSS receiver is used to ensure the safe passage of the vessel, the service and equipment used as a position reference for the DP system is understood to fall outside of the jurisdiction of the IMO regulations and hence outside the Marine Equipment Directive. This conclusion is something that needs to be confirmed by further discussions with Notified Bodies.

Whatever the challenges ahead, the landscape of satellite navigation is going to change improving on what is already available to users. These exciting times will see the development of new techniques and solutions which will help all users.

References

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Acknowledgments

Thanks to Kevin Gaffney for reviewing the paper. The opinions expressed in this paper are entirely those of the author and they do not necessarily reflect the opinions or policy of VERIPOS or Subsea7.