Positioning precision of GPS/Galileo integration in Vietnam

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***Abstract* – The design of Galileo has been conceived so as to facilitate its possible joint use with GPS thus contributing to a favorable multi-GNSS environment. Evaluating the performances of such multi-GNSS combination is crucial for end users to assess the quality of obtainable PVT and the easiness of interoperability of the two systems. In this paper, we evaluate the GPS/Galileo integration performances in terms of estimated precision in position determination and in terms of availability of the service. Results obtained from real data are presented and show that there is an improvement of both these criteria when the two systems are jointly used.**

Keywords – GPS, Galileo

I. INTRODUCTION

Over passed decades the use of GNSS-based PVT determination has been steadily increasing and it has become an essential tool for applications and services in almost any field social life from transportation (air, road, rail, maritime) and LBS to logistics, from surveying to agriculture, from environment protection and monitoring to disaster management and natural resources exploitation.

Until the end of last century the only two available systems were the US GPS and the Russian GLONASS. Both of them are military systems with no guarantee of service (since they could be switched off at any time without notice by their providers) and were providing low accuracy for the free service available for civilian use. At that time, most of the applications where based on GPS because its receivers were more easily available and also because GLONASS degraded its performances over a long period since satellites that went out of order were not replaced for several years.

Despite the fact that GPS was primarily a military system, many civilian applications improving business and productivity in several fields were developed using GPS. In the late nineties in the EU it was recognized that a disruption of the GPS services would cause considerable losses to the European economy that was increasingly dependent on GPS-based services. Meanwhile it was noticed that a guaranteed GNSS service with increased accuracy would allow better services and applications. These facts triggered preliminary studies for the setup of a European civilian GNSS. Then, in the early 2000s, the European Council took the Financing Decisions for the Galileo programme: the new European GNSS. After a Definition Phase (2000-2002), a Development and Validation Phase (2002-2008) and an In Orbit Validation Phase (2008-2014) the program is now in its Deployment Phase (2014-2020), on his way towards full operational capacity.

At the beginning the possible military use of Galileo by enemies raised concern in the US and Galileo was also perceived as a competitor for the open GPS service. The design of Galileo, taking advantage of latest technological developments, foresaw better performances in terms of accuracy than the existing GPS. So when the EU intention to build Galileo became real, the US ended the selective availability of the open GPS service (on 1st May 2000) thus improving considerably its accuracy. Rather soon, however, it was recognized that cooperation between the providers of GPS and Galileo is the best choice. While the ownership of an independent system protects Europe from disruptive effects of GPS shutdowns, yet in the most common case in which both systems are regularly working their joint use can provide better performances to end uses worldwide. The joint use of both systems can be indeed facilitated if, during the design stage, proper technical solutions are adopted. A EU-US Commission on GNSS carrying on regular consultations was created in 2004. The EU then agreed to switch to the BOC modulation for the Galileo signal thus allowing GPS and Galileo open services on the same frequencies while avoiding interference. Also for the synchronization of the Galileo and GPS time, solutions were adopted to facilitate the joint use of both systems.

So already in the first phases of its design and development, well before its first satellites were launched, the Galileo system brought some advantage to the GNSS community worldwide. It suggested the end of the Selective Availability boosting the GPS civil open service. While until the launch of the Galileo program GNSS research was primarily military driven and developed in connection with US interests, the development of Galileo facilitated the ending of this monopoly while contributing to the creation of a favorable Multi-GNSS environment available for civilian use. Last but not least, since Galileo design incorporates latest technological solutions in order to improve performances, it pushed other GNSS providers to modernize also their systems.

As noticed before, Galileo is in its Deployment Phase. At present the status of the system consists of 14 satellites [1]. Nine are fully operational, one is unavailable since 27-05-2014 until further notice, and the last four are in commissioning. Of these least, the two launched on 24-05-2016 should become operational in coming months. On top of this the launch of other four satellites is scheduled for next 17th November [2]. In such condition, although Galileo is not fully deployed, it is already possible to make some preliminary evaluation on real data of the advantages that the joint use of Galileo and GPS can provide to GNSS end users. The advantages are mainly related to the larger number of satellites that are visible. In such condition the uncertainty in the PVT determination is reduced. On top of this more satellites in view also increase the availability of PVT determination in demanding conditions when the sky is largely masked by different obstacles like in urban canyons or in locations with consistent presence of trees. In the next sections the results of a comparison between the joint use of Galileo and GPS versus their standalone use is analyzed using real data collected in Hanoi at the NAVIS Centre. This analysis shows the advantages of the use of a multi-GNSS environment with particular focus on Vietnam and South East Asia.

In the next future the Galileo system will bring some new advantages to Multi-GNSS open service end-users. Actually, based on recent statements delivered by GSA officers [3], it is expected that an authentication service will be provided for the Galileo signals in the next future. In this way it will become more difficult to spoof Galileo-enabled receivers that will be able to recognize whether the signal is transmitted by the Galileo satellites or by other devices. Actually the increasing number of security-sensitive applications (transport monitoring of hazardous/restricted goods, money/valueables transport, monitoring of fishery to avoid fishing in prohibited zones, etc.) highly increases the potential interest for spoofing the receivers used for such applications. In fact in this way it is possible to drive the spoofed receiver in a position different from the one in which it should be. This is a real threat, as shown by recent studies [5] and Galileo should make it possible, through the authentication of its signals, to contrast such malicious behaviors.

II. ACCURACY WITH THE JOINT USE OF GPS AND GALILEO

In this section we are going to analyze the accuracy of the PVT provided by the Multi-GNSS environment constituted by Galileo and GPS versus the accuracy provided by the standalone use of either system.

There are several techniques to compute user PVT. Kalman filtering and Least Mean Square Estimation (LMSE) are the most common. In this study it was decided to use LMSE in connection with its simple implementation and also because this technique avoids to integrate errors.

The setting of this approach in the context of the position determination from GNSS signals is shortly recalled hereafter.
According to Mirsa and Enge [4], the observed pseudorange can be expressed as follows:

$$\rho^k = r^k + c(\delta t_u - \delta t^k) + I^k + T^k + \epsilon^k \qquad (1)$$

where:
ρ^k is the pseudorange measurement of the satellite k
r^k is the geometric range between the receiver and the satellite k
c is the speed of light in vacuum
δt_u is the receiver clock offset relative to GPS (or Galileo) time
δt^k is the clock offset of the satellite k relative to GPS time
I^k is the delay of the satellite k caused by ionospheric layer
T^k is the propagation delay of the satellite k caused by tropospheric layer.
ϵ^k is the unknown error.

Remark that all GPS or Galileo satellites are considered as synchronized together and use the GPS (or Galileo) time. Hence, if the receiver uses a single constellation to compute PVT, the variable x defining the position of the receiver can be expressed as follows:

$$x = \begin{bmatrix} x_u \\ y_u \\ z_u \\ c\delta t_u \end{bmatrix} \qquad (2)$$

where x_u, y_u, z_u correspond to the user position according to WGS84 while δt_u is the time difference between the clock of the receiver and the time of GPS or Galileo. Let the observation vector y be defined as:

$$y = \begin{bmatrix} \rho^1 - I^1 - T^1 \\ \rho^2 - I^2 - T^2 \\ \dots \\ \rho^M - I^M - T^M \end{bmatrix} \qquad (3)$$

And indicate the vector $h(x)$, which depends on vector x, as:

$$h(x) = \begin{bmatrix} r^1 + c\delta t_u^G \\ r^2 + c\delta t_u^G \\ \dots \\ r^M + c\delta t_u^G \end{bmatrix} \qquad (4)$$

where r^i is the Euclidean distance from the receiver to the satellite i.
Noting that

$$y = h(x) + w \qquad (5)$$

Where w is a vector of errors, the LMSE solution to the PVT determination can be found iterating the following equation until its convergence

$$x = x_0 \qquad (6)$$
$$x_{i+1} = x_i + (H^T W H)^{-1} H^T W \big(y - h(x_i)\big)$$

where H is the partial derivative of $h(x)$ at $x = x_i$.

In the case in which GPS and Galileo satellites are used, the time offset between the two systems must be taken into account. This can be done either using the information that is broadcasted to users with an accuracy of about 5ns (equivalent to about 15cm) or one more element is added into the vector x that becomes

$$x = \begin{bmatrix} x_u \\ y_u \\ z_u \\ c\delta t_u^G \\ c\delta t_u^E \end{bmatrix}. \quad (7)$$

For the study presented in this paper we have adopted this last solution.
Assuming that there are M GPS satellites and $N - M$ Galileo satellites, then the vector $h(x)$ becomes:

$$h(x) = \begin{bmatrix} r^1 + c\delta_u^G \\ \dots \\ r^M + c\delta_u^G \\ r^{M+1} + c\delta_u^E \\ \dots \\ r^N + c\delta_u^E \end{bmatrix} \quad (8)$$

While vector *y* results to be:

$$y = \begin{bmatrix} \rho^1 - I^1 - T^1 \\ \dots \\ \rho^M - I^M - T^M \\ \rho^{M+1} - I^{M+1} - T^{M+1} \\ \dots \\ \rho^N - I^N - T^N \end{bmatrix}. \quad (9)$$

The LMSE solution to the PVT determination can again be derived iterating equation (3) until it converges.

III. Results

Two experiments were conducted to: (A) benchmark the GPS/Galileo integration performance with GPS and Galileo only; (B) verify the interoperability of GPS and Galileo.
For both scenarios, signals collected from the antenna installed on the roof of Ta Quang Buu building in Hanoi University of Science and Technology, where the NAVIS Centre is located, were processed with the Septentrio Receiver [6] installed in the Centre. The raw data provided by the receiver, including observation measurements and navigation messages from both GPS and Galileo satellites, were then processed to estimate the receiver position using MATLAB scripts proprietary of the NAVIS Centre.

A. Performance of GPS/Galileo integration in terms of precision

In the first scenario, 5 GPS and 5 Galileo satellites were chosen to compute PVT. The sky plot of those satellites is shown in Fig. 1.

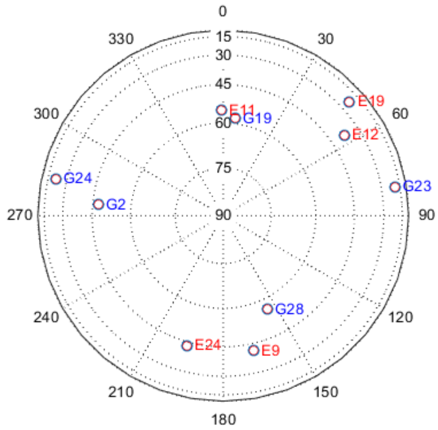

Fig. 1. Sky plot of satellites used for performance evaluation

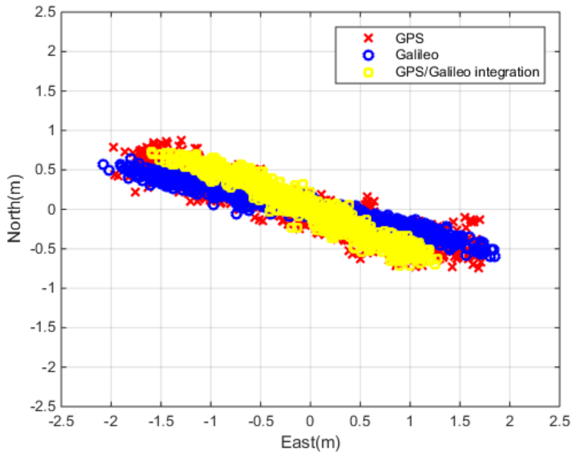

Fig. 2. The precision of the estimated user position along North and East direction using the single constellations as well as their combination.

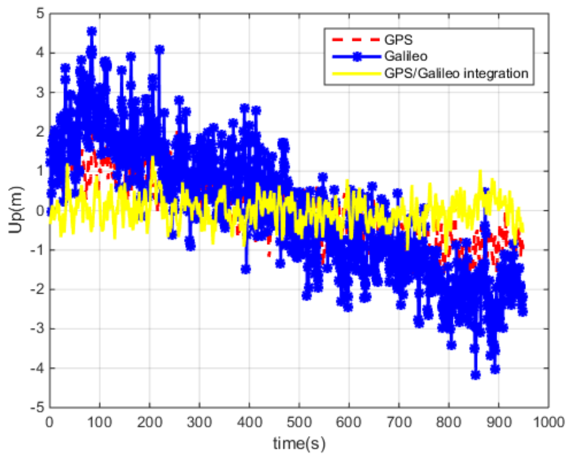

Fig. 3. The precision of the estimated user position along vertical direction using the single constellations as well as their combination.

As shown in Figures 2 and 3, the performances of GPS and Galileo in term of precision are comparable although the error on each axis is dissimilar. In particular, the largest error appears on the Up axis (4 meters).

This is consistent with the fact that the receiver has more information for determining the position in the horizontal plane than along the vertical axis [7]. The error occurred along the East axis (2 meters) is little higher than the one along the North axis (1 meter). This is due to the fact that satellites are not evenly distributed in the sky (Fig. 1).
As for the error in the determination of the user position using GPS/Galileo combination, Figures 2 and 3 show also the improvements that are obtained with the integrated use of both constellations. A better precision is achieved in particular for what concerns the vertical axis. Maximum error results for the different settings considered are also reported in the following table.

	GPS (m)	Galileo (m)	GPS/Galileo (m)
East	0.9476	0.9511	0.6850
North	0.3748	0.2700	0.3790
Up	0.8789	1.6611	0.3595

B. Interoperability of GPS and Galileo

In this experiment, the signals received from only 3 GPS satellites are used together with those of 3 Galileo satellites. Clearly, 3 satellites are not enough to compute PVT. Therefore, in this case it would not be possible to get the PVT using only one of the two systems while it is possible to compute it if the two systems are used jointly. Fig. 4 shows the estimated horizontal position obtained in this case. Obviously, the precision achieved with this combination of GPS and Galileo is similar to the precision that would be obtained using only one of the two systems if all the six satellites would belong to it.

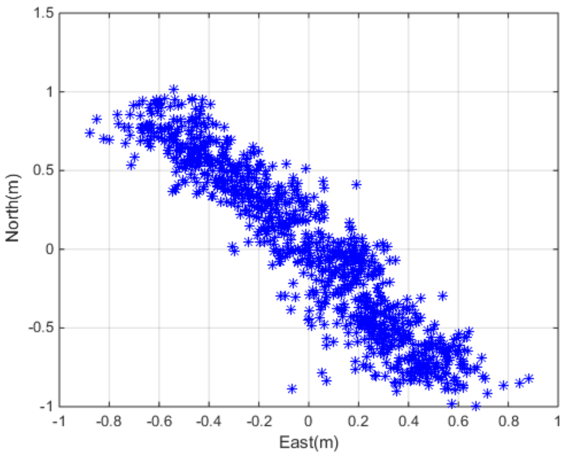

Fig. 4. The estimated position using 3 GPS satellites combined with 3 Galileo satellites.

IV. CONCLUSION

In this paper, the status of the Galileo system, which is in its Deployment Phase, is shortly described together with an evaluation of the performances achievable with the join use GPS and Galileo. These last are compared with those that can be obtained with each standalone system. From the results shown, it can be clearly seen that the combination of GPS and Galileo satellites not only improves the calculated position precision but also increases the availability of the service. Obtained results also show that currently standalone Galileo is also able to provide PVT with performances similar to those of GPS.

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Gustavo Belforte graduated in Electronic Engineering in 1974. Since 1975 he joined Politecnico di Torino where he covered different positions. In 1985 he became Associate Professor of Automatic Control. He has been teaching graduate and undergraduate courses in Automatic Control and related areas for more than 35 years. His research activity has been mainly focused on theoretic and applied problems related to modeling and identification. He also investigated classification and signal processing problems. In the early stage of his activity he was involved in biomedical applications while in more recent years he has been working on mechanical systems and on robotic applications in agriculture as well as on the use of Satellite Positioning Systems. He is author or co-author of more than hundred twenty papers published in international journals, books and conferences. Since 2002 he has been involved as general coordinator or local coordinator in six international cooperation projects funded by the European Commission in the ICT field. Since December 2011 he was appointed Co-Director of the NAVIS Centre in Hanoi University of Science and Technology.

Thuan Nguyen Dinh received his Engineer Degree on Computer Engineering in 2011 from Hanoi University of Science and Technology, Vietnam. He received his Specializing Master Degree of Navigation and Related Application in 2012 from Politecnico di Torino. Now, he is pursuing joint-PhD studies between Hanoi University of Science and Technology (HUST) and Politecnico di Torino (POLITO). His research has been focused on applying array signal processing for GNSS receivers.

Tung Ta Hai received his Engineer's degree (2003) and M.Sc. degree in information technology from Hanoi University of Science and Technology (HUST), Vietnam (2005), followed by his Master degree in navigation and related application (2006) and Ph.D. degree in information and communication technologies (2/2010) from Politecnico di Torino (PoliTo), Italy. Since 3/2011, he has worked in School of Information and Communication Technology, HUST as well as Collaboration Center for Research and Development of Satellite Navigation Technology in South-East Asia (Navis Center), Hanoi, Vietnam. Since December 2011, he has been the Director of NAVIS Centre. His research activities are focused on GNSS signal processing and Nav/Com integration technologies.