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Compatibity and Interoperapelity of GNSS and Its Impact on Positioning Accuracy (Egyptian Case Study)

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ملخص البحث:

تتكون أنظمة تعيين المـواقع بالرصـــد على الأقمار الصناعية من نظــامين أســاسيين هما أنظمة الملاحة بإستخدام الأقمار الصناعية وأنظمة التزايد بإستخدام الأقمار الصناعية.

تتكون أنظمة الملاحة بإستخدام الأقمار الصناعية من نظام جى بى إس الأمريكى ونظام جلوناس الروسى ونظام جاليليو الأوروبى ونظام بيدو الصينى. بينما تتكون أنظمة التزايد بإستخدام الأقمار الصناعية من نظام إيجنوس الأوربى ونظام واظ الأمريكى ونظام مساس اليابانى. وفى حقيقة الأمر فإنه حاليا يوجد أكثر من ستين قمر صناعى (يناير 2017) تدور فى مدارات مختلفة حول الأرض وتقوم بإرسال العديد من الإشارات ذات الترددات المتعددة.

وبحلول عام 2020 سوف تصل أنظمة جاليليو وبيدو إلى مراحل التشغيل المكتمل وفى نفس الوقت فإن أنظمة ملاحة إقليمية مثل آى أر إن إس إس الهندى ونظام كيو زد إس إس اليابانى تكون تحت التطوير. وأيضا تكون أنظمة تزايد جديدة مثل جاجان الهندى ونظام إس دى سى إم الروسى قد بدأت العمل. وهذا يعنى أنه خلال سنوات قليلة سوف تصل الأقمار الصناعية المخصصة لأغراض الملاحة وتعيين المواقع لرقم غير مسبوق مما يعنى وجود العديد من الإشارات والعديد من الترددات. كل هذه الأنظمة وكل الأقمار ذات الإشارات المختلفة يجب أن تكون متوافقة وأن تكون الخدمات المفتوحة لهذه الأنظمة متوافقة لأقصى درجة.

فى مصر حاليا تم إلتقاط إشارات من أنظمة جى بى إس وجلوناس وجاليليو وبيدو، ولكن لما كان نظامى جاليلو وبيدو مازالا فى مرحلة التشغيل الإبتدائى فإن عدد الأقمار المرصودة مازال قليل نسبيا (من واحد إلى أربعة أقمار) خصوصا نظام جاليليو. ومن جانب آخر تغطى أنظمة التزايد مناطق كثيرة فى العالم إلا أن مصر مازالت خارج هذه المناطق. وبالتالى فإن التوافق والعمل المشترك بين هذه الأنظمة من الموضوعات الجديرة بالبحث. وفى هذه المقالة يتم مناقشة التوافق والتكامل بين كل من أنظمة جى بى إس وجلوناس وجاليليو وبيدو من خلال معالجة الأرصاد المأخوذة عند نقطة ثابتة داخل مدينة القاهرة بمصر بإستخدام أسلوب إيجاد الإحداثيات المطلقة الدقيقة. وكذلك دراسة الفوائد المتوقعة من توافر العديد من الأنظمة والعديد من الإشارات الملتقطة مثل زيادة توافر الأقمار والدقة والإستمرارية والثقة والكفاءة وسرعة حل الغموض لعدد الذبذبات الصحيحة و كذلك سرعة الوصول للحل الصحيح.

Abstract:

GNSS (Global Navigation Satellite Systems) consists of two mainly systems, Satellite Navigation Systems (SNS) as GPS and GLONASS, Galileo and BeiDou and Satellite Based Augmentation Systems (SBAS) as EGNOS, WAAS and MSAS. Actually (In January 2017) more than 60 operational GNSS satellites are in orbits transmitting a variety of signals on multiple frequencies. By 2020 Galileo and BeiDou constellations will reach the full operation capabilities and in the same time new regional SNS as IRNSS in India and QZSS in Japan are under construction. Also new SBAS as GAGAN in India and SDCM in Russia are under consideration. This means that within few years the number of satellites which can be used in user's position computation will reach more than one hundred, with even more types of signals broadcast on even more frequencies. All these systems, all satellite signals and different services designed for the users must be compatible and open signals and services should also be interoperable to the maximum extent possible. In Egypt, at the moment, signals of Satellite Navigation Systems (SNS) as GPS and GLONASS, Galileo and BeiDou could be logged; however, since Galileo is still in Initial operation capability (IOC), observations of one to four satellites could be logged. On the other hand Satellite Based Augmentation Systems (SBAS) covers only some areas of the world; Egypt is not part of these areas. Consequently, no signals of SBAS satellites could be obtained. The part of compatibility and interoperability of Satellite Navigation Systems (SNS) in computation user's position and its impact on accuracy is presented in this paper by considering a case study of precise point positioning processing depending on GPS and GLONASS, Galileo and BeiDou observations and expected benefits of the extra satellites and their signals which can be categorized in terms of availability, accuracy, continuity, reliability, efficiency, and ambiguity resolution issues

Key Words: Satellite Navigation System (SNS), Saellite Based Augmentation System (SBAS), compability, interoperability, coordinate reference frame, time reference, and signal in space

1. Introduction:

GNSS provide the user with a three-dimensional positioning solution by passive ranging using radio signals transmitted by orbiting satellites. Selected parameters of GPS, GLONASS, Galileo and BeiDou (China intends to discontinue use of Compass as the English name for BeiDou) are presented in the **table 1**[**Januszewski, 2013**]. Positions can be obtained by means of many receivers: one, two, three or four mentioned above SNSs receivers with or without GNSS in differential mode, taking into consideration that interferences between signals of different satellites must be avoided.

To avoid interferences between signals of different satellites, satellite multiplexing methods exploit the one or the other orthogonality between signals. Code division multiple access (CDMA) guarantees access to different satellites by using orthogonal code sequences, in this case all satellites emit the signals on the same two or more frequencies, and this method is used or planned in GPS, Galileo and BeiDou systems. On the other hand, Frequency division multiple access (FDMA) exploits the spectral separation of different SNS signals, in this case all satellites use the same codes, and this method is used in GLONASS system (block M) only [**Januszewski, 2011**].

Many of the differences among GNSS signals can be reconciled within the user's receivers to produce a common position /velocity/time (PVT) solution. But the greater and more numerous the different corrections needed, the greater the computational overhead on the device itself, as well as adverse effects on performance, size, weight, power, and cost. Optimizing the alignment of signals and frequencies, time and geodetic coordinate systems, however, are long-term projects, although the sooner progress is made on them, the sooner they become a present reality.

Table 1: Selected parameters of GPS, GLONASS, Galileo and BeiDou

Parameters	*GNSS Systems*			
	GPS	*GLONASS*	*Galileo*	*BeiDou*
Operability	*global FOC* *sinceVII/1995*	*Global FOC* *since XII/2011*	*global IOC a 2014* *global FOC a 2020*	*global FOC a 2020*
Satellite identification	*CDMA*	*FDMA a L1, L2* *CDMA a L3*	*CDMA*	*CDMA*
Satellite constellation	*31 operational*	*24 operational + 5 ÷ 7 different status*	*27 operational + 3 active sphere*	*37 operational a 5 GEO, 27 MEO,5 IGSO*
Period	*11h56m*	*14h05m*	*11h15m*	
Number of carrier frequencies	*2 (satellites IIa,IIR, IIRaM)* *3 (satellites IIF)*	*2 (satellites M)* *3 (satellites K1)*	*4*	*3*
Frequencies (Civil use)	*L1:1575.42 MHz* *L2:1227.60 MHz* *L5:1176.45 MHz*	*G1:1602~1616 MHz* *G2:1246~1257 MHz* *3rd :TBD*	*E1:1575.42 MHz* *E5b:1207.14 MHz* *E5a:1176.45 MHz*	*B1C–B1A:* *1575.42 MHz* *B5b:1207.14 MHz* *B5a:1176.45 MHz*
System time	*GPST -* *GPS Time*	*GLONASSST – GLONASS System Time*	*GST – Galileo System Time*	*BDT – BeiDou Time*
Datum	*(WGS84)*	*(PZ 90)*	*(GTRF) – Galileo Terrestrial Reference Frame*	*China Geodetic System 2000*
Integrity	*Non*	*Non*	*yes, service Safety of Life*	*Unknown*
Horizontal position accuracy [m] 95%	*2 to 4 m*	*5 to 6 m*	*depending on service*	*10 m*

2. Compatibility and Interoperability

Compatibility refers to the ability of two services to be used separately or together without interfering with each individual service or signal. Interoperability, in contrast, refers to the ability to use two services together to achieve better performances at user level. The different global systems have been designed to be compatible. Meanwhile, an increasing number of agreements between the operators guarantee the interoperability of systems and signals. Signals have been specified to be in common between the systems; nevertheless some signals have intentionally been separated to avoid common mode failures. The coexistence of the four GNSS will either result in an alternative use or in a combination of the services and signals to gain a combined solution. An increasing number of systems and signals will provide an increasing number of observations. One could conclude that in general with an increasing number of satellites the DOP values decrease, and, consequently, the position accuracy increases. Using two systems for position determination will almost double the number of navigation satellites and, thus, double the number of observations for position computation.

3. Combined Solution

Although common reference systems (Coordinate systems, time systems, and signal) would have facilitated the interoperability, the systems have been intentionally designed to use different reference frames, in order to avoid common mode failures and, thus, to increase the integrity of combined solutions.

3.1. Reference Systems

3.1.1. Coordinate Systems

Different coordinate reference frames influence the satellite coordinates. Consequently, the satellite coordinates have to be transformed into a common system before the adjustment process is applied. Any difference in coordinate frame can be considered as orbital error of the respective satellites. Transformation parameters between the different coordinate systems are given according to the Helmert transformation. Due to the similarity of the reference systems, the transformation can be applied in differential form.

The international civil coordinate reference standard is the International Reference Frame (ITRF), each GNSS has its own reference frame, which depends on the control stations' coordinates hence guaranteeing independence among systems. The Galileo terrestrial reference frame (GTRF) is specified to maximally differ from the latest version of international terrestrial reference frame (ITRF) by no more than 3 centimeters. The difference of WGS84 to ITRF has been determined to be also within this range. Also BeiDou system – China Geodetic Coordinates System 2000 (CGCS2000), will be consistent with ITRF. Consequently, for navigation purposes and most user requirements, the agreement between ITRF, GTRF, and WGS-84 is sufficient and no coordinate transformations have to be applied. For geosciences, surveying, and other high-accuracy applications, an appropriate transformation has to be applied.

The coordinates of GLONASS system are based on the parameter of the Earth 1990 (PE-90) frame, also known as Parametry Zemli 1990 (PZ–90.02). There are many number of different transformation parameters for the transformation between PZ-90 and WGS-84 coordinate systems. The Radio Technical Commission for Maritime Services specifies a standard transformation between PE-90 and WGS-84 using as rotation angle around the Z-axis of −0.343

arcseconds. The scale is equal to one, and all other parameters are set to zero. It is expected that PZ-90 will in future be improved to better agree with ITRF.

Global transformation parameters will be available for all reference systems. Users may also determine their local transformation parameters if necessary.

3.1.2. Time References Frame

While most clocks in the world are synchronized to UTC (Universal Time Coordinated), the atomic clocks on the satellites are set to own SNS time. The time offset between the different reference time systems will be emitted in the navigation message of the systems. Various agreements, e.g., between US and EU, Russia, and Japan, already specify the time offsets and its provision to the user.

3.1.2.1. GPS System Time (GPST)

● GPS system uses its own particular, continuous time scale GPS System Time (GPST) referenced to UTC (US Naval Observatory – USNO). GPST differs from UTC by a nearly integer number of seconds.

● GPST is a continuous time scale that is not corrected to match the rotation of the Earth, so it does not contain leap seconds or other corrections which are periodically added to UTC.

● GPST and UTC (USNO) were coincident at 0h January 6, 1980. As at this moment the difference between TAI (Time Atomic Scale) and UTC was 19 seconds, GPST remains at a constant offset (19 seconds) with TAI.

● At the moment, the difference between GPST and UTC is 16 seconds.

3.1. 2.2. Glonass System Time (GLONASSST)

● GLONASS time, based on an atomic time scale similar to GPS, is strongly linked to the national time scale of Russian Federation − UTC(SU) which is maintained by the Main Metrological Center of the Russian Time and Frequency service at Mendeleevo in the Moscow region.

● The GLONASS time is closely related to the UTC but has a constant offset of three hours reflecting the difference between Moscow time and Greenwich time. This relation implies leap seconds for the GLONASS time. Apart from the constant offset, the difference between GLONASS time and UTC shall be within 1 millisecond arising from the keeping of the time scales by different clocks.

● The relation between UTC and GLONASSST is:

$$UTC = GLONASSST + \tau c - 3h$$

The discrepancy, τc, comes from the different clock ensembles used and is communicated to the GLONASS users in the GLONASS navigation message (**Seeber, 2003**).

3.1.2. 3. Galileo System Time (GST)

● The Galileo system time (GST) is a continuous atomic time scale with a nominal constant offset (i.e., integer number of seconds) with respect to the international atomic time (TAI)

● The offset of GST with respect to TAI and UTC will be included in the navigation message and broadcast to the users.

● The GPS to Galileo time offset (GGTO) will be computed and distributed to the users via the Galileo space segment.

3.1.2. 4. BeiDou System Time (GST)

● Chinese SNS the time reference is BeiDou Time (BDT), related to UTC through UTC (NTSC – National Time Service Center of Chinese Academy of Science). BDT offset will respect to UTC is controlled within 100 ns (modulo 1 second).

4.3. Signal in Space

● The current and future frequencies carrier of GPS, Galileo, BeiDou, GLONASS (satellites K1, K2 and later using format CDMA only), are presented in the table 2. Signal interoperability is achieved when the signal provided by different SNS are similar enough to allow an integrated GNSS receiver to use all those signals with minor modification. Therefore the signals have been specified to be in common between the systems; nevertheless same signals have intentionally been separated to avoid common mode failures [**Hofmann-Wellenhof B. et al., 2008]**.

● Each SNS uses or will use three different frequencies at least but one frequency (1176.45 MHz) is (will be) the same in all four SNS, and next two are 1207.14 MHz and 1575.42 MHz. Nowadays the frequency 1575.42 MHz is common for all SBAS for broadcast GNSS correction, the other frequency 1176.45 MHz will be it in the near future.

● All five frequencies currently used or planned in three SNS, GPS, Galileo and BeiDou are based on the fundamental frequency fo = 10.23 MHz, in the case of 1176.45 MHz, 1207.14 MHz, 1227.60 MHz, 1278.75 MHz and 1575.42 MHz, the factor (fo) is 115, 118, 120, 125 and 154, respectively. In the case of GLONASS system the signals use FDMA techniques, hence a different carrier frequency per satellite

4. The Benefits of More Satellites

The new generation of GNSS will bring extra satellites and signals to deliver better accuracy, availability, continuity, reliability, and efficiency as follow [**Yu-Sheng Huang, 2007**], [**Rizos C., et al 2005]**:

4.1 Accuracy:

Positioning accuracy can be achieved sooner by observing more satellites. Moreover, the effects of multi-path and interference/ jamming can be mitigated, which improve the measurements quality.

4.2 Availability:

The most important benefits of simultaneously using GPS, GLONASS, Galileo, BeiDou is the improvement in availability, especially in urban areas, under tree canopies or in open-cut mines.

4.3 Continuity:

As GPS, GLONASS, Galileo, and BeiDou are independent systems, the possibility of problems occurring simultaneously is very far away.

4.4 Reliability:

More signals means that service is not as easily denied due to interference or jamming of one frequency that may prevent the making of critical pseudorange and/or carrier phase measurements.

4.5 Efficiency:

The extra satellite signals will significantly reduce the time required to resolve ambiguities to achieve centimeter accuracy.

5. Case Study

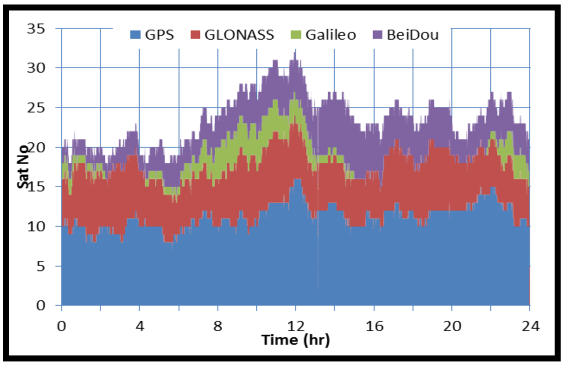
Static GNSS observations, collected at fixed point (K) in Cairo on July 14, 2015, are used for numerical analysis as shown in fig (1).

5.1 Processing Strategies, Achieved Results and Comments

As mentioned before, static GNSS observations have been collected at such point (**K**) on Sunday, July 14, 2015. So, in GNSS calendar the corresponding day of year was 195, modified Julian date number was 57217, and GPS week number was 18532. The WGS84 coordinates of such point (**K**) were obtained by using technique of standalone precise Point Positioning (**PPP**) with data post processing which mainly depends on the proper modeling of GNSS errors and bias and satellite availability. While the first order ionospheric effect is canceled out by using the un-differenced ionosphere free linear combination of GNSS code and phase measurements, final products of IGS precise orbital and clock are used to account for the satellite orbits and clock errors.

Figure 1. The fixed GNSS station (K) in Cairo

Figure 2 shows the GNSS availability and GDOP for the quad constellations at Cairo for logging observations day. It is obvious that maximum of four satellites of Galileo can be tracked while six to seven satellites of BeiDou can be tracked at Cairo. It can also be seen that, except Galileo, there are sufficient number of both GLONASS and BeiDou all the day. However, there are certain GDOP jumps for both GPS and GLONASS which probably are due to the low elevation angles of part of the satellites which significantly worsen the GDOP. These jumps are hardly appeared in GNSS GDOP due to the addition of GNSS satellites which significantly enhance the GDOP in comparison with the GDOP of the GPS only. However, this contribution attributes mainly from the additional GLONASS observations while the GDOP for the combined GPS/Galileo is marginally enhanced because of the limited number of Galileo satellites available.



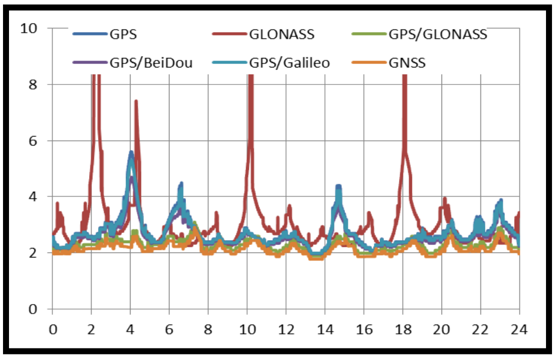


Figure 2 shows The Quad- Constellations GNSS satellites availability and GDOP for Cairo on July 14, 2015.

Table 1 illustrates root mean square error RMSE of the obtained results for all processed data of different sessions GPS PPP and all GNSS PPP. Where it is easy to find that, the GNSS PPP obtained an enhancement of 30 cm after 5 mins in comparison with GPS PPP, while it took about 120 mins to obtain the accuracy.

Table 2 shows 3D positioning accuracy after different processing times of different GPS PPP and all GNSS PPP, using dual-frequency PPP model

Time (min)	3D positioning accuracy (m)	
	GPS	GNSS
5	0.99	0.68
10	0.22	0.11
30	0.04	0.01
60	0.04	0.01
120	0.02	0.02

Table 3 shows the mean convergence times of GPS PPP and GNSS PPP. For each data set, the mean convergence time are obtained as the average of the convergence times in the three positioning directions, namely, X, Y and Z, respectively. In comparison with GPS PPP, a reduction of the positioning convergence by 7 minutes is obtained by all GNSS observations, which represent 38% in convergence time improvement.

Table 3 shows the convergence time for GPS PPP and GNSS PPP using dual frequency PPP model

Poisoning Combination	CT (min)
GPS	19.5
GNSS	12

6. Conclusions

The new generation of GNSS will bring extra satellites and signals to deliver better accuracy, reliability and availability. Extra satellites will make possible improved performance for all applications, and especially where satellite signals can be obscured, such as in urban canyons, under tree canopies or in open-cut mines. In its various modes, modernized GNSS will also deliver higher accuracy and improved speed-to-first-fix for carrier phase-based positioning and reduce convergence time. The extra satellites and signals will improve the performance and reliability for all applications right down to the centimeter accuracy techniques used in surveying and geodesy.

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