GPS: The Holy Grail?

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The development and introduction of GPS in the early Eighties has led to an exponential growth in military and civilian applications. Worldwide, GPS is becoming a cornerstone in applications of transport, (offshore) survey, (precision) agriculture, network timing, military operations and many other applications. And yet, for a number of applications, GPS as sole-means or augmented – has some deficiencies, and its performance does not satisfy the user's requirements. Some of these deficiencies will be discussed in this paper. A number of maritime operations will be mentioned where (D)GPS as sole-means is considered by the author as unsafe navigational practice. Development and implementation of integrated navigation receivers using multiple navigation-signal sensors ((D)*Galileo*, (D)GPS, *Eurofix*, DR) using receiver autonomous integrity monitoring (RAIM) could solve the majority of the deficiencies of these systems in their stand-alone state.

KEY WORDS

1. GNSS. 2. AIS. 3. VTS. 4. Safety.

1. INTRODUCTION. The following deficiencies of GPS can be identified:

1.1. *Weak Signals*. In many applications, it is inconvenient or even dangerous when the signal from one or more satellites is lost due to trees, roofs or other obstructions, causing a degraded navigation solution or no solution at all. In GPS IIF and Galileo, a somewhat stronger signal will be implemented. Related to this inconvenience is:

1.2. *Shadowing/Masking*. Using GPS in urban canyons, fjords, mountainous areas, on moving craft with changing attitude (aircraft), under bridges and in tunnels, signals are lost from satellites that are not in line-of-sight. This again leads to a degraded navigation solution or loss of solution. In urban canyons, the satellites in view may produce a solution that gives accurately the progress in the direction of the street; however, the solution could very well position the user way off the street on which he is proceeding due to the geometry of the satellites in view.

1.3. *Accuracy*. When compared to the navigation systems before the GPS era, (D)GPS accuracy is a giant leap forward. The almost 100% use of (D)GPS by the maritime community, both commercial and leisure, and in many other applications for transport and non-transport, shows that in practice almost all accuracy requirements of users are met. However, the accuracy of charted dangers to navigation is, in most cases, worse than the accuracy of the (D)GPS positioned craft. This concern has already been expressed by IMO at the last session of the Subcommittee on Safety of Navigation in September 1999 (NAV45). More money should be made available for re-surveying areas of interest, in order to provide users with (electronic) charts compatible with satellite navigation accuracy.

1.4. *Availability and Continuity of Service*. Tests performed with (D)GPS seldom show the *five nines* as required for a number of applications (Sharkey, 1997). For instance, at an inquiry for ESA's Galileo mission definition study, ship-owners have stated that maximum availability (no numbers mentioned, IMO requires 99·8% over 30 days) of a navigation solution is essential in harbour approaches, one man bridge operations and remote pilot operations, notably on modern bridges with ECDIS interfaced with electronic positioning. Availability of the signal-in-space (SIS) is mainly reduced by intentional and unintentional interference/jamming – for instance, by the jamming tests necessary for the transition from Selective Availability to Selective Denial (as recently occurred at the US Coast). By definition, the signal availability refers to the SIS; however, different ways of signal processing in different receivers at the same location show differences in available navigation solutions (Sharkey, 1997). In the certification requirements for receivers to be used in safety critical operations, this issue should be taken into account.

IMO-NAV45 noted in September 1999 that there were practical difficulties with Differential Correction Services in achieving the required performance of Resolution A815(19), in particular the update rate of 2s, the signal availability of 99·8% and the service reliability of 99·97%. IALA has been asked to analyse the problems and inform IMO accordingly.

1.5. *Integrity*. GPS as sole-means does certainly not fulfil the stringent requirements for integrity (warning the user when the system should not be used) in aeronautical and maritime applications. The regional augmentations WAAS, EGNOS, MSAS, *Eurofix* and the local augmentation systems (D)GPS and LAAS are (being) developed to fill the gap. However, when the basic GPS signal is not there, the augmentation service is useless except for *Eurofix*.

1.6. *Institutional*. On 29 March 1996, Vice-President Al Gore, on behalf of the President, announced US policy on GPS. The policy contained among others the following statements:

(a) The intention to discontinue Selective Availability between 2000 and 2006;
(b) The continuous, worldwide, public access to GPS for peaceful, civil, commercial and scientific use free of direct user charges/fees.

In February 1999, the European Commission identified that continued reliance on third countries' systems created the following problems:

(a) Serious issues of both sovereignty and security if Europe's safety critical navigation systems are out of Europe's control;
(b) The failure of present systems to meet all the requirements of civil users in terms of performance;
(c) The dominant position or virtual monopoly of other countries with the risk of changes in the future service or excessive future charges or fees;
(d) The limited opportunities for EU industry to compete in this lucrative market.

The transport ministers of the European Union decided on 17 June 1999 that Europe cannot indefinitely remain reliant on US (mainly military) governed GPS and therefore Europe should develop an open, global satellite navigation system – *Galileo* – compatible (or rather interoperable) with GPS, but independent from it.

The compatibility as defined so far will at least consist of: MEO constellation, identical geodetic and time references.

1.7. *Liability*. Michael (1998) argues that there has never been a successful reported recovery against the United States Government for a malfunctioning ground-based aviation navigational aid. Preliminary studies for the *Galileo* system show that the system intends to provide an open-access service (OAS) without charges, with a performance level similar to GPS IIF, and two controlled access services (CAS1 and CAS2). CAS1 is intended for users who require a guaranteed service level with liability for the service taken by the provider. CAS2 is intended for users with national security/safety functions.

1.8. *Robustness*. It is only recently that the concept of robustness has shown up as a requirement for safety-critical navigation solutions. In the glossaries of navigation terms of ICAO, IMO and, for instance, the US Federal Radio Navigation Plan, the definition of this concept cannot be found. Robustness could be described as: *The ability of a receiver to provide a navigation solution with specified accuracy and integrity risk, even in conditions when one or more observations are not available.*

The objective of augmented GPS such as WAAS etc. is to provide the navigation performance as required for CAT-1 precision approaches. The number of redundant observations when using (augmented) GPS is not always sufficient for on-board integrity monitoring to detect and delete observations affected by local disturbances. In case of GPS-denial by jamming, there is no solution available. IMO NAV45 raised concern with regard to the characteristics of on-board satellite navigation receivers; the concern was triggered by events such as interference from Inmarsat and other sources, the resolutions on standards for high speed craft and the experience gained from collisions/groundings etc. Therefore, augmented GPS as a stand-alone system cannot be classified as a robust navigation system. Integrated navigation receivers using observations from multiple sensors increase the robustness of the navigation solution and should be preferred for safety critical applications.

2. SAFETY CONSIDERATIONS FOR MARITIME OPERATIONS WITH (D)GPS. In commercial shipping, fishing and other maritime operations, four activities can be identified where the use of (D)GPS as sole-means should be considered as unsafe navigational practice:

(a) Position reporting in GMDSS,
(b) Position interface to the Automatic Identification System (AIS),
(c) Automatic track keeping,
(d) Harbour operations including berthing.

2.1. *Position Reporting in GMDSS*. A vessel in distress will transmit emergency signals through one of the GMDSS communication means on board. The IEC document 61097–10 requires that a Ship Earth Station (SES), intended for installation on passenger ships, shall have an interface to receive information on the ship's position for inclusion in the initial distress alert (for non-passenger vessels this is not mandatory, but often installed). A Regional Co-ordination Centre (RCC) on land will receive this alert and co-ordinate the rescue operation. Without going into further detail of the Search and Rescue (SAR) operation itself, it will be clear that the position of the vessel in distress is of major importance to the success of the operation.

At present, on most SOLAS vessels (vessels complying with the Safety of Life Convention at Sea of IMO, ie most commercial vessels > 100 gt) the GMDSS is linked to a (the) GPS receiver and will automatically transmit the GPS position with the distress alert. Some EPIRBS (Emergency Position-Indicating Radio Beacons) have GPS receivers included and transmit – when floated – the position of the EPIRB via Inmarsat satellites to an RCC. The lesson is: *When the* (*GPS*) *position transmitted in an emergency call is not correct*, *human lives will be at risk*.

2.2. *Position Interface to the AIS*. In the VTMIS-NET project of the 4th Framework programme, the European Commission has promoted the use of Automatic Identification Systems (rather Automatic Tracking systems!) in maritime traffic, notably in VTS-covered areas. The performance standards for AIS were accepted during NAV 42 of IMO; IEC is now drafting the methods of testing and the required test results for the on-board equipment. During NAV 45 in September 1999, it was decided that the carriage of AIS on board SOLAS vessels shall be introduced between 2002 and 2007. A ship equipped with AIS transmits in her own timeslots (based on GPS timing) – among other details – position (including accuracy), ground course, ground speed, heading, rate of turn etc. IEC 61993–1 prescribes that information such as the ship's position, ground course and ground speed shall be programmed into the installation automatically either from integral equipment or from suitable sensors. The information is now usually taken from a (D)GPS receiver. The information is transmitted by VHF to other vessels and the shore-VTS; it is used to give a better traffic picture than radar alone. Transmission of erroneous position information will cause the AIS position of a ship to differ from its radar plot on the radars of other vessels and of the VTS, giving ambiguous traffic pictures to both the navigators on other vessels and the VTS operators. Erroneous course and speed information could lead to wrong collision avoidance (CA) actions by other vessels, with the risk of AIS assisted collisions. The lesson is: *The position and course/speed information transmitted by AIS must be of the highest accuracy and integrity*.

2.3. *Automatic Track Keeping*. The use of automatic track keeping systems controlled by a single (D)GPS system (and an additional mandatory back-up system such as a non-interfaced dead reckoning (DR) system) is becoming more and more common practice. Erroneous position information from the GPS could lead to a grounding, as was the case with the cruise ship *Royal Majesty* on August 15, 1995. The lesson is: *Automatic track keeping systems must be controlled by navigation systems with highest accuracy and integrity*.

2.4. *Harbour Operations Including Berthing*. In restricted waters, harbour approaches and harbours, where the manoeuvring space of a vessel is restricted, it is essential that a proper voyage plan is prepared and manoeuvres are executed at the right time and place to avoid grounding and to avoid collision with another vessel or a shore-based installation, and to berth the vessel without damage to ship and shore. Large vessels and vessels with high freeboards are especially difficult to handle in restricted waters, notably when the visibility is restricted, in strong currents and/or with strong winds. Usually a local maritime pilot will assist the ship's master in these operations. For very large ships even two pilots will board, as one pilot will continually monitor the lateral speed and rate of turn visually from the centre line of the vessel, while the other pilot can, for instance, make (visual) observations at the side of the vessel.

In order to reduce costs for ship owners and to increase the economic attractiveness of harbours, exemptions are given in certain harbours to certified ships to enter without the use of a local pilot, or by means of navigational assistance from the VTS. In order to receive pilot exemption, ships have to be equipped (among other measures) with proper navigation equipment, notably (D)GPS interfaced with ECDIS. (D)GPS linked with the ECDIS is being used more and more, now that raster charts (as a complement to paper charts) can be used and more vector-based ECDIS charts are becoming available. Navigators will rely even more on the information displayed on ECDIS, as *one man bridge operations* become more common practice and navigators have less time to cross-check the navigation information with other means.

In a recent PhD thesis (Ueno, 1999), GPS-RTK – with three antennas for attitude determination – was tested for berthing guidance with the following requirements (1σ): position 0·3 m; velocity 2 cm/s; heading 0·05° and yaw rate 0·02°/s; the reliability criteria (in the sense of fulfilling these requirements) was 100%. Not all requirements were met during the experiments. Multipath was considered the largest source of error in the harbour environment. It was also concluded that large scale electronic charts of the harbour with an accuracy in the order of dms are required for proper berthing assistance (as is done in the harbour at Holyhead in Wales for the Stena Line High Speed Ferries docking with the aid of GPS-RTK). The lesson is: *In restricted waters, the navigation information provided to the ECDIS-system must be of the highest accuracy and integrity*.

3. REQUIREMENT FOR MARITIME APPLICATIONS WITH SAFETY INVOLVED. From the above section it can be concluded that, apart from the accuracy, the integrity of information from the navigation system (in the sense of the trust that can be placed upon it) is the major requirement in applications where safety is involved. As the integrity of stand-alone (D)GPS cannot be guaranteed, the use of (D)GPS as sole-means of (automatic) input for GMDSS, AIS, automatic track keeping and ECDIS should be considered as unsafe navigational practice. It is therefore recommended that:

(a) Programmes should be started to develop low-cost integrated navigation receivers, using multiple navigation-signal-sensors ((D)*Galileo*, (D)GPS, *Eurofix* and DR), and smart software such that the observations/measurements from the different systems are processed in an optimal way, applying autonomous integrity monitoring to the observations.
(b) IMO amends the Resolutions with the Performance requirements of GMDSS, AIS, track keeping systems and ECDIS to require a certified multiple-integrated navigation system as input for these systems.

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