MODULE 10

MODULE 10: Introduction to GPS and Best Practice Guidelines

Building capacity to implement natural resources information management systems.

www.nlwra.gov.au

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Product Number: PN21205

ISBN: 978-0-642-37155-3

Guide for managers

Context

One of the prerequisites for natural resources management (NRM) involves the establishment and maintenance of a good database of information in digital format. Access to reliable and up-to-date information reduces the uncertainty in planning and management by helping identify and analyse situations and issues. Strategies to overcome them may then be prepared and implemented, with the impacts monitored as part of an overall system. The value of the information and the effectiveness of the decision-making/planning processes are very closely related to the quality and completeness of the information and the manner in which it is made available. In this respect data access, management, integration, analysis, standards, and communication are key components.

Under current arrangements, funding for NRM projects is increasingly being channelled from government agencies to regional groups, such as catchment management authorities and resource information centres. This often involves gaining access to, developing new, and processing existing data. It is important these data are collected to an existing standard and, once collected and processed, become part of the national resource base, and subsequently made available to the broader community.

Recent progresses in technology, and reductions in the cost of many products, has made it possible for general practitioners to have access to equipment previously considered the domain of specialists. The global positioning system (GPS) is one such piece of equipment becoming increasingly used by the general community. GPS receivers are widely used in NRM projects, e.g. determining the location of a stream recoding station, through to precision agriculture tasks relating yield to paddock locations, and sophisticated geodetic control surveys.

As with any data collection exercise, GPS surveys can be time consuming and expensive. As such, they should be treated like any other data collection and processing activity, and be carefully designed and planned to return maximum benefit. A number of issues need to be considered prior to undertaking a GPS survey. The intent of this guideline is to provide background information on the operations of GPS and an outline of the issues involved in designing GPS surveys.

It is acknowledged that each state and territory jurisdiction may have its own initiatives related to data collection and information management including governance guidelines and protocols related to the use of GPS.

Module 10: Introduction to GPS and best practice guidelines provides general material to assist practitioners and NRM regional groups in the selection and use of GPS.

Actions

Managers should be aware that in any data collection exercise there is a need for careful planning in the initial design stages.

Best practice guidelines and standards are available to assist in the design and implementation of GPS surveys. These should be followed to ensure that the collection of GPS data fulfils the level of accuracy required for the particular study. Similarly, when purchasing GPS equipment it is important to determine the functionality required. A template is provided to assist in identifying some of the criteria to consider when selecting GPS receivers.

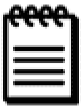
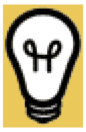
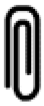
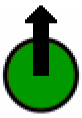
Acknowledgements

This module draws heavily on material from the Surveyors Board of Victoria (http://www.surveyorsboard.vic.gov.au/gps.htm) and has been included in this Toolkit with its permission.

In addition, material from the Point of Beginning Magazine website (http://www.pobonline.com) has also been incorporated into this module. These sources are duly acknowledged.

Guide to symbols

The following symbols are used throughout the Toolkit as a guide to users, and draw attention to important issues and information.

	Information which readers should take particular note of
	Best practice information
	Tips for readers—based on experience and aimed at saving time and resources
	Caution—readers are advised that particular care should be taken or that the subject issue may be complex
	Additional information
	Capability raising—used to show a signpost to a higher capability level
Bold Text	Used to highlight a particular issue
Boxed Text	Highlighting of issues specifically related to ANZLIC or the Audit

10.1 Introduction

The following material is taken from the Surveyors Board of Victoria’s website.

A checklist of criteria for selecting GPS receivers is given at Attachment 10–1 and background material and technical details involved in satellite positioning is given at Attachment 10–2.

1 ⏩ 2 — Low understanding of GPS principles. GPS procurement driven by individual needs.

2 ⏩ 3 — Understanding of GPS principles. GPS procurement integrated with needs and procurement based on endorsed plan.

10.2 Best practice guidelines for GPS surveys

In addition to these guidelines, the Surveyors Board recently worked in cooperation with the Intergovernmental Committee on Surveying and Mapping (ISCM) to develop a handbook on ‘GPS Data Collection For Integration with Geographic Information Systems (GIS) Standards, Specifications & Best Practice Field Guide’.

An updated Version 7.2 of the handbook is available at:

http://www.nre.vic.gov.au/CA256F310024B628/0/311F3E48EE0204AFCA257110001EFCDE/$File/GPS+Handbook+v7.2.pdf

10.2.1 Introduction

There are a number of different methods by which surveyors can use GPS technology for surveying applications. The static and rapid static techniques are most common, however, with the development of real-time operation, kinematic techniques are becoming increasingly popular. The signals received from the GPS satellites are prone to a number of errors, many of which are removed by using differential positioning techniques. However, errors such as those caused by multipath are site dependent and are not removed using the differential approach. This highlights that each GPS survey is different in that the observing conditions are unlikely to be the same from day-to-day, month-to-month or year-to-year. It is, therefore, extremely difficult to develop a set of procedural guidelines which will ensure that required survey accuracy is achieved in all circumstances. A set of best practice guidelines can be developed to provide instruction to surveyors in a manner that will realise satisfactory results in most circumstances. As with any set of recommendations, it is up to the surveyor’s professional discretion to judge the most appropriate manner in which a survey should be performed. Best practice guidelines provide a solid framework on which to base survey practice.

10.2.2 Guideline objectives

The guidelines recommended in this section are based on those developed by the ICSM. The aims of the guidelines for Victoria are:

- to provide a solid set of observation procedures that will enable inexperienced users to perform GPS surveys successfully
- to establish guidelines that can be adapted to specific circumstances by not being too prescriptive—this falls in line with the state survey regulations regarding cadastral surveys
- to provide conservative operating procedures which will be successful for the majority of observation conditions—surveyors should apply professional experience in adapting these guidelines for specific surveys.

10.2.3 The ICSM guidelines

The ICSM has developed a document titled 'Best Practice Guidelines – Use of The Global Positioning System (GPS) For Surveying Applications'. The first version of the document was released in May of 1996. The second version was released one year later and incorporates changes to enable application of the guidelines in New Zealand. The development of the document has involved representatives from all states and territories of Australia, in addition to the army, navy and New Zealand representatives. The guidelines are, therefore, reflective of the views of surveyors from across the country.

The ICSM best practice guidelines are suitable for providing the framework for GPS surveying in Victoria (in the description of the ICSM guidelines, if a modification is recommended for use in Victoria, the * character is attached). All surveyors planning to perform GPS surveys should read the guidelines before attempting GPS surveys. The document contains a section discussing methods of classifying survey types which will not be discussed as each client's needs will differ according to the project being undertaken. The operational procedures of the document are of more relevance. The main points of the guidelines are:

10.2.4 Equipment validation

The ICSM recommends that all equipment should be validated on an appropriate network of control points. The network should contain baselines ranging in length from 50m to 10km and should be measured with electromagnetiic distance measurement (EDM) equipment where possible . If an EDM cannot be used, the points should be part of a first order geodetic network. Stations should have forced centering pillars if available. Currently, Land Victoria is funding a project which aims to develop a scheme for providing legal traceability of GPS measurements. The preliminary findings of the research involve connection to existing survey marks which have traceable coordinates. This concept is different from that described by the ICSM as the EDM is used to measure length, not position. GPS systems provide three-dimensional position differences, not simply lengths.

The ICSM guidelines also recommend that a zero baseline test be performed and the baseline length checked to be zero. The zero baseline test involves connecting two receivers to the same antenna using an antenna splitter device. However, rather than analysing the baseline length from a processing package, the raw measurements should be analysed. In the case of double differences, the double difference carrier phase residuals will provide an estimate as to how well the measurements are being recorded by the receiver. This enables the zero baseline test to be used to verify the performance of the receiver electronic circuitry in isolation.

10.2.5 Selection of observation technique

The observation technique used to perform a GPS survey will vary depending on the type of survey being performed. A section on Designing GPS Surveys, discusses several issues that need to be considered when planning a GPS survey. The ICSM has not made any recommendation regarding the observation technique employed by surveyors. The surveying industry is comprised of professionals who, given the correct background material, are capable of deciding on a surveying technique which is suitable and cost-effective for the survey task at hand.

> In Victoria, the selection of the surveying technique can be left to the discretion of the surveyor, however, with the following qualifier—if the accuracy required by the survey is at the limits of kinematic survey capability as defined by the manufacturer's specifications, or if the region of the survey is extremely large, static observation techniques should be adopted. In addition, if there is any doubt as to whether kinematic surveying techniques are appropriate, the surveyor should be conservative and choose the static option. Static surveys require the acquisition of measurements using stationary receivers. This provides a higher solution reliability than kinematic techniques as occupation times per point are longer.

10.2.6 General requirements

The general requirements for surveys recommended by the ICSM apply to all types of GPS surveys—static, rapid static and kinematic. It should be noted that the ICSM also provides guidelines for pseudo-kinematic (sometimes called intermittent static) surveying. This technique involves two short static occupations of the same mark, separated in time by a period of approximately one hour. This technique is extremely difficult to manage in practice and is not recommended for use in Victoria. The user should apply rapid static procedures in place of the pseudo-kinematic technique.

The general requirements include:

- Refer to the manufacturer's documentation for instructions as to the correct use of equipment.
- All ancillary equipment such as tripods and tribrachs should be in good condition.
- **Users should take extreme care when measuring the height of the antenna above the ground mark.**
- The point identifier should be recorded at the time of survey.

- Satellite geometry as defined by the GDOP should be less than 8.
- All receivers must observe at least four common satellites.
- The elevation mask in Australia should not be less than 15 degrees
- When establishing reference stations, marks with high quality coordinates should be adopted.
- When heights are required, marks with high quality height values must be used..
- Field observation sheets (as provided) should be used for all static survey occupations.
- It is not necessary to record meteorological readings and standard models should be used instead during data processing.
- Measurements for horizontal coordination purposes must form a closed figure and be connected to at least two marks with known coordinates in the desired coordinate system.
- Least squares adjustments should be carried out to ascertain whether required accuracy standards have been met.
- All least squares adjustments should be three dimensional in nature.

The best practice guidelines provide a basic framework for performing surveys. In Victoria, several modifications to these general guidelines have been made.

The ICSM also provides a set of guidelines for each of the observation techniques. The following details are recommended.

Static surveying

- The minimum observation period for baselines less than ten kilometres should be 30 minutes *.
- The recording rate should be 15 or 30 seconds.
- The satellite geometry should change significantly during the observation session.
- Single frequency receivers may be used for short lines for non high-precision applications.
- It is essential that the carrier phase ambiguities are constrained for lines less than 15km.

Rapid static surveying

- Baselines must be less than ten kilometres in length
- Manufacturer's documentation should be consulted for determining the occupation period.
- Dual frequency receivers are preferred.
- Five or more satellite should be observed.
- The recording rate may vary between five and ten seconds.

Stop and go kinematic surveying

- Five or more satellites should be observed.
- Receivers should be initialised per the manufacturer’s recommendations.
- Each point should be occupied in a different session with different satellite geometry.
- The recording rate should be between one and five seconds.
- Each station should be occupied for between five and ten epochs.
- Single frequency receivers may be used although dual frequency receivers are preferred.

The guidelines conclude by recommending that all raw measurements be archived as they may be needed for future verification of coordinates.

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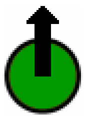
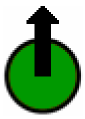
10.3 Criteria for selecting a GPS receiver

As with GIS software, GPS receivers have been the subject of a number of industry surveys. Criteria that may be used as a template to guide the purchase of GPS receivers are given as Attachment 10–1.



3⏩4

Good understanding of GPS principles. Formal methods for GPS survey and processing. Procurement integrated with needs and procurement based on endorsed plan.



4⏩5

Benchmarking of performance, with continuous effort for improving.

10.4 Additional Support

A range of resource material related to GPS is currently available online covering such topics as guidelines for purchasing GPS receivers, tutorials, frequently asked questions, news groups, and forums, etc.

The following sites are provided as a starting point. Note: Listing does not provide endorsement of product or view.

General information including reviews

http://gpsinformation.net/

http://www.gpsnuts.com/

http://www.innovativegis.com/basis/pfprimer/Topic7/TOPIC7.html

Vendor Information

Most vendors have detailed information on the range of products they provide along with additional support material, manuals and software downloads. The following sites are provided for illustration purposes:

Garmin: http://www.garmin.com

Trimble: http://www.trimble.com

Magellan: http://www.magellan.com.au

Topcon: http://www.topcon.com.au/

Organisations and industry sites

Australian GPS Society: http://www.gps-society.org/index.html

GPS World: http://www.gpsworld.com/gpsworld/

GIS software downloads

GPS Software Downloads: http://www.geocomm.com/channel/gps/software/

Attachment 10–1

Criteria for Selecting a GPS Receiver

Choosing a GPS

The following criteria, taken from the Point of Beginning website, serve as a template from which GPS receiver requirements and software products can be assessed. For additional information refer to http://www.pobonline.com/.

Program Name	GIS X
Manufacturer/Distributor	Company X
Manufacturer's Phone Number	
Receiver Model	
Receiver tracking characteristics	
- L1 only, C/A-Code	
- L1 codeless and L2 codeless	
- Other	
Max. number of satellites tracked simultaneously	
Number of receiver channels	
- Independent?	
- By multiplexing?	
- Fast-sequencing?	
If multiplexing or fast-sequencing, maximum number of satellites tracked per channel	
Can a satellite be swapped with another satellite without affecting lock-on in other channels?	
When four satellites are tracked, does the receiver display provide:	
- Satellite tracking status?	
- Coordinated Universal Time (UTC)?	
- Three-dimensional positions?	
- Velocity?	
- Dilution of precision?	
Does the receiver accurately measure and output:	
- Code Phase?	
- Carrier Phase?	
- Integrated Doppler?	
- Pseudo-range data?	
- Full wavelength L2 carrier-phase data when A/S is implemented?	
- Cross-correlated Y2 - Y1 pseudoranges?	
- Other dual-frequency technology	
On what medium is observed data recorded during the	

observations?	
- Cassette?	
- Disk?	
- Internal memory?	
- Other medium?	
If recorded in the internal memory, what medium is available to transfer to after the observations end?	
Can the receiver perform real-time Differential GPS (DGPS)?	
- Is the receiver capable of picking up signals from U.S. CoastGuard beacons?	
- Is the receiver capable of picking up signals from the commercially available DGPS service companies?	
To lock on the GPS signals, does the system require a reference position?	
- If "Yes," how accurate (e.g., 100m, 30km, etc.):	
- Horizontal position?	
- Vertical position?	
- How long does it take between when system connected to antenna is turned "On" and there is successful lock-on the first satellite? (seconds)	
- for all available satellites? (seconds)	
Can the system be preprogrammed or initialized with session observing criteria at an office before going to the sites?	
- If "Yes," can the system be programmed with information for multiple sessions?	
Size: (H" x W" x D")	
Weight: (lbs.)	
Is antenna included in the weight?	
ANTENNA	
Type:	
- Other?	
Is antenna built into the receiver?	
- If the answer is "Yes," is antenna removable?	
POSTPROCESSOR	
Is a system available for postprocessing data in the field?	
- If "Yes," is the processor IBM PC compatible?	
SUGGESTED LIST PRICE ($)	
- Receiver?	
- Antenna?	
- Post processing hardware and software?	

- Post processing software only?	
Warranty (months)	
- Receiver?	
- Antenna?	
- Post processing hardware?	

Attachment 10–2

The Global Positioning System – An Overview

The Global Positioning System (GPS)

An Overview

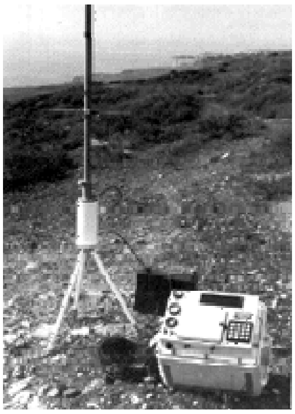
The following material is taken from the Surveyors Board of Victoria, who maintain a dedicated web area dealing with 'Surveying using the Global Positioning System' refer: http://www.surveyorsboard.vic.gov.au/gps.htm (Material has been included in this Toolkit with the permission of the Surveyors Board of Victoria).

The NAVSTAR (NAVigation Satellite with Timing And Ranging) Global Positioning System (GPS) is a military controlled venture designed for positioning, navigation and timing purposes. Although not designed for surveying, the use of interferometric techniques has enabled surveyors to use the satellite signals to great effect. The first GPS satellite was launched on the 22nd February, 1978 and became operational on the 29th March, almost one month later. As the end of the millennium approaches, more than twenty years since the first satellite launch, GPS promises to become one of the most widely used systems for marine navigation, aviation, vehicle tracking and management, recreational activities and surveying. The use of GPS is seen as an extension, *not a replacement*, to the surveyors range of equipment which, when combined with a total station, level and steel tape, enable the surveyor to use the most efficient positioning tool available for their client.

In the modern business environment, it is often difficult to keep up to date with changing technology. In the surveying industry, changes in microchip technology have seen electromagnetic distance measuring equipment (EDM), electronic total stations (ETS), digital levels, computer aided drafting and design (CADD) software, computer based engineering and mapping software, and now GPS, all become a reality in the surveying profession. Keeping abreast of the rapid changes in technology can be a full time job in itself, let alone trying to stay ahead of the competition in the highly competitive surveying industry.

Use of the Global Positioning System requires specialised equipment, data collection techniques and data processing algorithms. This document aims to provide a theoretical and practical foundation for surveyors as they try to embrace GPS technology and integrate use of GPS equipment into their daily business operations.

History of Satellite Positioning - The Transit System



The use of satellites for surveying purposes first became a practical reality with the development of the Transit system by the United States Navy. The Transit system used Doppler measurements from seven satellites arranged in polar orbits to determine position and trajectory. The orbits of the seven satellites form a circular birdcage effect with an orbital altitude approximately 1100km above the surface of the Earth.

The system was used for geodetic surveying applications in the 1970's and 1980's. However, due to the limited number of satellites, positioning was performed by observing for long periods. The low altitude of the satellites also meant that satellites were not visible at all times and gaps of 90 minutes between satellite passes had to be contended with. Typically, several satellite passes were required to position marks accurately on the ground.

Another limitation of the Transit system was also caused by the low orbital altitude of the satellites. The 1100km orbital altitude resulted in large forces, which are difficult to model, disturbing the satellite orbits. As a result, the accuracy of position estimates was not as high as ideally required for many applications. Regardless, the development and use of the Transit system provided a solid foundation from which to develop the Global Positioning System. The primary limitations of the Transit system that have been rectified in the development of GPS include the ability to now observe 24 hours per day and to coordinate features to a higher accuracy. The former has been achieved by increasing the number of satellites, the latter by placing the GPS satellites in significantly higher orbits than the Transit satellites.

The Global Positioning System

The Global Positioning System (GPS) is a space based radio-navigation system designed to satisfy the requirements of the United States Department of Defence (DoD). The system consists of satellites and their signals, a series of control stations which monitor and maintain the satellites, GPS receivers which are capable of recording the satellite signals and users who coordinate themselves using observation techniques designed to achieve certain levels of accuracy. Many texts discussing the use of GPS refer to these components as the three systems; space, control and user.

In order to use the GPS satellite transmissions for surveying purposes, a number of concessions must be made. First, a receiver capable of precise measurements is required. Such a receiver may cost in excess of $35,000 as compared to a lower accuracy receiver which may cost several hundred dollars. Second, more than one receiver must be used. The use of more than one receiver is termed differential operation and is mandatory for all surveying applications of GPS technology. Third, specially designed observation techniques must be used. This is to facilitate resolution of an integer bias that exists in the precise portion of the GPS signal. Finally, sophisticated mathematical algorithms are required to convert the satellite measurements to the user position. In addition to these requirements, the system is only useable in locations with a clear, unobstructed view of the sky. This obviously restricts the use of GPS in urban areas and for underground work.

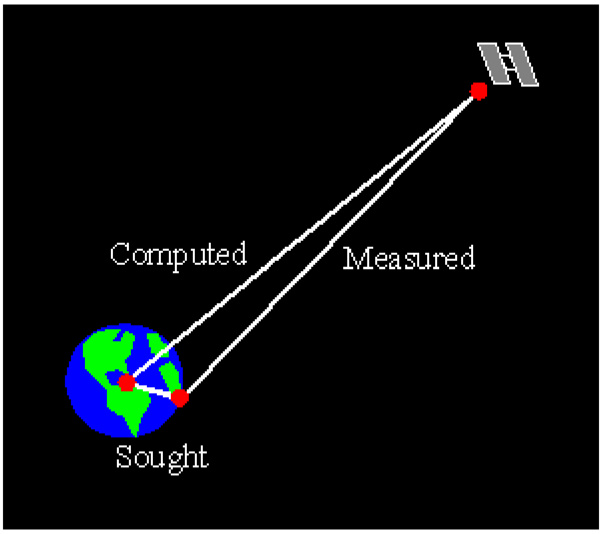
There are, however, a number of advantages of surveying using the GPS satellites. The system has been designed to provide continuous satellite coverage, which can be used at all times of day (and night). This provides additional flexibility when it comes to designing surveys. The satellites transmit L-band microwave signals which are not significantly affected by poor weather conditions. As a result, GPS equipment can be used in all types of weather. The system is also global and can be used in any location. Perhaps the greatest advantage of GPS is that the two receivers, required for differential operation (commonly termed the *reference* and *rover* in kinematic applications), can be separated by several tens of kilometres and do not require line of sight intervisibility. This enables surveyors to coordinate marks to survey accuracy over distances which previously may have required several days of traverse measurements. It is this feature that makes GPS so attractive for control survey work. No longer do marks need to placed on top of difficult to access hills, they can now be placed where they are needed. The use of GPS for control survey work is rapidly becoming routine.

The use of GPS technology introduces several concepts which are not used in terrestrial surveying applications. However, surveyors with a basic understanding of geodetic positioning will have little trouble in extending that positioning scenario to satellite use. Surveying with GPS is little more than a distance resection problem with the satellites acting as, albeit moving, control points.

Basic Positioning Concept

The basic positioning concept used by the Global Positioning System is illustrated by a diagram comprising a satellite which orbits the Earth and continuously transmits signals, the Earth with its geocentre defined as the centre of mass, and a user on the Earth with a receiver capable of interpreting the broadcast satellite signal.

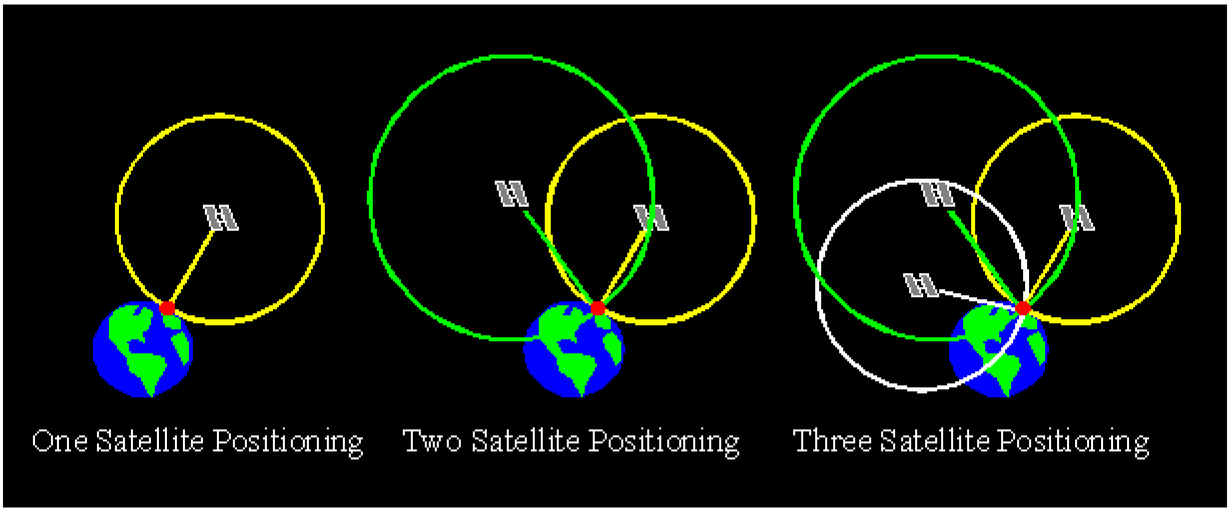
The position of the user can be represented by the vector from the Earth's geocentre to the receiver on the Earth's surface. This vector is three dimensional and is unknown. The vector from the Earth's geocentre to the satellite defines the three dimensional position of the satellite and is determined using the ephemeris transmitted as part of the satellite signal. The third vector is between the user on the Earth and the satellite. The magnitude of this vector, in other words, the one dimensional distance from the receiver to the satellite, is measured by the receiver.



If one satellite is observed, the user position lies somewhere on a sphere with radius equal to the distance to the satellite.

If a second satellite is simultaneously observed, the user position lies on a circle defined by the intersection of two spheres with radii equal to the two measured distances.

If a third satellite is introduced, the receiver position can be determined uniquely by the intersection of the three spheres with radii equal to the measured distances to the satellites. The use of three satellites simultaneously facilitates calculation of the three dimensional position of the receiver. Therefore, GPS is more than just a two dimensional positioning system, height information is also computed.



The development of the GPS signal structure required the system to be passive in order to protect the position of military users. To facilitate this, the satellite signals are generated by precise atomic clocks aboard the satellites. The user on the Earth utilises a receiver which generates internal signals, however, a less precise quartz crystal clock is used. The distance between the satellite and receiver is measured by aligning the satellite signal and the internally generated signal. The measurement relies on the satellite and receiver clocks being synchronised. A timing error of one microsecond (0.000001 seconds) results in a distance error of approximately 300m. Therefore, the measurement of time is a vital component of the GPS system. To eliminate the timing error from the computed receiver position, a fourth satellite is observed. This enables the three position components and the mis-alignment of the satellite and receiver clocks to be determined. All surveying applications of GPS technology require a minimum of four satellites to be simultaneously observed to obtain position estimates to a suitable accuracy.

Timing Reference System

The maintenance of precise time is a key element in the effective use of the GPS system. The satellites generate signals which are referenced to a specific epoch. The time is kept by atomic clocks, or *oscillators*, aboard the satellites. These clocks are also used to generate the signals transmitted by the satellites. The receivers used by surveyors on the Earth also house clocks which generate replica versions of the satellite signals for internal comparison purposes. To be able to use the satellite signals effectively, the time component of the measuring process must be regulated to a common time frame. The synchronisation of time in the entire GPS positioning process is paramount, therefore, a brief description of the timing reference system used by GPS is warranted.

A complete description of the GPS timing reference can be found at www.usno.navy.mil (Web), however, the underlying basis of the system is referenced to the second as defined by an atomic time scale. The United States Naval Observatory (USNO) monitors GPS time (GPST) as defined by the oscillations of an atom. The GPS satellite clock correction parameters are developed to correct the atomic clocks on board the satellites to this time frame. Universal Time Coordinated (UTC) is another atomic time scale, which is modified by inserting periodic leap seconds to keep

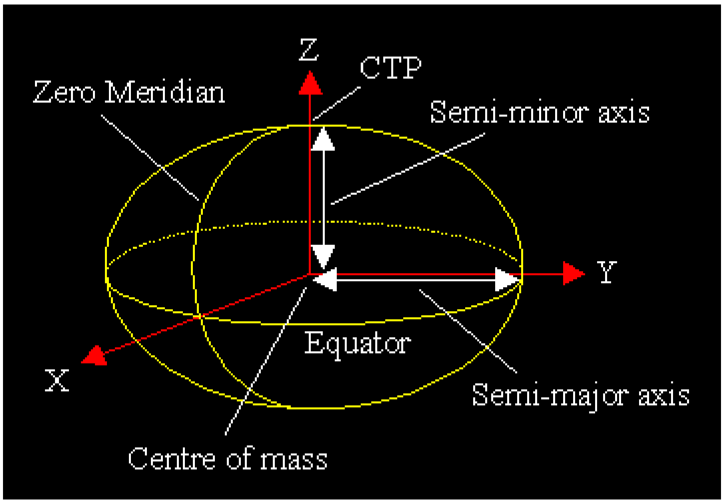
UTC close to Universal Time (UT). UT is governed by the Earth's rotation and the position of the sun (this is wrist watch time). Therefore, the offset between GPS time and UTC will alter by one additional leap second when the periodic adjustments are made to UTC. An adjustment is expected at the end of June, 1997 which will result in GPS and UTC differing by 12 seconds.

The time in the GPS system is referenced by the number of seconds in one week and a week number. GPS time was officially initialised at zero hours on January 6th, 1980. At this epoch, the difference between GPS time and UTC was zero. The week number has incremented every 604,800 seconds since this time. In the GPS signal specification, the week number is stored as a 10 bit integer value. The maximum value that the week number can have in an integer of this size is 2^{10} = 1024 weeks. This maximum value can be expected to "roll-over" before the end of the millennium. Users should be aware of this occurrence and check to see that their equipment and software are not affected by this week number roll-over.

For surveying applications, the maintenance of GPS time is a function performed by the GPS receiver and processing software. As a result, there is little intervention required by the user with regards to the elements of time. One point of interest regarding the time scales, the GPS satellite clocks are essentially keeping GPS time as defined by the USNO. After the clock correction parameters are applied, all satellites are synchronised to this highly accurate time frame. The GPS receiver uses an inexpensive quartz crystal oscillator, however, the observation of at least four satellites is required to compute the three dimensional user position and the receiver clock synchronisation error. Therefore, once the satellites are tracked and position computed, the receiver clock has effectively been transformed into an atomic clock as it is now synchronised with the satellite clocks. This is the manner in which precise time can be transferred using GPS equipment.

Coordinate Reference System

There are two reference systems employed by the Global Positioning System, the atomic GPS time reference as maintained by the United States Naval Observatory (USNO), and the coordinate reference system which has been defined by the Defence Mapping Agency (DMA). **The coordinate reference system used by the GPS system is the World Geodetic System 1984 (WGS84**). This system is a geocentric based coordinate system with the origin of the defining spheroid located at the Earth's centre of mass. The spheroid has a semi-major axis of 6,378,137.0m and an inverse flattening of 298.257223563. The semi-minor axis is computed as 6,356,752.3142m. These parameters are the same



as those used to define the Geodetic Reference System 1980 (GRS80) spheroid.

The semi-major axis and flattening define the shape of the WGS84 spheroid. The centre of the spheroid is fixed to the Earth's centre of mass. The direction of the three Cartesian axes need to be defined to constrain the spheroid in space. The Z-axis is defined as passing through the Conventional Terrestrial Pole (CTP) at epoch 1984.0 as defined by the Bureau International de l'Heure (BIH). The X-axis is defined as being the intersection of the WGS84 reference meridian plane and the plane of the CTP's equator. The WGS84 reference meridian passes through Greenwich and is specifically defined by the BIH zero meridian at epoch 1984.0. The Y-axis completes a right handed, Earth Centred, Earth Fixed (ECEF) orthogonal coordinate system, measured in the plane of the CTP equator, 90 degrees east of the X-axis.

The position of the satellite at the instant of measurement is required in order to compute the unknown receiver position. The broadcast ephemeris is a set of orbital parameters that enable the Cartesian coordinates of the satellite to be easily computed. The resultant position of the satellite is referenced to the WGS84 coordinate datum. Therefore, the position estimates derived from GPS measurements are also referenced to the WGS84 datum. **In order to obtain coordinates in other systems, such as the Australian Geodetic Datum (AGD), users must transform their GPS coordinates from WGS84 to the new system.** As the next millennium approaches, Australia is moving towards a new geodetic datum, termed the Geocentric Datum of Australia 1994 (GDA94). This new datum is compatible with WGS84, therefore, users will directly obtain GDA94 coordinates from their GPS receivers. This will eliminate the need to perform transformation computations to integrate GPS observations into the GDA94 coordinate system.

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