

THE GLOBAL POSITIONING SYSTEM-NAVIGATION TOOL OF THE FUTURE

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ABSTRACT

Navigation is an important issue in maritime transport In todays world, marine accidents and their effects to environment are key factors for maritime safety. GPS / DGPS are introduced as navigational tool of the future. Structure and positioning principles of GPS / DGPS are explained. Operational issues of the systems are discussed. Benefits of GPS / DGPS on safety improvements and cost efficiencys are examined.

Keywords: Global Positioning Sytems, Differantial Global Positioning Systems, Navigation Systems, Maritime Safety.

1. INTRODUCTION

The art of navigation has seen many revolutionary advances during the past millenium. This progression has seen the art gradually transformed into a science with the increasing use of new technology brought to bear on solving the outstanding problems of the age. The development path runs from the introduction of the magnetic compass through to the evolution of the quadrant, astrolabe, sextant, cronometer, radio navigation systems and finally to the today's Global Positioning System (GPS) satellite-based navigation system.

As a general rule obtaining position for navigation has often beer trade-off between the mutually exclusive requirements of accuracy versus world wide availability accurate positioning was available within a hundred miles

of and but these system were very regional. While systems providing covarage over large ocean areas offered only very limited navigational accuracy [1].

The advent of GPS and more specifically differential GPS, has radically changed this imbalance and offers the navigator both world-wide positioning capability with a single receiver as well as reliable and precise positioning accuracy.

2. STRUCTURE OF GPS

The system consists of three operational segments:

- Ground station tracking processing network.

synchronised with that of the satellite clock, leading to unacceptably large position errors. This problem is solved by observing a sufficient number of satellites-four or more-so that in addition to calculating lat/long/ht the clock offset between receiver and satellite is also computed, so removing the errors [2].

The key to understanding the principle of GPS position calculation is to liken it to a typical radio navigation system where three or more ranges are measured to fixed ground stations with known coordinates. In the case of GPS, although we are measuring to satellites which are moving very fast, we can consider that at an instantaneous moment in time each satellite is fixed at a known position in space, thus providing a network of fixed stations to which we measure. Of course this network is constantly in motion and will change every time we compute a new position for vessel but this is all done for us in the GPS receiver. (Figure 3)

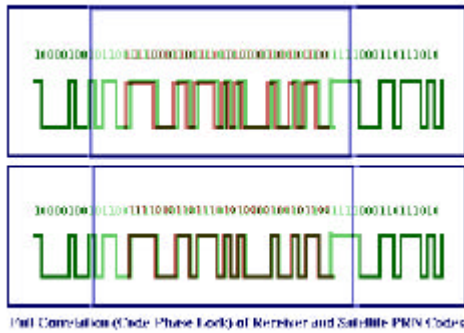


Figure 3. Distance Measurement

As mentioned earlier GPS appears to offer us the perfect navigation solution and we are being given it for free, so what is the catch ?

The US Department of Defence decided at an early stage to allow free, but limited, civilian access to the system using the lower accuracy L1 frequency coarse acquisition signal (C/A code) which would provide a positioning accuracy of approximately 100 m. However when it became apparent that inniative civilian developers were able to improve this performance to an accuracy equivalent to the full military capability, this was considered undesirable so modifications were made to the GPS signal enabling the USDOD to deliberately degrade the GPS stand alone positioning performance to an accuracy of +/- 100 m. This is known as *selective availability* (SA) and its magnitude is under the control of

the USDOD so that in the future the accuracy of the GPS system could be increased or decreased. The errors arising from SA vary in magnitude over time so that your position only has a reliability of +/- 100 m for 95 % of the time: it is possible that it could occasionally exceed this value for very short periods.

4. DGPS POSITIONING

While even the reduced accuracy of stand alone GPS is adequate for many general marine navigation applications, for those mariners requiring special positioning this reduced performance is acceptable :

- Seismic surveying
- Hydrographic surveying
- Offshore construction vessels
- Dynamically positioned vessels
- Fast ferry autopilots
- FPSO vessels
- Vessels navigating in confined waters.

In the mid 1980s a number of the international surveying companies, already supplying precision radio navigation-based positioning services began developing a commercial enhancement of GPS to remove the effects of selective availability.

Differential GPS (DGPS) offers all the benefits of GPS plus an improvement in positioning accuracy to better than +/- 3-5 metres.

The principle of DGPS is that by siting one or more GPS receivers at fixed reference stations for which the position coordinates are very well known, and measuring ranges to all satellites in view, it is possible to calculate all the errors in the signals including those due to selective availability.

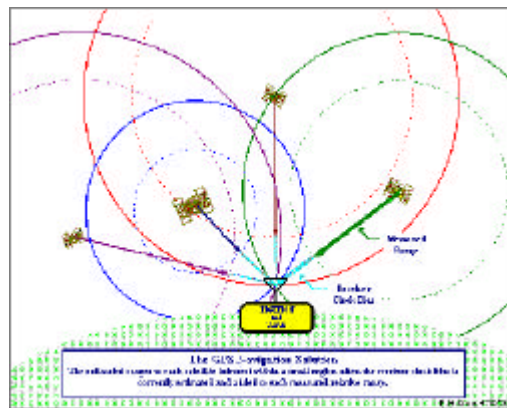


Figure 4. DGPS system configuration

This is only the first part of the process, since knowing these errors at a known ground station is of little value – they need to be sent rapidly to a user's receiver so that they can then be used to correct the same errors which are affecting the measurements at this receiver. This is achieved by packaging all the correction data into a series of industry standard message formats – known as RTCM SC104 – and then transmitting them via a radio link/satellite communication systems/cell phone to the user who decodes them via a DGPS demodulator / decoder ; see Figure 4 above.

If these DGPS correction messages are received frequently enough – every 10 – 15 seconds or faster – then the user can benefit from improved positioning performance with accuracies of +/- 3-5 metres being possible.

To ensure that all errors are equally accounted for at both reference station and user vessel, most DGPS receivers only calculate position using satellites which are simultaneously visible at both locations.

The basic GPS service is available globally with no more equipment required than a basic receiver and is adequate for any marine user, requiring

only limited navigation accuracy. For those users demanding precision services (accuracy better than +/- 20 m) then DGPS is an ideal choice. However it is important to realise that there are variety of services which are available offering different levels of performance/coverage at widely varying costs [3].

5. FREE DGPS

There are a number of free access DGPS services, the most important of which operate on the IALA beacons and are administered by the Lighthouse Authority in the UK and by the USCG in the USA. All you require to receive these signals is IALA beacon- compatible DGPS receiver which is then connected to your existing GPS receiver. This low cost solution will provide vessels with positioning accuracy of + / - 10 m within a distance of up to 150 miles from coastlines of countries operating this type of service: see Figure 5.

There are other services broadcasting on FM radio frequencies which are available in coastal/inland waterways areas which can also be used such as Focus FM in the UK.

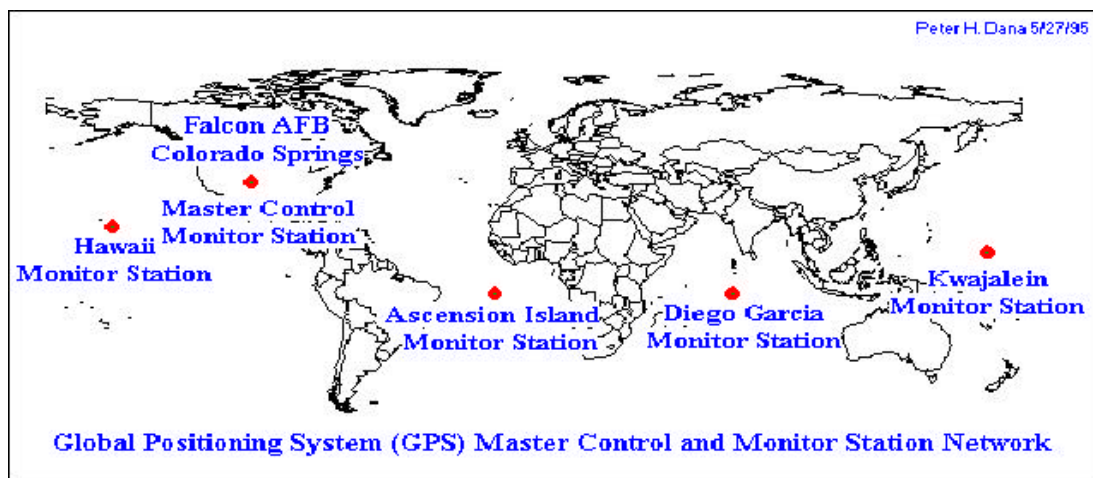


Figure 5. GPS Master Control and Monitor Station Network

6. COMMERCIAL SERVICES

For applications which demand the highest accuracy (3-5 m/ s) and reliability, a number of commercial DGPS services have been established by international offshore survey companies such as Fugro Survey, Racal Survey and Veripos. These services are broadly similar

in performance and can be classified into three categories, based on the communication system used to deliver the DGPS corrections.

HF radio link

The DGPS corrections are relayed to the offshore marine user via an single/dual high frequency

radio link. The signals are received by a small, simple to install antenna array. These services are typically regional in availability and operate from coastal stations with a range capability of up to 700 km [4].

Due to the nature of the radio link there is the possibility of noise / interference due to the tropospheric scattering of the signals with the “ dawn / dusk “ effect being most notable: dual frequency systems attempt to overcome this effect by transmitting on diverse frequencies which tends to mitigate the loss of correction data.

Reception of HF signals is not directional so that it is often able to operate where direct line-of-sight systems, such as satellite based receivers are blocked due to obstructions, eg vessels working alongside the north face of oil platforms.

Inmarsat satellite service

In this configuration the DGPS corrections are transmitted via the Inmarsat marine satellite communications network. This is achieved by either utilising the existing receiver terminal on the vessel or installing a dedicated unit for DGPS reception. Receiving units need to be either Inmarsat A,B or M compatible : type C terminals are unsuitable for this application.

Inmarsat is an extremely reliable method of relaying corrections and provides near world wide coverage for users who will regularly transit the oceans. The only restriction on coverage comes from the location of the geostationary Inmarsat satellites over the equator which limits reception of signals to latitudes of below 75 ° N / S.

In the past the size/cost of deck antenna assembly has been a restriction on the types of the vessel which can use this configuration but the recent development of miniature M-dome receivers has removed this limitation on all but the very smallest of vessels.

Spot beam satellite service

This service makes use of regional high power spot beam satellite transmissions. These communications satellites are also geostationary but, unlike Inmarsat which transmits over a very wide area to provide coverage of ocean as well as land regions, they transmit a concentrated high

power signal over a limited geographical area eg NW Europe, N America , Australia etc.

This enables the use of smaller, lower cost antennae which, in some cases, can be a simple omni-directional whip antenna.

System performance is the equal of the Inmarsat based service with the exception that coverage is limited to sea areas adjacent to the geographical areas listed above.

7. GPS PERFORMANCE

DPGS positioning performance depends on a number of factors, most of which are predictable any many of which can be evaluated by simple assessment of the quality parameters which can be seen on most quality DPGS navigation receivers/systems.

Distance from reference station

Due to the DPGS computational model and the requirement for commonly visible satellites to be used, the operational performance works best when the distance between reference station and vessel is constrained; typically service providers recommend a value of 1000km. However DPGS will operate far beyond this range and accuracies of +/- 5-10m are common at ranges of up to 2000 km.

Multi-reference v single reference

Most wide area DPGS services operate using a widespread network of reference stations, either regional or global in extent. Typically the user will set up his DPGS receiver to calculate position using the nearest three or four reference stations, thus providing contingency in the event of station failure or corrupted data. Using a multi-ref solution also generally improves the stability and accuracy of the solution so that for a typical network in the North Sea, we might expect a positioning accuracy of +/- 1-2 compared to +/- 5 m for a single ref solution.

Signal multi -path/shading/interference

The GPS signals are very low power and lie in the same Lband frequency as radar systems. This can cause a number of problems which can seriously affect system performance.

The frequency is very similar to that of 10cm radar systems which typically output many watts of power. *If a GPS antenna is sited close to or*

within the radar transmitting beam, then the GPS receiver is unlikely to operate successfully. A similar problem can occur close to Inmarsat A/B/M satellite domes.

Due to the signal frequency, *GPS signals are also prone the masking* by any solid metal/concrete structures. There for mounting the antenna low down at deck level/too close behind a large mast. Or mooring the vessel alongside on oil platform/rig etc will cause blocking of the signals from the GPS satellites and may well reduce its performance [5].

In addition, poor siting of the antenna can cause multiple signal reflections – off adjacent decks, bulkheads, cranes, masts etc – to arrive at the GPS antenna simultaneously. This can confuse the receiver leading to at best nosisy signals or at worst erroneous position calculations.

The solution to all these problems is to ensure the GPS antenna is correctly installed and is given a priority siting at the top of the mast.

Number of satellites

The mininum number of satellites required to derive a GPS position fix is four: It is possible to operate with only three satellites in a special mode known as *height aiding* but care must be exercised before using this position in order to avoid position errors. During periods of good GPS coverage you may see up to a peak of 12 satellites. (Figure 6)

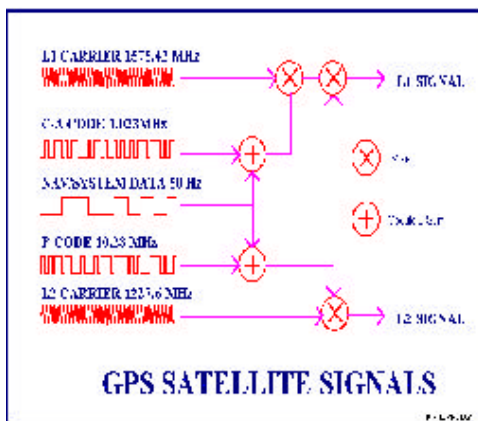


Figure 6. GPS Satellite Signals

DOP – dilution of precision

GDOP , PDOP and HDOP are commonly used terms output as quality factors by GPS/DGPS

receivers. They are commonly misunderstood as representing the accuracy of GPS.

A better description is that they indicate the reliability of the position fix based on the geometrical strenght of the current GPS satellite consiltation. As mariners plying our trade on the surface of the world’s oceans we are not really interested in height so that the HDOP parameter-horizontal DOP- best defines the value we refer to.

As a general rule the greater the number of satellites which are visible to us, the lower the HDOP. A working figure to use as a benchmark for operations would be HDOP<3. If the HDOP is much greater than this figure then it is unlikely that you would want to rely on the computed position in safety critical operations. (Figure 7)

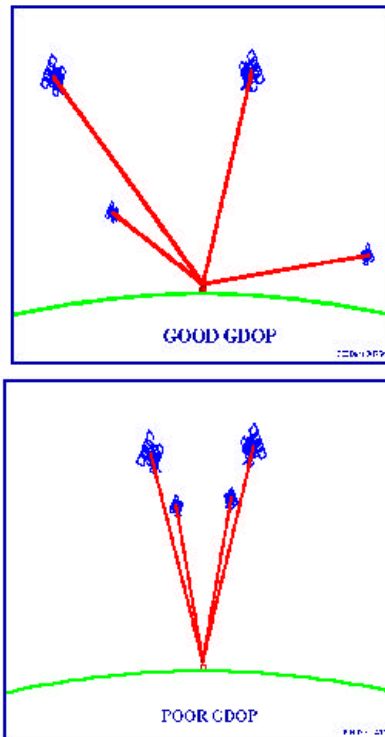


Figure 7. GPS geometrical dilution of precision

Other DGPS quality indicates

A. SD / SDUW / LPME :

- SD – Standard deviation
- SDUW – Standard deviation of unit weight
- LPME – Line of position mean error

These parameters are statistical estimators of the DGPS position fix precision in metres – different suppliers use different terms. Acceptable values should be < 5 m.

B. URA

User range accuracy – this is an estimate of the accuracy of the satellite range measurements – acceptable values should be < 5 m.

C. DQI

DGPS quality indicator - This figure is being introduced as a standard quality indicator as defined by UKOOA and is output as part of the suggested NMEA GPS position string output format. The scale runs from 0 = failure to 9=DGPS position accuracy of < 1 m. For most critical applications only values of 7 to 9 are acceptable indicating an accuracy of < 5 m.

Data and projections

It is very important to realise that a GPS receiver will compute its position in latitude/longitude with respect to a specific coordinate reference system based on the WGS-84 datum and spheroid. (world geodetic system-84 is the datum chosen for representing the satellite/user positions in the GPS network.) In many cases this will not match the datum/spheroid on the charts being used by marine users. If the position from the GPS system is plotted, directly on to the chart without correction then position errors of several hundred metres can result. Similarly, if the data is input directly in a digital format to a DP/dynamic positioning system or ECDIS/digital charting system, the same problem occurs.

Some GPS receivers allow the operator to set up the configuration so that the conversion is applied internally but common practice is to apply the corrections by hand when plotting to a chart – the corrections are generally printed in the chart notes – or to apply the conversion within the vessel navigation/DP system.

A final note of caution is that the correction/conversion parameters may well vary if the vessel is transiting between different geographical regions, ie North sea to gulf of Mexico, and it is likely that changes to the system set up will be needed before arrival at the new location.

8. OPERATIONAL ISSUES

Solar sunspot peak activity

Solar sunspot activity occurs on average over an 11 year cycle and during the peak creates high levels of electromagnetic noise in the ionosphere. Since GPS signals have to pass through the earth's atmosphere and the signal strength is relatively weak, the additional background noise may have an effect on the performance of GPS during the next three years culminating in a peak around 2001.

It is unknown, as yet, exactly how badly GPS signals will be affected: it is unlikely that the system will fail completely but users may experience short periods of instability and/or reduce numbers of satellites being available which may lead to a drop out of services over a few tens of minutes to, at worst several hours.

Effects are likely to vary with time of day, seasonally and with geographical location. Some operators in Brazil have already reported outages which have been linked to this phenomenon.

Automatic route planning with GPS

With GPS/DGPS giving us the capability of highly accurate navigation even in mid-ocean, another problem can arise. During route planning it is common practice to enter a great circle route for the vessel autopilot to follow, using GPS as the position reference.

Even stand alone GPS will enable the vessel to track the required route within +/-100m and if several vessels are all using a similar system, you can arrive at a situation in mid-ocean where vessels are being programmed to approach each other on a potential collision course. This situation has already occurred on at least one occasion involving mid-Atlantic airliners.

GPS and Y2K/WNRO

Like many other electronic devices, GPS systems may not be capable of coping with the millennium calendar update. In the case of GPS this is particularly important as the system relies absolutely on very accurate time measurement [6].

GPS receivers must be able to recognise correctly the transition from 1999 to 2000 rather than 1999 to '1990' in order for the satellite ephemeris data to be properly interpreted: without

this GPS receivers will either fail to operate or give wildly erroneous positions. It is likely that receivers purchased in the last two to three years will be compliant but for any safety critical applications, and particularly for older GPS receivers, it is essential that manufacturers are contacted to confirm that each model is fully compliant.

In addition, GPS also has to cope with its own separate date re-referencing issue which will occur at midnight on 21 August 1999 ie four months before the true millennium. This issue is known as WNRO- the week number rollover – and results from the fact that GPS time is referenced to a repeating clock sequence starting in 1980 and cycling through 0 every 1024 weeks. This is analogous to the mileometer on your car reverting to 0 once it reaches 999.999.9 miles.

The effects of this change will vary depending on individual receiver design but in the worst case, effects may be seen in the week before and/or after 21/08/99 and may not be provided GPS information for a period of between five minutes and one week after this date.

Again, the best advice is not to rely solely on GPS during this period and to contact the manufacturer for detailed information on your receiver hardware version.

It is extremely unlikely that the GPS system itself-tracking/satellite network- will fail as extensive testing has already confirmed its compliance with Y2K/WKRO.

DGPS systems may failed due to the communication link used to transmit the correction signals so that additional monitoring of the system could be essential during the critical periods: it is also worth recommending that DGPS should not be used as a sole/primary reference during this time.

9. FUTURE DEVELOPMENTS OF GPS

The development and progressively widespread use of GPS related equipment continues to expand at an increasingly fast pace: it often seems difficult enough just to keep abreast with the current technology. In this next section we intend to look into the crystal ball and give a brief summary of the forthcoming system

enhancements which may be of benefit to the user.

Developments of the GPS system

President Clinton has signed a presidential directive stating that the deliberate degrading of GPS accuracy for the civilian user – selective availability - will be switched off at some time between 2000 – 2006 thus giving civilian user access to the full un – degraded performance of the L1 frequency. This would allow GPS receivers to be able to position with an accuracy of 10 – 20 m in real time without the need for DGPS.

There are also plans for further improvements within the GPS infrastructure – the ground tracking network and satellite constellation. If these improvements are implemented along with the removal of SA. It is possible that civilian GPS accuracy could improve to +/- 3–5 m within the next six years.

Glionass

Glionass is the Russian ... developed equivalent of the GPS system and it operates in a very similar manner. The primary difference is that the... satellites signals are not degraded by any form of SA, thus the system performance for civilian receivers is typically of order of +/- 15-20 m.

Glionass receivers are available from a number of manufacturers but the drawback to using the system is that in the current Russian economic situation, maintenance of the system is at a low level and at the present time there are only 15 operational satellites out of a full constellation of 24. This results in the system suffering from periods then there are insufficient numbers of satellites to calculate a vessel position.

GNSS

This is a generic term denoting global navigation satellite systems and it incorporates a number of developments aimed at integrating additional services to expand the scope and effectiveness beyond the capabilities of the GPS system itself.

Inmarsat has developed an additional payload for its next generation of satellites which will enable them to operate as a **oGPS** satellites is that these . this will increase the number of GPS satellites available to users by up to two depending on their geographic location.

The different from existing GPS satellites is that these will not be under the control of the USDOD: they will not be degraded by SA ; and so will act as an independent check on the performance of the GPS system at all times :this is possible as they are geo-stationary satellites and are thus not constantly moving in the way that GPS satellites are.

GNSS also covers the integration of GPS and Glonass into a single system. This system operates by accepting signals from both satellite systems and computing position with whatever mix of information is possible eg six GPS+ three Glonass satellites or three GPS+ three Glonass etc.

This type integrated solution can be very beneficial, combining the benefits of significant additional satellites, improved system reliability, better internal performance checks and some degree of protection against failure of any one system. When combined with DGPS and/or D Glonass correction, this combination may possibly show the way forward for positioning in demanding DP environments such as station keeping in deep water.

GPS gyrocompass

Recent development in the processing of GPS signals have led to the introduction of a new generation of vessel heading and motion sensors. These are able to determine true heading with accuracy significantly better than conventional fluxgate compass or gyrocompass units.

These systems are fully electronic with no moving parts, requiring less maintenance. Because they do not measure heading to the true pole directly but compute heading by using two GPS -between them they are immune to errors caused by vessel motion and to loss of heading accuracy in high latitudes associated with latitude errors affecting the traditional gyrocompass. The accuracy of these systems is typically of the order of +/-0.1.

Such systems are currently replacing gyrocompasses for specialist survey applications such as multi-beam surveys of the seabed and installation of subsea structures.

10. CONCLUSION

The GPS revolution promises to provide the mariner with a navigation tool of unparalleled performance. Even the current stand alone GPS service improves on the accuracy and geographical performance of the Decca main chain and Loran-C navigation systems.

GPS simplifies the choice and operation of navigation systems for vessel operators as well as continuing the trend towards seamless integration of sensors required by the development of the electronic bridge.

With this improved vessel navigation capability it will be possible to connect vessels automatically with greater precision in restricted waters and for the vessel to be tracked remotely at vessel traffic management centres for improved routing of vessels: much as air traffic control operates for aircraft today.

Many of the benefits of GPS facilitate enhanced vessel safety such as GMDSS by providing automated vessel position monitoring and reporting.

GPS offers us improved safety of operations and efficiency if we use it properly. Like all other systems it has its advantages and limitations with the user must recognise in order to optimise his/her own use of the system. This will include knowledge of how the system works, how to evaluate its performance and reliability under a variety of operating conditions, what to do if it fails to perform and how to identify/rectify system faults. Investment in the technology is only part of the solution: training of personnel in its use, safety and efficiency is an equally important, and often ignored factor.

GPS is the navigation tool of the future: how well we implement it and use it will define how well we benefit from the safety improvements and cost efficiencies it offers.

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M. Nusret SARISAKAL, See Vol.2, Number 1, page 334.