A REVIEW OF GPS TECHNOLOGY AND ITS APPLICATIONS FOR THE FOREST INDUSTRY IN 1997

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1. INTRODUCTION

GPS is a technology which has now gained worldwide acceptance as a navigational and positioning tool and is being put to use in many industries. It's uses and applications are multiplying rapidly as users come to terms with it's capabilities and potential. As people apply the technology to various positioning problems, new uses of GPS emerge.

But GPS also has limitations and a wide range of achievable accuracies which people often fail to grasp. It is not the answer to every problem. We will discuss its limitations as well as its advantages, particularly as they apply to forestry applications.

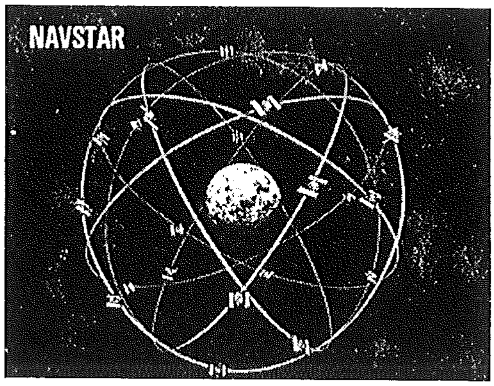
In order to fully understand and grasp the uses, potential applications, and pitfalls of GPS in forestry applications, we must have a good basic grounding in how the system works and how certain accuracies are obtained.

2. OVERVIEW OF THE GPS SYSTEM

How did the Global Positioning System start?

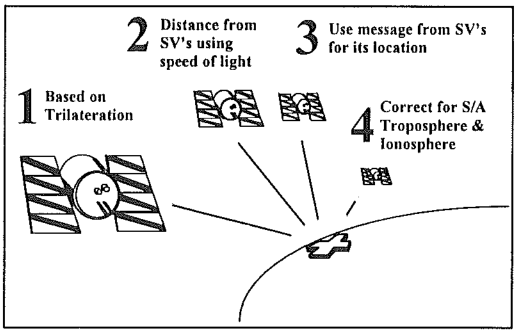
The U.S. Department of Defence decided that the military had to have a super precise form of worldwide positioning and fortunately they had the $12 Billion it took to build a very worthwhile system.

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites (known as "Navstar") and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. With advanced GPS units positional accuracy of better than 1cm can be obtained.



GPS receivers have been miniaturised to just a few integrated circuits and so are becoming very economical. And that makes the technology very accessible.

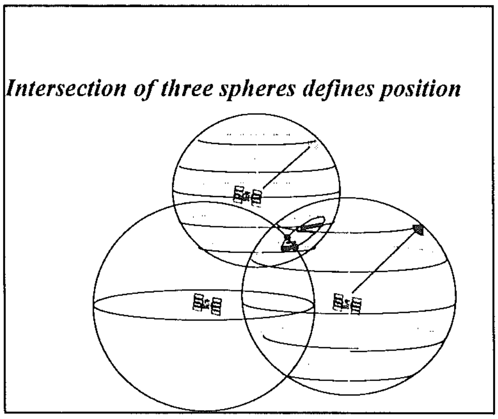
Basic GPS principles in 4 steps:



1. GPS is based on "Trilateration"

This is a simple geometric principle that says, in 2D terms, if an observer's distance from two known points is measured, the observer's XY position can be calculated. To calculate a 3D position (XYZ), a minimum of 3 distances to 3 known points is required.

In the case of the Global Positioning System, to eliminate timing errors we require information from 4 satellites to get a good 3D fix.



2. To "trilaterate," we need distances.

A GPS receiver measures distances from earth to satellites using the travel time of radio signals. Radio signals travel at the speed of light so it is a simple operation to calculate distance.

Distance to satellite = travel time of signal x speed of light

km = sec x km/sec

The system also depends on very accurate timing. Atomic clocks are used in each satellite to time stamp the GPS signals emitted, and quality quartz clocks are used in the GPS receivers to analyse the signals received and determine the time delay between SV and Observer.

The time delays are determined by analysing and synchronising "psuedo random code" which both the satellite and receiver generates.

3. We need satellite position

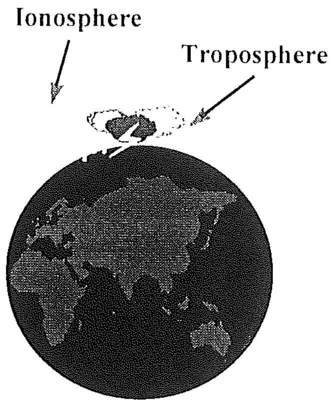
To trilaterate, we need to know exactly where the satellites are in space.

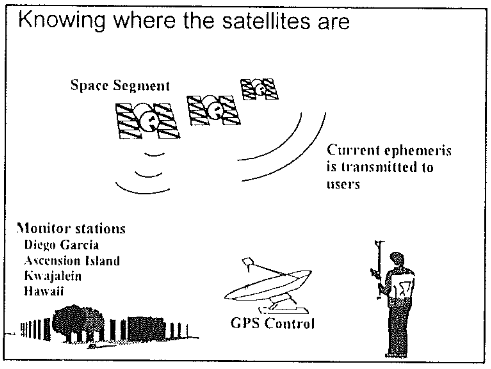
High orbits and careful monitoring are crucial in continually calculating updated positions of the entire constellation of satellites.

The GPS satellite constellation orbits the earth at a distance of 20,000 km which is a very high orbit. There are several advantages in using high orbiting satellites; less atmosphere means less drag on the vehicle and this makes orbits more stable and more predictable, at that height there is a very low risk of collision, because of their distance from earth the satellites can "see" more of the surface at one time, giving a better coverage.

There are 4 GPS monitoring stations on earth which constantly receive positional data from the satellites. This data is used to continuously update the orbits of the constellation. Accurate information on the precise position of all satellites in the GPS constellation, "ephemeris" data, is compiled into a file called an "Almanac".

Every satellite regularly receives a current almanac from the GPS control centre, and in turn broadcasts this almanac to roving GPS receivers. Each GPS receiver must have this almanac, detailing current positions of each satellite, in order to calculate a position on earth.





4. Error corrections must be made.

As the GPS signals pass through the troposphere and ionosphere they are delayed and this causes slight errors which must be corrected.

For civilian users the signals are subjected to an introduced error called "Selective Availability" (S/A) and this also must be corrected. S/A will be discussed further below.

There is more than one method for correcting these errors, but the most common technique, particularly for mapping grade GPS commonly used in forestry, is "Differential Correction" or DGPS. DGPS will also be discussed further below.

3. ACHIEVABLE ACCURACY

There are many levels of positional accuracy achievable when using GPS. Lower grade hand held receivers commonly used for recreation have a typical accuracy (autonomous) of ±100m. GIS Mapping receivers which use code phase data are typically capable of giving positions to an accuracy of ±½m to ±5m. High grade receivers suitable for Land Surveying or Monitoring work which use carrier phase data are capable of accuracies better than ±1cm. Myths about GPS accuracy abound!

Factors Affecting Accuracy

The achievable accuracy of any GPS receiver depends on the following:

- Design of the receiver. What accuracy is it designed for? Higher grade receivers use complex correction techniques and have high quality, low noise componentry as well as using advanced software algorithms for processing. Lower grade receivers, being less expensive, use cheaper components and less advanced techniques.

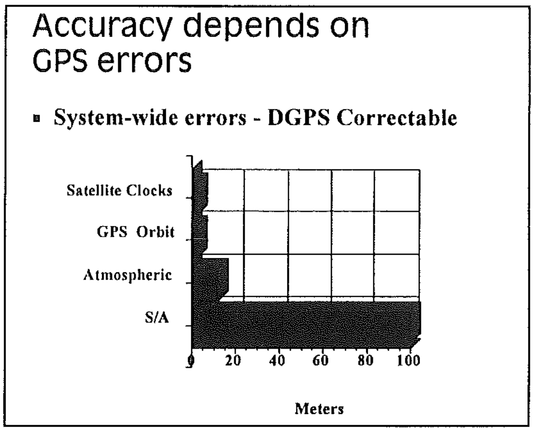
- Time spent on measurements. For most GPS receivers accuracy is enhanced when a point is occupied for some time. For example a more accurate solution is likely when occupying a point for 1 minute rather than 1 second, though some receivers are capable of very high accuracy in just a few seconds.

- Relative positions of satellites. Because we use trilateration to calculate position, more accurate solutions are obtained when there is a large degree of separation between satellites. This gives us larger angles to work with and a better geometric solution. The measure of satellite geometry is termed "PDOP" or Position Dilution of Precision. For reliable positions we should log data with a PDOP of 6.0 or lower.

- Multipath. When GPS signals bounce off an object, or pass through a medium such as forest canopy, before being picked up by a GPS receiver, some distortion occurs due to time delay and this is known as multipath. It can be compared to "ghosting" of a TV signal causing double images. Typical high multipath conditions are found in urban areas with tall glassy buildings, or areas with obstructions such as forest canopy.

  Multipath mitigation firmware such as "Everest" technology can help reduce these problems.

- Use of Differential Techniques. Because of S/A (discussed below) the accuracy of any receiver working autonomously (without differential correction) can only be guaranteed to ± 100m. It is only by using some form of differential correction that we can obtain lower accuracy. This is often not fully grasped by consumers who expect to be able to use small inexpensive GPS units to 10-20m accuracy.



Selective Availability

The US Department of Defence can (and does) intentionally introduce a random error into the code emitted by the GPS satellites. This error is often as much as 100m in X and Y, and 300m in Z.

The purpose of S/A is to prevent hostile forces from using GPS to it's full capability. To achieve useable accuracy for military purposes one would have to use some form of real time differential correction which is difficult over long distances. The US military use GPS receivers capable of unencoding the signals and achieve accuracies in the order of 20m autonomously.

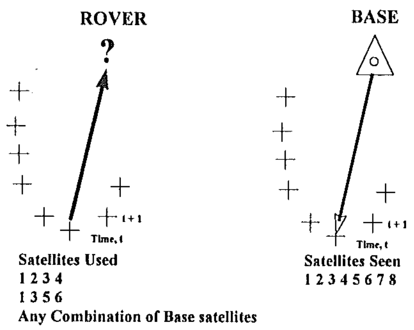
Differential Correction

Differential Correction, or DGPS is very common in mapping and forestry applications and allows us to improve the accuracy of logged positions from ±100m to ±½m-5m.

Simply described, DGPS employs a second GPS receiver in addition to the roving unit. This is known as the base station and it occupies a known position and continuously collects

GPS position data. From this data it is able to calculate positional errors at specific time intervals, say every 5 seconds. It can do this because it occupies a known coordinate, and can therefore monitor the differences between the positions the GPS is providing, and this known coordinate.

This error information is stored and the roving unit can then apply these known errors, either in real time in the field using a radio data link, or post processed back in the office, and refine it's position to a much higher level of accuracy.



Base station data is available from a variety of sources. In New Zealand there are commercially owned and operated base stations in all of our main centres. For a small fee users can access the base station data externally via a modem or get it posted on a disk. The differential processing is done back in the office using software provided with the GPS.

Alternatively the differential correction process can be carried out in real time in the field, providing the GPS is capable of it, and providing a differential correction signal from a base station is being broadcast in the area

4. FOREST CANOPY ISSUES

What about Forest Canopy?

This is a frequently asked question in forestry circles when contemplating using GPS. How are GPS signals affected by forest canopy? The simple answer is that GPS signals are adversely affected, but there are many variables which influence how badly.

In short, heavy forest canopy is not an ideal environment for GPS and we can never *guarantee* good results in heavy canopy. The effect of forest canopy is to block, or delay the GPS signals as they attempt to pass through it. The symptoms to the user are that the receiver will have trouble registering enough satellites to get a positional fix i.e. less than 4 satellites. Also, when fixes are able to be attained their positional accuracy will be degraded, typically in the order of 2-3 times the accuracy achievable in open sky environments.

Having said that, there are things we can do to maximise performance under canopy.

Factors Affecting Reception in Forests

- Age of forest and stocking. Older forests will have a larger basal area and will be taller. This means that signals from satellites at a low elevation will have to contend with a large amount of wood as opposed to leaves. High stocking levels in a stand will have the same effect.

  There are many GPS tasks to be carried out in young forests where thick canopy is not a problem. Even if a forest is mature, if the stocking is low better results may be obtained.

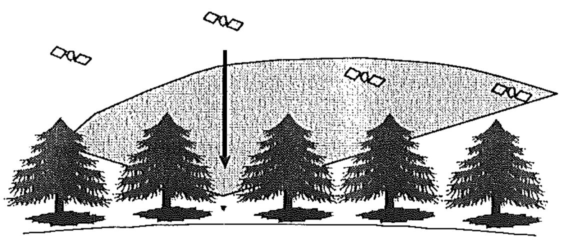
- Species. Some species are better then others at repelling GPS signals. Pinus Radiata tends to be one of the more challenging species for GPS users while some of our native forests are more GPS friendly.

The influencing factor here is generally the density of the leaves.

- Amount of moisture. Generally, if it is raining, or the leaves of the trees are wet, it adds to the difficulties of using GPS under canopy.

- Antenna height. Raising the GPS antenna height has the effect of lowering the basal area of the forest around the antenna, and also effectively lowers the height of the stand, thus creating a more open sky. It increases the likelihood of reception.

- Signal angle of attack. A signal from a satellite orbiting at a high angle to the horizon has more penetrating power through the canopy than one which is low on the horizon and must penetrate the canopy at an angle. When there are a good number of satellites orbiting at a high elevation, there is a better chance of obtaining good GPS fixes.



Using planning software supplied with the GPS system, we can make very accurate predictions about the positions of satellites and when there will be a high number overhead. This allows us to plan our activities for a time which will give us the best results. But while this is a good work around, it is not always practical in real life to limit the hours which field crews can work.

- Number of channels in receiver. In a receiver a channel "listens" to the GPS signals. If a receiver only has one channel it must continuously switch between satellites to obtain positions. In multi channel receivers satellites can be tracked simultaneously. This greatly assists the receiver in locating satellites that are hidden behind obstacles such as tree canopy, when they reappear.

5. APPLICATIONS IN FORESTRY

As we have discovered, GPS is not ideally suited to heavy forested areas even though we can sometimes alleviate forest canopy problems. It is important therefore to justify the use or purchase of a GPS unit around tasks which can be achieved in unforested areas, and there are many of them. Then when the system is utilised in challenging environments such as heavy forested areas, it is an added bonus.

Some of the applications are as follows:

- GIS Mapping

Geographical Information Systems (GIS) are now an integral part of forest management. Among their many advantages, they enable forest managers to gain instant access to forest data collected in the field and view it spatially. GPS can help build the information in a GIS system.

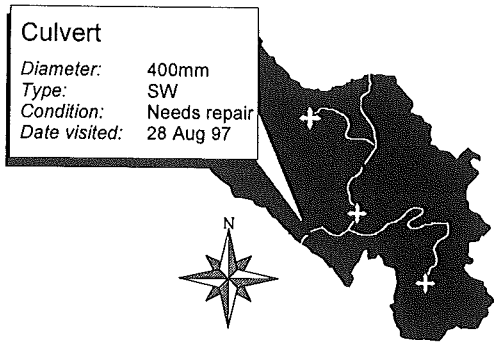
Features such as forest areas, compartments, roads, culverts, skid sites etc. can be positioned with GPS in the field and this information passed seamlessly through to the GIS where it can be manipulated, viewed spatially, and maps produced. Many of these tasks can be carried out in the absence of forest canopy.

Some of these activities are currently being carried out more than adequately by aerial photography, and GPS should not necessarily be seen as a total replacement for this. Rather it is a tool to enhance, compliment, and in some cases reduce the need to fly all forests.

- GIS Data Capture

In addition to logging and storing GPS positions of features in the forest, a GPS mapping unit has advanced data capture capability. The user can create "data dictionaries" and load these into the GPS so that while a position is being logged, he or she is prompted to enter certain predefined data fields, using pop up menus, or the key pad to describe and detail the feature.

For instance the GIS manager may require culverts to be positioned for his GIS but he may also require that the culvert size be logged along with other maintenance related information. This information is then tied to the positional information and is exported to the GIS so that when a feature is queried the information is accessible.



This is one area where GPS has advantages over photogrammetry in that because the features must be visited physically, a lot of useful information can be obtained while the field crew are on the ground. Another feature of this "digital data capture" is that the flow-through of the information eliminates the need for paper notes with later time consuming data entry in the office, and the inevitable errors.

- Control Points for Photogrammetry.

GPS is being used in partnership with aerial photography to define the positions of photo-control points. Once the coordinates of these points are defined they can be matched up with the position on the photograph and an ortho correction can be carried out, reducing the distortion in the aerial photograph.

It is difficult to get accurate coordinates of control points in forests using conventional surveying techniques because of their distance from known survey points or Trig stations. GPS allows a lay person (as opposed to a surveyor) to position control points accurately without the need of a reference position.

- Contractor payments by area

Forest owners are using GPS to monitor the progress of contractors. For instance, when a pruning operation is completed the owner can walk around the pruned compartment and obtain an accurate area in hectares, or square meters, in order to accurately pay the contractor.

- PSP Location and navigation

Forest contractors are using GPS to pinpoint the location of permanent sample plots. While they are carrying out their mensuration tasks they can leave the GPS logging in the centre of the plot and obtain a fix for the plot centre. This can be transferred to the GIS system.

Later contractors can use a GPS to navigate back to the plot centre. This will become more relevant in the future as real time differential correction signals become more accessible in forests.

- Selective Logging

Companies involved in selective, or sustainable logging of our native forests are required by the Ministry of Forestry to accurately pinpoint the location of every tree they remove so they can be audited. GPS is being used in these operations to locate these positions.

- Vehicle Tracking

In many industries GPS units are being installed in vehicles for tracking purposes. Organisations such as the Police, Ambulance services, Search and Rescue organisations, Taxi companies, Rental car companies, and Trucking companies, are utilising GPS in this way.

GPS units used in vehicle tracking applications are usually small OEM type products which can also broadcast position data to a base via telemetry.

Forestry companies are also looking to invest in vehicle tracking GPS units for tracking vehicles employed in the forest industry. This extends from tracking logging trucks to monitoring skid site vehicles to learn more about their behaviour, in all cases the aim is to maximise operating efficiency.

6. FUTURE DEVELOPMENTS

Where will GPS go from here?

Over the next 10 years look to see GPS become more and more accepted and widely used. Manufacturers are predicting that it will become a utility much like electricity.

We expect to see the obvious advancements in the technology which are already happening. i.e. units become smaller, lighter, more powerful and feature rich.

The current trend by manufacturers is to produce new units capable of better accuracy and more functionality while maintaining a fairly constant price structure. Expect this trend to continue.

More specifically some of the things we can expect to see are:

- Better Realtime coverage. As the use of GPS increases and expands users will demand real time differential correction as standard both for navigation and also to avoid having to post process data in the office. Low Earth Orbiting Satellites (LEOS) are currently being launched for communications and it is expected that these will enhance real time differential coverage.

- Further receiver enhancements. This year has seen the release of a number of firmware upgrades to GPS receivers which has increased their accuracy and productivity. We can expect to see this trend continue.

- Integrated antenna's. This year has also seen the release from Trimble Navigation of a number of "integrated antennas". These have the ability to receive real time differential radio signals as well as signals from the GPS satellite constellation. This means that real time GPS is seamless and almost unseen to the user. Previously real time GPS involved the use of external radios and radio modems, adding weight and complexity to the system. We expect to see further development in this area.

- Increase in application software written around GPS systems i.e. we can expect to see more specialised programmes written specifically for GPS applications. Vehicle tracking software is a good example, or forestry software such as log optimisation or log making can be built around GPS.

- Direct GPS to GIS. We expect to see development in GIS systems so that the GIS can be taken into the field in a ruggedised pen type computer and GPS data stored straight into it. Obviously there is a requirement for real time differential GPS here.

- The use of external sensors. There will be a move towards capturing data using digital external sensors linked to GPS. For example by connecting a digital camera or scanner digital images can be collected and seamlessly logged into the GPS unit. The image and GPS location are then tied together. The use of external sensors is expected to proliferate. Instruments such as bar code wands, laser rangefinders, digital calipers, pH meters etc. can all be linked to GPS receivers.

- Machine Control. GPS is starting to be used to control machinery and this will propagate. Machines such as graders and scrapers are being controlled using GPS, as is the precise positioning of large structures. Look for these developments to continue.

7. CONCLUSION

GPS as a technology has now matured to a point where it is generally accepted as very useful by professionals, and this includes the forest industry.

As users become more proficient with its capabilities as well as limitations, and the technology continues to improve, its use in NZ forests can only increase.

This will ultimately result in forest managers having a better information infrastructure and more reliable data at their finger tips. In turn our forests will be more efficiently managed.