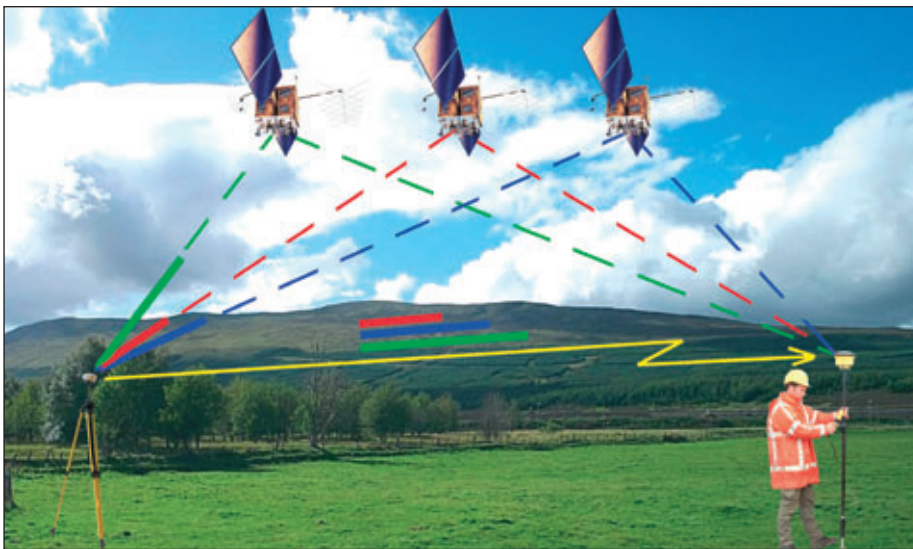


Part 4: Differential GPS system

Practical Satellite Navigation

Most professional users will find the precision and reliability of the standalone GPS signal below standard. The error sources mentioned in the previous article play a large role in this assessment. Therefore, soon after the introduction of GPS, users started looking for methods and techniques to improve the reliability and precision of GPS positioning. Next to the improvement of the receivers themselves, a solution was found in the use of differential GPS (dGPS).

By Huibert-Jan Lekkerkerk



Principle of code phase dGPS. Pseudo corrections between base and satellite are determined.

Base and Rover

The term differential GPS is derived from measurement technique. All dGPS systems use a reference station (base) in combination with a mobile station (rover). The base antenna is deployed over a benchmark or control point for which the position is exactly known. The base receiver is set to compute its position from the satellite signals. This calculated position is then compared with the benchmark position with a position difference as a result. The differences found result from errors and inaccuracies in the entire measurement. The calculated differences can now be sent from the base to the rover. In the rover the corrections are applied to enhance the rover position.

There are two principal techniques used to calculate the differences between base and rover, called code phase and carrier phase dGPS. The main difference between the two lies in the part of the GPS signal used for calculating the corrections.

Code Phase dGPS

With code phase dGPS, the base measures the pseudo ranges towards the satellites using the C/A code. The base calculates the theoretical pseudo ranges from its (known) location to the satellite as well and compares the two to derive a pseudo range correction. These corrections are then sent, one per satellite, to the rover where they are applied to the ranges measured from the corresponding satellites.

The real error at the rover will of course differ from that at the base, but since the satellites are at a relatively long distance when compared to the distance between base and rover, they are generally valid. The further the distance between base and rover, the lower the accuracy of the corrections and thus the precision of the rover position. Errors at the base position like multi path will have a direct influence on the quality of the dGPS signal and thus on the rover position. With code phase dGPS a precision in the order of one

meter to a couple of meters can be achieved. The actual precision depends on the distance between base and rover and the telemetry frequency chosen for transmitting the corrections.

Carrier Phase dGPS

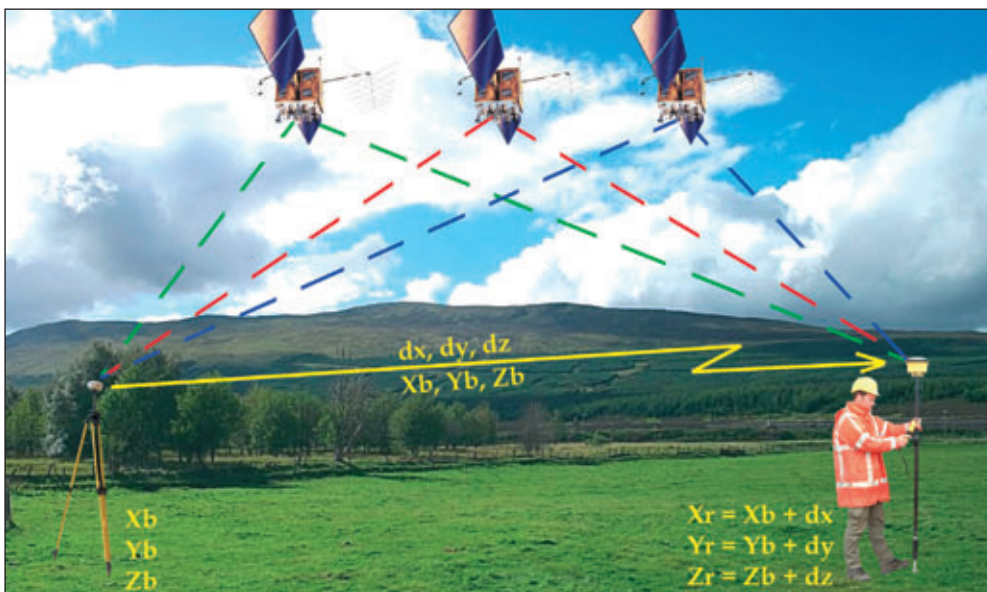
This technique uses the carrier wave (L1 and L2) of the GPS signal. The length of the carrier wave is in the order of 20 centimetres and has as such a much shorter wavelength than the code signal (300 meters). As a result carrier phase dGPS is more precise than code phase dGPS.

As a consequence however, the determining corrections with carrier phase dGPS requires more computation than when using the code signal. A large hurdle to overcome is the determination of the whole number of wavelengths (cycles) between the satellite and receiver. This whole number of cycles is also called the integer ambiguity and needs to be resolved during the initialisation of the system. Resolving this is usually done with two receivers measuring towards at least 5 identical satellites. Between these two receivers the difference in whole number of cycles is determined (single, double and triple differencing). From this starting point the receiver tracks the change in cycles as the distance between satellite and receiver changes.

Absolute Positions

The result of a carrier phase position determination is a position difference between base and rover. No absolute positions are calculated in either base or rover. The only function of the base is gathering raw data from the satellites and re-transmitting (or storing) these for use in the rover. The absolute rover position is found by adding the found Δx , y and Δz to the absolute x , y and z entered manually in the base. For practical purposes a carrier

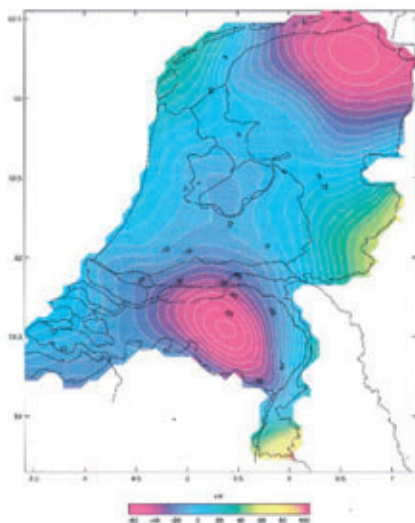
ms and RTK Techniques



Principle of carrier phase dGPS. Position differences between base and rover are determined.

phase dGPS system can thus be seen as land survey 'total station'. Although it is one without the need to have a line of sight between instrument and beacon and an effective range of kilometres. There are a number of carrier phase techniques in use today; the table on page 57 gives an overview of the most important ones. The following definitions are important when using the table:

- Post processing. Measurements are taken in the field and processed in the office. Results are not visible online;



Difference for the Netherlands between the ellipsoid of Bessel and Dutch Datum (NAP), based upon the geoid of the Min (1996). (source: Dutch Geo Information and ICT department of Rijkswaterstaat).

- Real time. The measurements are taken in the field and are online visible;
- Static initialisation. The system may not move during initialisation, movement of the rover is not allowed;
- Continuous measurement. Measurements can be taken while moving, thus creating a continuous profile or measurement.

Height Measurement

Accurate height measurement is not possible with code phase dGPS. Carrier phase dGPS however does offer this possibility and is the primary reason for choosing carrier phase dGPS over code phase dGPS for certain applications. Carrier phase dGPS seems to replace the total station and level instrument as such for all but the most accurate jobs.

An important difference between the height measurement of a carrier phase dGPS system and the more traditional land survey methods is that the height reference used is different. With GPS, heights are determined relative to the WGS84 ellipsoid and not as with level instruments relative to a gravity based reference or geoid such as mean sea level. When measuring over distances of kilometres, the difference between the ellipsoid and geoid can cause height errors in the order of centimetres to decimetres. In order to reference the GPS measurements to the geoid a correction is needed. Most geodetic type receivers and software packages use so-called geoid models to correct for this.

Telemetry

There are a multitude of methods to get the dGPS correction signal from the base to the rover. Much used techniques are:

- Radio telemetry;
- Satellite telemetry;
- Mobile telephone.

Radio Telemetry

This method is mostly used for small-scale projects where high precision is needed or where no regular dGPS infrastructure is in place. With radio telemetry, the achievable range depends on the chosen frequency band and power used. Much used bands are the UHF band (RTK systems) with a maximum range equal to the line of sight or roughly 40 kilometres. Another widely used band is the MF band (IALA beacons) with a range of tens of kilometres. The International Association of Lighthouse Authorities (IALA) transmits free to air signals from beacons close to harbours of shipping lanes.

A specific form of radio telemetry is the Eurofix system. With Eurofix, Loran-C transmitters transmit the dGPS correction signal. Loran-C is a terrestrial radio positioning system that seemed to become victim to the widespread use of dGPS. However, since then various reports (the Volpe report - United States and Helios study - Europe) criticized the vulnerability of GPS as a sole means of navigation. Since Loran-C uses terrestrial transmitters with high power signals in a different frequency band it is not vulnerable to the same sources as GPS.



European IALA dGPS chain (source: IALA).

Technique	Specifics	Applications	Precision
Static	Post processing Static initialisation 1-2 hour measurement Range: tens of kilometres	Geodetic surveys	< Centimetre X,Y Centimetres Z
Rapid Static	Post processing Static initialisation 5-15 min. measurement Range: tens of kilometres	Geodetic surveys	< Centimetre X,Y Centimetres Z
Kinematic	Post processing Static initialisation Continuous measurement Range: tens of kilometres	Topographic and location surveys	Centimetre X,Y Centimetre Z
Real Time Kinematic On the Fly (RTK OTF)	Real time or post processing Initialisation during moving Continuous measurement Range up to 15 km	Topographic and location surveys Hydrographic survey inshore / near shore	Centimetre X,Y Centimetre Z
Long Range RTK OTF	Real time or post processing Initialisation during moving Continuous measurement Range up to 40 km	Hydrographic survey coast / offshore zone	Centimetre X,Y Centimetre Z
Satellite RTK OTF	Real time or post processing Initialisation during moving Continuous measurement Range: hundreds of kilometres	Oceanographic survey en offshore survey	Decimetre X,Y Decimetre Z

Overview of carrier phase techniques.

As a stand-alone system it is however less precise. By combining Loran and GPS, a system is created that is less vulnerable and which can achieve a precision of meters even when the GPS signal is interrupted. The Americans are fully convinced that Loran-C should remain active for this reason and are modernizing their Loran-C transmitters. Some European governments however are less convinced and one of the Loran-C chains, the Northwest Europe Loran-C System (NELS) is reportedly threatened to be shut down. The argument often heard is that Galileo will solve the problems mentioned. This is not a valid argument however, since Galileo is vulnerable in much the same way as GPS and/or GLONASS since all systems are based on the same principles and frequency bands.

Satellite telemetry

At the moment corrections via mobile telephones are offered by commercial services only. When dGPS signals are transmitted via a satellite network, they can cover a much larger area than when transmitted from terrestrial beacons. There are a number of commercial networks based upon satellite telemetry. An example of such a network is the Fugro Omnistar / Starfix network.

A special form of satellite dGPS is WAAS (Wide Area Augmentation System) and its European counterpart Egnos (European Geostationary Overlay System). With Egnos the - free - correction signals are transmitted on the same frequency as the GPS signals themselves. As a result no expensive separate dGPS receiver is needed. The GPS receiver however needs to be able to receive the so-called SBAS messages that are transmitted by geo-stationary satellites.

Mobile telephone

Corrections via mobile telephone are at the moment offered by commercial services only. Dutch examples are LNR Globalcom (see the article on page 32 of this issue) and o6-GPS networks. The advantage of these networks is that they offer a large number of reference stations over a relatively small area. As a result high precision is achievable without the need to erect an own base station. The main disadvantage is the high cost when performing continuous measurements. As a result these networks are commonly used for calculating base positions. However with the introduction of UMTS and GPRS techniques costs will probably drop considerably.

Multi Reference Systems

Most dGPS systems consist of a network of reference stations whereby the stations continuously check each other. As a result, errors in a single base station can be easily detected resulting in a higher reliability. Another advantage is the possibility to use combined corrections from multiple base stations.

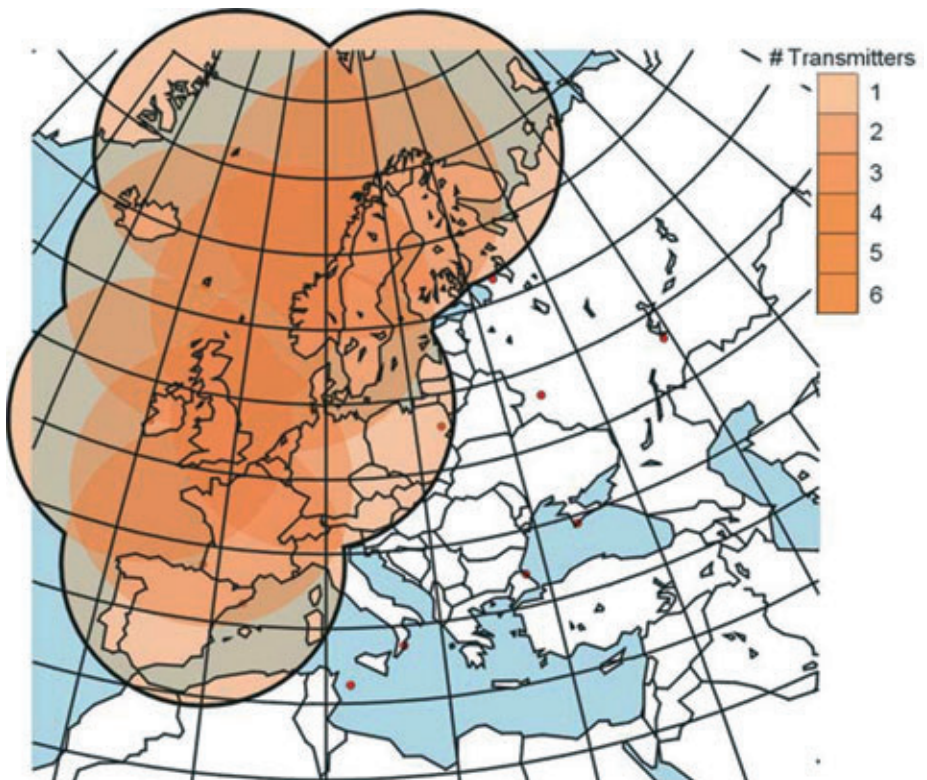
Depending on the network, there are many ways to combine the different corrections into a single solution. Some receivers obtain information from multiple base stations and will calculate the optimal solution based upon the rover position. Another method is to perform the calculation in the network itself. This way the receiver can be simpler but we will need to transmit our position to the network. This means that we need bi-directional telemetry. This technique often consists of telemetry via the mobile telephone.

Conclusion

With dGPS techniques we cannot only improve the precision of our position to within centimetres using carrier phase dGPS, but more important, we have a means to check the reliability of the GPS signal itself.

Huibert-Jan Lekkerkerk

(hlekkerkerk@geoinformatics.com) is a freelance writer and trainer in the field of positioning and hydrography.



Eurofix coverage with the NELS chain. (source: www.eurofix.tudelft.nl).