ABSTRACT

Nowadays the use of geographic information is widespread as a component of very specialized applications like traffic management, route optimisations, civil engineering, urbanism, cadastre maintenance, agriculture, emergency management and many others. This high demand need better performances of the cartography validity in terms of accuracy, and even more in many cases, in terms of how updated and reliable is the geographic information. There are applications that work directly over the changes that are affecting the cartography information, demanding a quick update and immediate delivery of a maintained new cartography. Representative examples are traffic or emergency management where decisions require very recent information.

The GNSS technology is being a key driver and enabler of this boom of GIS based applications, up to now with GPS and in the close future with EGNOS and GALILEO. These systems allow, in comparison with classical technologies, a much easier and faster surveying of the geographical references of the data to be incorporated into the cartography.

The range of positioning accuracies achievable with GNSS depends on the used technology. A GNSS stand-alone receiver has an error level which improvement requires the use of diverse techniques of differential processing with respect to a static GNSS reference station. In comparison with GPS, EGNOS and GALILEO are systems that have been designed to provide highly improved levels of accuracy in the basic stand-alone application. Therefore there is a range of applications that now with EGNOS and in the future with GALILEO will be affordable by using an stand-alone receiver while a similar accuracy with GPS requires differential technologies. Additionally, as in the case of GPS, differential techniques for high accuracy applications are available for EGNOS and GALILEO.

In addition there are some design aspects of EGNOS and GALILEO that will make affordable applications that are not possible now with GPS, like the ones that demand a specifiable confidence or liability to the geographic information: the level of accuracy in the cartography information must be assured with high and known confidence levels. These are the cases where the positioning information could have legal implications or judicial consequences, like critical uses by the public administration or private services where errors in the information cause damages to the users that can be matter of a Court process. As consequence of being the aeronautical application one of the main reference applications, EGNOS and GALILEO have as one of the key design drivers the integrity of the positioning information obtained directly in the stand-alone use of the receiver. GPS does not provide such integrity directly in the stand-alone application. The mechanisms existing for GPS require either high margins in absolute navigation, in the order of tenths of meters, or just the support of differential processing techniques.

1. INTRODUCTION

The breakthrough in space navigation came with the deployment during the last two decades of the US NAVSTAR Global Positioning System (GPS), based on a constellation of 21 satellites plus three active spares, transmitting dual frequency coded signals at the 1.2 GHz and 1.5 GHz frequency ranges. The USSR and now Russia also developed and partly deployed a similar system, GLONASS, which presently has about 12 operational satellites. These systems, although military, offer also to civil users the capability of relatively low-cost global positioning with an accuracy of a few tens of meters.

What these systems are currently not capable of providing by themselves is the integrity of the information they provide and the certainty to the user that the service will be availability under any condition. To overcome the limitations of the GPS or GLONASS, there are two parallel developments taking place at worldwide scale:

- Development of augmentation services to the existing GPS (or GLONASS) constellations, in order to improve the accuracy and provide a higher integrity of the signals:
Through ground-based local differential GPS services: GBAS systems as the American LAAS.

Through space-based wide area differential GPS services: SBAS systems as the European EGNOS.

- Development of a new constellation of navigation satellites, as GALILEO.

2. EGNOS

EGNOS, European Geostationary Navigation Overlay System, (see [Ref.1]) is the Space-based augmentation system being currently developed in Europe. It aims to provide additional navigation payloads, based on transponders mounted on geostationary satellites, which will broadcast a GPS-like navigation signal. The navigation message modulated on the signal contains accurate real-time corrections to GPS and GLONASS ephemeris data, a precise ionospheric model to be applied by the user, along with integrity information on the service provided. The system will be used in Civil Aviation operations, including precision approaches up to Cat-I. This implies that its design has to be compliant with very demanding safety requirements. EGNOS is part of a mosaic of inter-regional satellite-based augmentation services (SBAS) that complement GPS and GLONASS. The other systems are the United States WAAS and the Japanese MSAS systems.

Recently, India and China have launched similar initiatives, called GAGAN and SNAS, respectively.

Figure 1 depicts the infrastructure of the different segments of the EGNOS system including:

- GPS, GEO and GLONASS data reception at a dense network of reference stations (RIMS, ranging and integrity monitoring system).
- Control and processing centres (Central Control Facility, CCF and Central Processing Facility, CPF, in the EGNOS realisation). Both are collocated in the so called Master Control Centres (MCC).
- Uplink stations (NLES, Navigation Land-Earth stations)
- Communications capabilities between the different ground-segment elements implemented in the so called EGNOS Wide Area Network (EWAN).
- Navigation payload in geostationary satellites
- User reception and data processing

![Figure 1. The European Geostationary Navigation Overly System, EGNOS](image)

EGNOS will significantly improve the accuracy of GPS, typically from 10-15 meters to 1-to-3 meters. Moreover, EGNOS will offer a service guarantee by means of the Integrity signal and it will also provide additional ranging signals. It will operate on the GPS L1 frequency, and will thus be receivable with standard GPS front-ends. The coverage area serviced by EGNOS will be the European Civil Aviation Conference (ECAC) service area comprising the Flight Instrument Regions (FIR) under the responsibility of ECAC member states. ECAC is
defined in Fig. 2. The EGNOS coverage area could be readily extended to include other regions within the Broadcast Area of the geostationary satellites, such as Africa, Central / South America, Eastern countries, and Russia. EGNOS will meet, in combination with GPS and GLONASS, many of the current positioning, velocity and timing requirements of the land, maritime and aeronautical modes of transport in the European Region, as well as other terrestrial applications.

Figure 2. European Civil Aviation Conference (ECAC) approximate area coverage

3. GALILEO

Galileo will be an independent, worldwide global European-controlled civilian satellite-based navigation system, at the same time than compatible and interoperable with other signals such as GPS or GLONASS systems (see [Ref.2]). It will have a constellation of satellites monitored and controlled by a Ground Control Segment providing also the capability to detect satellite or system malfunctions and broadcast real-time warnings (integrity messages).

The Galileo Space Segment will comprise a constellation of thirty satellites in medium-Earth orbit (MEO). Each satellite will broadcast four ranging signals carrying clock synchronisation, ephemeris, integrity and other data, depending on the particular signal. A user equipped with a suitable receiver will be able to determine his position to within a few metres when receiving signals from visible Galileo satellites.

The Galileo Ground Segment will control the whole Galileo constellation, monitor the satellite health and up-load data for subsequent broadcast to users. The key elements of this data such as clock synchronisation, ephemeris and integrity, will be calculated from measurements made by a network of Galileo receiving stations.

Galileo will provide an interface to service centres. These service centres will give users a point-of-contact to the Galileo system and will provide a variety of value-added services. Galileo will thus provide a range of guaranteed services to users equipped with receivers meeting Galileo specifications:

- Satellite-only navigation services.
  - Open services providing navigation and timing.
  - Safety-of-life services providing integrity messages, incorporated into the navigation data messages of open service signals.
  - Satellite-only commercial services providing dissemination of commercial ranging and data signals, including integrity messages.
- Public regulated services providing navigation and timing by means of independent, restricted-access navigation signals.

- Satellite plus local services:
  - Precision navigation services providing local differential correction signals on a single frequency.
  - High-precision navigation services providing local differential correction signals on three frequencies to allow carrier ambiguity resolution to obtain high-precision position, velocity or time.
  - Locally assisted services providing two-way communications services by which users can obtain automated assistance for the computation of position, velocity or time measurements.
  - Augmented-availability services providing supplementary “pseudolite” transmissions overlaying the Galileo satellite signals, which together provide improved availability of position, velocity or time measurements.

- Support to external services:
  - Support to the COSPAS/SARSAT by means of the search & rescue service.
  - Support to external regional integrity services. The Galileo system will be able to provide the support for disseminating by selected Galileo satellites additional integrity data generated by independent, external regional integrity services.

Each satellite of the Galileo navigation system will be responsible for providing several services, as per its assigned mission, with each service being defined by a different set of signals. So, each service will be supported by at least two frequency broad bands.

In general, the use of “spread spectrum” techniques supports the required precision performances of the system. Hence the presence of at least two frequency bands per service, with enough distinction, will allow to compute an ionospheric correction. The use of broadband signals allows to enhance the resistance to scrambling and jamming.

Information sources remain the same (clock, ephemeris, etc.), yet receive different source codes that allow simplifying use, or even introducing information complements (integrity, differential corrections, etc.).
4. GNSS PERFORMANCES FOR CARTOGRAPHY

The achievable performances using the GNSS signals vary enormously depending on the used methodology. The simplest approach consists on the absolute navigation with GPS or Galileo, with a stand-alone receiver. To improve the accuracy and the integrity additional information is required. These schemes correspond to the differential or relative positioning, which involve several receivers with a twofold purpose. On one side, to compensate common errors between the end user receiver and the one or several reference receivers. On the other side, the reference receivers, in surveyed and controlled conditions, allow to detect satellites measurements that are in no usable conditions, and therefore to support an integrity service to the end user receiver. Furthermore, the performances of the relative positioning affordable using pseudorange measurements can be highly increased using carrier phase measurements.

For cartography purposes, these ranges of performances are available, and the used technique will depend on a compromise between performances and operational feasibility. Local cartography is affordable with carrier phase differential methods, while for global maps similar performances would require a dense network of surveyed reference receivers. The constraints imposed by the need to prepare fast and liable maps make the applicability of the different positioning techniques very different.

Since the suspension of the “Selective availability” in GPS in May 2000, the positioning precision of the civil GPS service has been improved to the level of a few meters, below its specifications of some tenths of meters (see table below). However GPS still provides no quality guarantee and therefore no integrity.

<table>
<thead>
<tr>
<th></th>
<th>GPS SPS(^1) All-in-view Single frequency receiver</th>
<th>GPS + EGNOS (10°m.a.) Single frequency receiver</th>
<th>Galileo OS (10°m.a.) Single frequency receiver</th>
<th>Galileo OS + GPS (10° m.a.) Single frequency receiver</th>
<th>Galileo OS + GPS (10° m.a.) Dual frequency receiver</th>
<th>Galileo OS + GPS (10° m.a.) Dual frequency receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal accuracy</td>
<td>3,5</td>
<td>1-3</td>
<td>15</td>
<td>7-11</td>
<td>4</td>
<td>3-4</td>
</tr>
<tr>
<td>Vertical accuracy</td>
<td>5</td>
<td>2-5</td>
<td>35</td>
<td>13-26</td>
<td>8</td>
<td>6-8</td>
</tr>
</tbody>
</table>

\(^1\) Actual values according to performance measurements by IGEB, corresponding to a 95% threshold in all-in-view conditions. These measured performances exceed the October 2001 SPS specifications corresponding to 36 and 77 m. respectively.
By virtue of its design, Galileo targets a significantly improved level of precision, on the order of a few meters in association with synchronization to within 50 nanoseconds. On the contrary than for GPS, Galileo has planned to provide also a global integrity service.

An increase of performances is achievable with differential techniques, which involve measurements from several receivers. EGNOS is an overlay system of the family of SBAS systems. These are wide area differential GNSS systems that provide measurements corrections that increase the accuracy, but more important, this system provides an overlay of integrity for the positioning results obtained with EGNOS and GPS or GLONASS and with Galileo in the future.

Although EGNOS is a differential system, its operation is similar to GPS or GLONASS in the sense that only a user receiver is needed.

Local area differential systems as GBAS, that provides corrections and integrity to pseudorange measurements, allow to reduce the horizontal error to values typically below the meter level, and to provide a faster integrity information. However, operationally the support of one or a network of reference stations is required. This aspect difficults the operation of differential techniques for wide geographical areas.

To achieve higher position accuracies (position errors clearly less than about 1 m) the satellite navigation system user needs to exploit not only the differential techniques in code pseudoranges but also – and more importantly – in the carrier phase measurements. However, the carrier phase measurements are ambiguous with respect to the integer number of cycles from satellite to receiver. There are several well-known Carrier Phase ambiguity resolution approaches, the methods for RTK (float and fixed) as well as the TCAR/MCAR methods, in real time or in post processing using externally precisely known ephemeris (see [Ref.3]):

- Float RTK: A standard kinematic DGPS solution including carrier-phase measurements. The unknown integer ambiguities are part of the filter state and will be estimated within the positioning (Kalman) filter. They will be used as float values and are not fixed to integers.
- Fixed RTK: This approach is the same as in the float RTK case. But, when enough information in the positioning filter is available (variances in the ambiguity states are low or other statistical tests are positive), the ambiguities are fixed to integer values. In the further processing only the fixed values of the ambiguities are used for positioning.

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**Figure 4. Comparative performances of positioning techniques**

- **Float RTK:** A standard kinematic DGPS solution including carrier-phase measurements. The unknown integer ambiguities are part of the filter state and will be estimated within the positioning (Kalman) filter. They will be used as float values and are not fixed to integers.
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• TCAR: This is a quite new approach designed for GPS. It makes use of at least three different carrier frequencies and is able to fix the ambiguities directly, without using the information of the positioning filter. This means that no ambiguity search is necessary with this type of approach.

MCAR: This is a generalised approach of TCAR using more than three carrier frequencies. Considering the availability of more frequencies, the approach will be more robust (more integer) than TCAR alone. Again, no ambiguity search is needed here. This is the method expected to be the usual with Galileo.

If the ambiguity fixing could be performed successfully, the position accuracy is in the centimetre-range. In case of GALILEO, the individual and different signal structures have only negligible impact on further accuracy improvements. However, the success rate (robustness) will increase dramatically, when several frequencies are used in the approach, opening the door to determine an integrity level to the obtained Galileo MCAR solution.

5. THE INTEGRITY AMONG THE CARTOGRAPHY REQUIREMENTS TO GNSS

All the applications in which positioning integrity is demanded imply that when the information has to be displayed over a GIS support, this GIS data has to be also integer. These applications correspond to critical operations where safety of life or legal liability aspects are important, like landing systems, or situations with legal implications like cadastr, surveying of disasters and agriculture and infrastructure losses or police authenticated location information with potential to be used in court processes. Some examples of these applications are:

• Urban and road traffic tolling
• Emergency public services fleet management
• Disasters prevention:
  o Terrain deformation measurement
  o Infrastructures status inventory
• Surveying for:
  o Disasters and agriculture and infrastructure losses

  o Contingency infrastructures
  o Agriculture parcel recovery

• Border control: border agreements, monitoring of activities in territorial waters, geo-referencing of border sensors
• Agricultural and Fishing Services for Law Enforcement
• Justice:
  o Police (personnel, vehicles, resources) tracking and dispatch
  o Suspect tracking
  o Accident reconstruction and crime scene investigation
  o Tracking in parole and probation

Some of these examples do not only require integrity to the GIS data, but also that this information has to be up to date. The oldness of the geographical referenced information must be minimum for example in cases of support to emergency management or in police interventions. This aging aspect involves not only the pure geographical data but also associated information, like urban works inventory or the urban and road traffic status. The utility of the optimal guidance of car navigation systems will be highly improved when they incorporate current instead of theoretical information.

In addition to the GIS data integrity and maximum allowed age there are other aspects that determine the most suitable GNSS technology to be used to prepare and maintain the cartography.

The accuracy of the cartography has to be at least equal and preferably higher than the accuracy of the positioning of the end user. Currently, in many applications that the end user is employing a stand-alone GPS receiver, an accuracy of the cartography in the order of 3 to 5 meters is being enough. However, as EGNOS and Galileo will improve the end user accuracies to the level of 1 to 5 meters, the base cartography accuracy will have to be improved correspondingly. In particular, a case in which higher errors of the cartography can lead to bad application performances is the map matching. As map matching is part of the positioning process, the map paths accuracy will condition the accuracy of the end user navigation system.
Another aspect to be considered is the difference of treatment required by the Ground Control Points and by other georeferenced map contents. Ground control points are key elements in the map production process from satellite images (see [Ref.4]) and refer to physical points on the ground whose ground positions are known with regard to some horizontal coordinate system and/or vertical datum. When mutual identifiable on the ground and on an image, ground control points can be used to establish the exact spatial position and orientation of an image relative to the ground at the instant of exposure. Due to their permanent nature and the fact that a few spread points allow to georeference a full satellite or aerial image, the high accuracies of the relative carrier phase techniques are operationally affordable, and Galileo MCAR techniques will be in conditions to support the reliability of the obtained positions up to liability levels easier than with the current post processing coherence analysis methods.

On the contrary, the georeferenced map contents, of more dynamical nature and much more dense over the map, requires a faster operational method with the added value of integrity in many of the above identified applications. Considering the aspects of required accuracy, update rate and integrity of the cartography information, there are plenty of applications in which cartography preparation and maintenance requirements will be satisfied using EGNOS or Galileo receivers much better than with the current GPS. These are the cases where surveying campaigns of georeferenced information to be mapped can be afforded with stand-alone receivers. Requiring only one operator such campaigns are operatively easy and fast, minimising the time required to collect the geographical information and without the constraints that a reference station imposes in deployment time or accessible terrain to the surveyor. In these situations the stand alone use of EGNOS and GALILEO provide an accuracy level in...
a range between one and a few meters, better than GPS, as well as an integrity of the obtained positioning that is a key feature not available directly with stand alone GPS.

6. EXAMPLES OF FAST AND LIABLE CARTOGRAPHY

An example where fast and liable cartography is required is preparation of maps to support aiding resources in case of disaster situations. A picture of the disaster needs to be prepared urgently, to show differences with respect to nominal cartography (when available), as well as specific disaster situation data. Typical steps in this process, as the example that can be found in [Ref.5], are:

1. A field team is deployed within hours of disaster. While in transit to the emergency place, team collates any pre-existing mapping data covering affected area. These may include satellite imagery, aerial photography, digitised paper maps, GIS vector layers, etc. This allows to plan an effective initial surveying of the most critical data to be collected.

2. The field team arrives on scene. A field base is set up. This team surveys and maps the extent of the basic disaster (e.g. flooding) and also reports the location of basic food and water resources. Security situation is also assessed and evacuation routes plotted. This allows to issue first orientation maps to search-and-rescue teams within hours.

3. In a third stage remaining field team members arrive on site and detailed situational mapping begins.

4. In a fourth stage the survey of the disaster area continues, locating and mapping information valuable to aid organisations: for example locations of medical facilities, access routes, and movements of affected populations. Information captured using hand-held PDA devices is relayed digitally to field base via satellite phones.

5. In a fifth stage, Data is analysed rapidly at the field base using GIS software. Paper maps are issued to partner aid agencies on the scene as required, showing the required layers of information. Overview maps are also prepared for access by disaster response agencies internationally.

7. CONCLUSIONS

The use of GIS and location technologies is widespread and growing nowadays, as well as the performances expected from the systems that include these technologies. There are many applications that, in addition to accuracy, demand to consider other aspects as information oldness and update rate and integrity of liability to the cartography.

The preparation and maintenance of such cartography and associated information would need an easy and fast operational approach. After review of the different GNSS technologies and their application to cartography, the advantages of EGNOS and Galileo over GPS are clear. The stand alone use of EGNOS and GALILEO provide an accuracy level in a range between one and a few meters, better than GPS specifications, as well as an integrity of the obtained positioning that is a key feature not available directly with stand alone GPS.

Furthermore, when centimetre level accuracy is needed, what implies to use differential techniques with carrier phase measurements, the capabilities of MCAR with Galileo will be better than the RTK methods currently affordable with GPS, in particular the robustness of the validity of the positioning results.

8. REFERENCES

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