Oregon Department of Transportation GNSS Guidelines

2014

Geometronics
OREGON DEPARTMENT OF TRANSPORTATION

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REVISION HISTORY

Due to the nature of GNSS, techniques and guidelines will evolve and those changes will be reflected in future versions of this document.

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Introduction

This document is produced by ODOT's Geometronics unit and is designed as a guide for ODOT crews to understand the methodology for GPS surveys within the agency. This is not a step-by-step technical document nor does it address all the complexities of GNSS. Many methods defined herein are a product of years of applied experience of a very dynamic system. Equipment and infrastructure have advanced greatly since inception and continue to evolve. This document is a living document that addresses the state of the art and will evolve with the technology. Crews are encouraged to embrace the system, use it with care and continue to stay current with its capabilities.

This document does not describe the Oregon Coordinate Reference System or State Plane Coordinates (SPC) used by the Oregon Department of Transportation (ODOT). *http://www.oregon.gov/ODOT/HWY/GEOMETRONICS/Pages/ocrs.aspx*

The use of the NAVSTAR Global Positioning System (GPS), which is the U.S. part of the Global Navigation Satellite System (GNSS), for surveying purposes has added great flexibility and accuracy to the traditional survey. The need for line-of-sight between the known and unknown point has been eliminated, and the nominal working distance between the two has been significantly increased. However, there are still limitations that have to be accounted for. The GPS antenna must have a relatively unobstructed view of the sky and the nature of the GNSS signals makes them susceptible to interference and distortion. For very short lines, typically under 100m, the total station has better relative accuracy. The guidelines listed in this document aim to expose the benefits of GNSS while limiting the potential errors that are encountered with this technology.

Although the GNSS system has been designed to be as accurate as possible, it is critical to understand the error inherent in the system. Whether the survey is Static or Dynamic, error exists when a GPS receiver makes a ranging measurement to a GPS satellite. Survey-grade GPS requires Differential Correction to eliminate the majority of error in the GNSS signal. Differential Correction requires a second GPS receiver (a base) collecting data at a stationary position on a known point. The process of carrier phase double-differencing calculates the baseline vectors (ΔX, ΔY, ΔZ) between the two stations and these vectors are used to compute the position of the unknown site. See Table 1 for the typical GNSS error budget, User Equivalent Range Errors (UERE), that Differential Correction addresses:

GNSS Error Budget (U.E.R.E.)

Source	Uncorrected	With Differential
Ionosphere	0-30m	Mostly Removed
Troposphere	0-30m	Mostly Removed
Signal Noise	0-10m	Removed
Ephemeris Data	1-5m	Removed
Clock Drift	0-1.5m	Removed
Multipath	variable	Not Removed but Reduced

Table 1

This table does not account for setup error

See Glossary for further explanation of error sources

A general requirement for all GNSS survey methods to make sure that the equipment used in the field is calibrated and in good working order. The GPS receiver must be dual frequency (L1/L2) and have the correct absolute antenna calibration developed by the National Geodetic Survey (NGS). As with all surveys, especially high accuracy static surveys, level vials and optical plummets should be calibrated prior to the start of a project.

GNSS Horizontal Project Control

Static Survey Method

Static GPS surveying was the first method used in the field and it continues to be the primary technique used for control today. Static survey allows for systematic errors to be resolved when high- accuracy positions are required through simultaneous data collection at two stationary receivers for an extended period of time (typically 1-5 hours) and is usually reserved for baselines of 20km to several hundred km. The long occupation times are designed to overcome the effects of local multipath on the antenna by observing data under a longer duration of changing satellite geometry. Using this method requires careful design of the control network and an observation schedule for the coordination of receivers. Post-processing and a least squares adjustment are required to generate the final coordinates.

Static Baselines

A GNSS baseline is created between two points that are *simultaneously* occupied by GPS receivers. Through baseline post-processing, a vector is computed. The vector establishes the relative 3D coordinate differences between both points. In diagram form, the baseline is usually represented by a straight line between the two points (Figure 1). With 3 receivers observing simultaneously there are 3 possible baselines; and 4 receivers will produce 6 possible baselines. However, some of those baselines are considered to be *dependent* (trivial) because they are derived from the same observational data as *independent* (non-trivial) baselines. In other words, once the independent baselines have been resolved by the processing software, there are no more "unknowns" left. Processing the remaining dependent baselines merely adds false redundancy and causes the adjustment statistics to be overly optimistic. The number of independent baselines available for any single GNSS session can be easily calculated. If "n" represents the number of GPS receivers that are simultaneously observing, then "n-1" is the number of independent baselines available. Therefore, 4 receivers would produce 3 independent baselines (Figure 1). During post-processing the surveyor can then designate which baselines are trivial or non-trivial for that observation session.

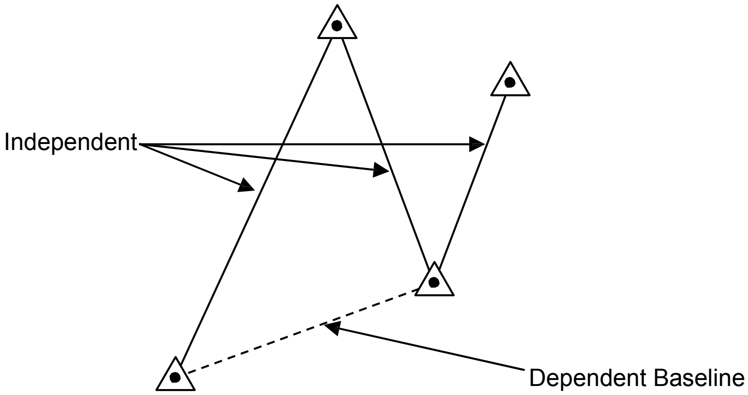


Figure 1

Static Network Design

The geometry of a network will determine how errors are distributed, and subsequently, the quality of final network coordinates. The selection of observation baselines is therefore very important. The dependent baselines must not be used in the final network adjustment.

Each network point needs to be connected to at least two other network points, and be occupied at least twice using an independent setup. This requires off-leveling the tripod, re-measuring the H.I. using height hook in meters and measuring again in feet to the ARP (Antenna Reference Point) as a blunder check.

The network should consist of a series of interconnected, closed loops. Avoid having a "hinged" network (Figure 2). Connect all adjacent stations using the "20% rule." This rule states that an independent baseline should be measured between points that are closer than 20% of the total distance between those points traced along existing baselines (Figure 2).

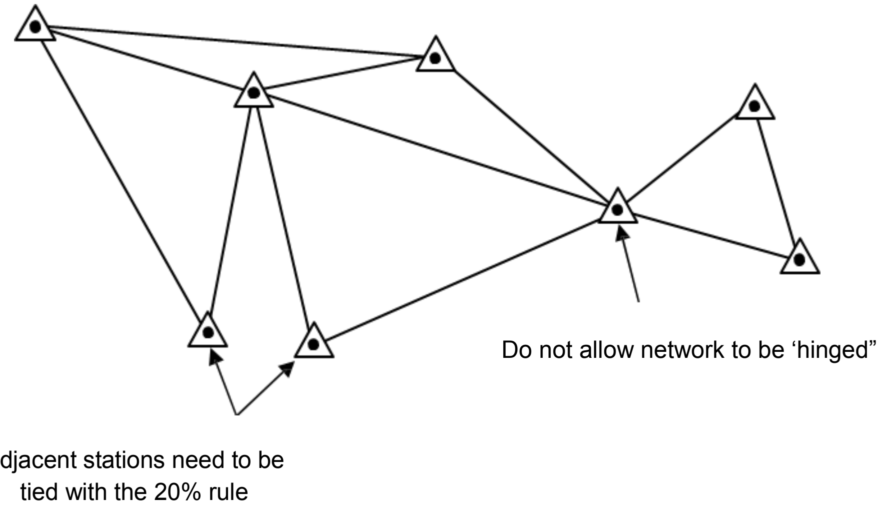


Figure 2

At a minimum, <u>two</u> geodetic reference stations must be used to control the network. They both must be an "active mark." This means that they are part of, or adjusted to, the National Geodetic Survey's (NGS) CORS network or the Oregon Real Time GPS Network (ORGN). The coordinates for the reference station must be on the same datum, NAD 83, and should be a part of the same realization and epoch. If the project has previously established geodetic control, ties to the CORS or ORGN may not be necessary. Further information for the CORS and ORGN at:

http://geodesy.noaa.gov/CORS/
http://www.oregon.gov/ODOT/HWY/THEORGN/Pages/Theorgn-Home.aspx

Ties from a CORS or ORGN station should be situated to provide a strong geometric figure, with respect to the center of the project. NGS OPUS (Online Positioning User Service) or OPUS Projects may be used to process "passive mark" coordinates relative to the CORS network in the current NAD 83 realization. The use of OPUS is expanded upon later in the document.

Mission Planning

Office

1. Roughly locate points on a map for desired network design considering access
2. For each session draw independent baselines to be observed. Consider color coding to correspond to session.

3. Referring the satellite almanac and mission planning software, choose appropriate observation times that avoid DOP spikes.
4. Schedule observation times in a way that's understandable for crews to follow.

Field Reconnaissance

1. Determine the location and sky visibility of existing and new stations.
2. Record sky visibility chart (obstruction diagram) for all points.
3. Flag and mark points for easy identification by crews.
4. Consider right-of-entry laws and make necessary accommodations.
5. Plan logistics for movement between points

Field Procedures

Accurate GNSS observations depend on clean and unaltered signals. Nearby objects like buildings, trees and vehicles can reflect the GNSS signals (multipath) and cause measurement errors. Strong radio transmissions from handheld radios, radio towers or power lines may also degrade the GNSS signals. Avoid such areas when possible. An open view of the sky allows more satellites to be tracked by the receiver.

Back-to-back observations on the same point should be considered "independent." In order to achieve the proper second occupation the setup should be off-leveled, the tribrach turned 120°, and re-leveled with a new HI (height of instrument) noted. Taking these steps will help to reduce systematic error and blunders. The time it takes to off level and re-level is enough time gap between observations. The network will be adjusted through least squares which negates the need for an extended time period for constellation change.

Blunders in antenna height measurements are the most common source of error in GNSS surveys. HI blunders are critical to detect because all GNSS surveys are three dimensional whether the vertical component will be used or not. Antenna height measurements determine the height from the survey monument mark to the Antenna Reference Point (ARP) of the GPS antenna. With the exception of fixed-height tripods and permanently mounted GPS antennas, independent antenna heights should be measured in both meters and feet at the beginning and end of the observation session. A Leica height hook shall be used for the meter measurement and a tape to the ARP for the foot measurement. Antenna height measurements in both meters and feet should check to within +/-1.5mm.

For each occupation take thorough notes including:

- Start and stop time
- A brief description of the mark including swing ties to nearby objects
- Antenna height. Such as "1.184m with Leica height hook" or 4.25′ slope height to ARP with tape. The difference between the height hook and the ARP is .360m and is normally compensated for in the instrument's survey software.

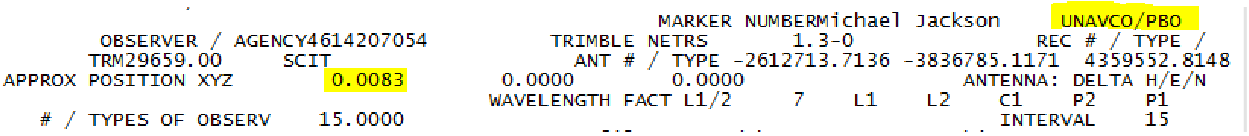
For each station collect:

- A digital close-up photo of the mark so stamping is legible and a photo of station from about 30′ out to include horizon and vicinity.
- A detailed description including measurements to reference objects.
- Make a sketch in the field book of the general location of network points and their relation to each other.

Office Procedures

The post-processing software must be capable of performing a constrained least-squares adjustment and producing the appropriate statistics. Analysis of the baseline residuals, error ellipses, degrees of freedom, etc. will determine the quality of the final coordinates. The final coordinates for all points must come from a fully constrained adjustment (2 or more points held fixed).

Upon import of observation data, care must be taken to ensure that the correct antenna type and height are included in the file. LGO (Leica Geo Office) interprets the header that is included with the RINEX file and on certain PBO (Plate Boundary Observatory) stations a vertical offset is applied (Figure 3). Be aware and correct for this offset by setting the "Height Reading" field to zero for a correct station height.
http://www.oregon.gov/ODOT/HWY/theorgn/Pages/Rinex.aspx



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                                   MARKER NUMBERMichael Jackson      UNAVCO/PBO
    OBSERVER / AGENCY4614207054          TRIMBLE NETRS       1.3-0             REC # / TYPE /
   TRM29659.00      SCIT                   ANT # / TYPE -2612713.7136 -3836785.1171  4359552.8148
APPROX POSITION XYZ          0.0083       0.0000         0.0000                 ANTENNA: DELTA H/E/N
                                          WAVELENGTH FACT L1/2      7     L1     L2     C1     P2     P1
  # / TYPES OF OBSERV     15.0000                                                INTERVAL     15
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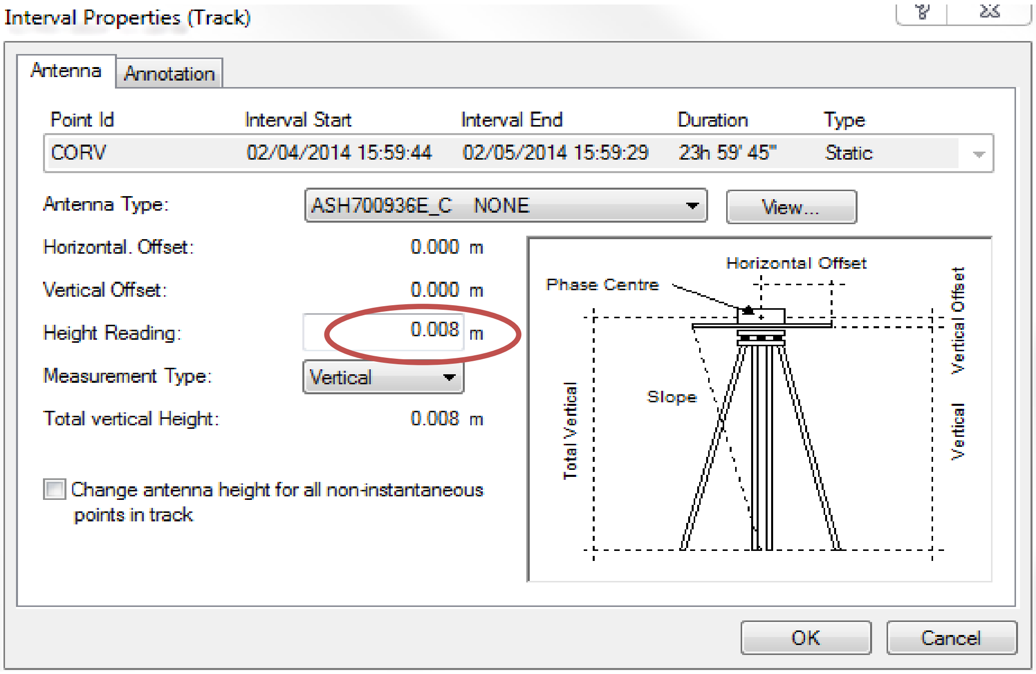


Interval Properties (Track)

Point Id	Interval Start	Interval End	Duration	Type
CORV	02/04/2014 15:59:44	02/05/2014 15:59:29	23h 59' 45"	Static

Antenna Type: ASH700936E_C NONE

Horizontal. Offset: 0.000 m

Vertical Offset: 0.000 m

Height Reading: 0.008 m

Measurement Type: Vertical

Total vertical Height: 0.008 m

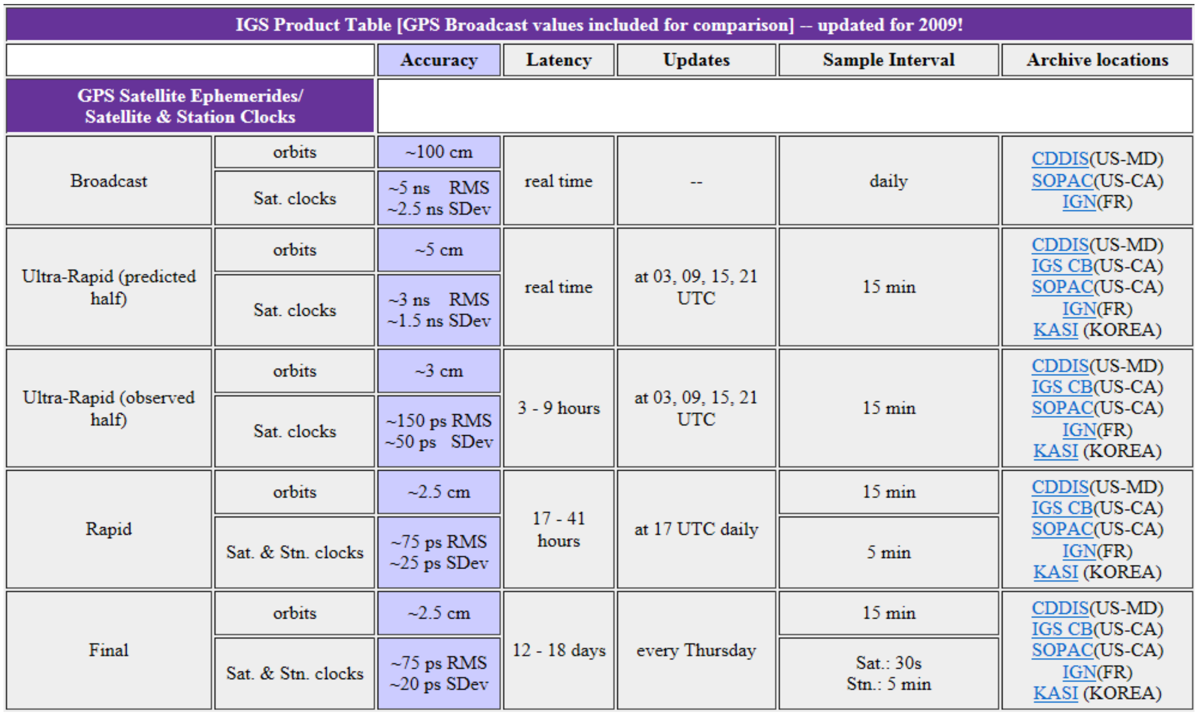
☐ Change antenna height for all non-instantaneous points in track

Figure 3

A fixed integer solution is required for all baselines processed. Most software that processes GNSS observations will try to determine the integer ambiguity of the satellite signals. The integer ambiguity is simply the unknown number of full wavelength cycles that exist between the antenna and the satellite. When the integer ambiguity is "fixed" or "resolved," then the software has calculated the exact number of cycles. Otherwise, the final coordinate solution is a "float" solution. Noisy signals or short occupation times will prevent the ambiguities from being fixed.

Problematic baselines may occur even with properly occupied points. Look for cycle slips in the baseline data; these will show up as breaks in the graph from a particular satellite. Cycle Slips occur with a loss of lock on a particular satellite. Possible causes of cycle slips are obstructions, low signal strength, higher powered nearby radio signals, etc. If several breaks occur eliminate the satellite and re-process the baseline. Primary quality checks to look for are float solutions and elevated position + height RMS values in LGO. Consider removing lower quality satellite signals by raising the baseline processing mask then reprocessing and don't include float solutions in least squares solutions.

In order to get an accurate coordinate, the orbit information for the GPS satellites must be known. This information is known as the ephemeris. A predicted ephemeris is broadcast from each satellite. The broadcast message contains orbit parameters that *predict* where the satellites will be for the next several hours. However, for most static observation post-processing, a more accurate "observed" ephemeris should be used. The observed half of the Ultra-Rapid ephemeris is sufficient enough for most project control work. See Table 2 for ephemerides comparisons:



IGS Product Table [GPS Broadcast values included for comparison] -- updated for 2009!

		Accuracy	Latency	Updates	Sample Interval	Archive locations
GPS Satellite Ephemerides/ Satellite & Station Clocks						
Broadcast	orbits	~100 cm	real time	--	daily	CDDIS(US-MD) SOPAC(US-CA) IGN(FR)
	Sat. clocks	~5 ns RMS ~2.5 ns SDev				
Ultra-Rapid (predicted half)	orbits	~5 cm	real time	at 03, 09, 15, 21 UTC	15 min	CDDIS(US-MD) IGS CB(US-CA) SOPAC(US-CA) IGN(FR) KASI (KOREA)
	Sat. clocks	~3 ns RMS ~1.5 ns SDev				
Ultra-Rapid (observed half)	orbits	~3 cm	3 - 9 hours	at 03, 09, 15, 21 UTC	15 min	CDDIS(US-MD) IGS CB(US-CA) SOPAC(US-CA) IGN(FR) KASI (KOREA)
	Sat. clocks	~150 ps RMS ~50 ps SDev				
Rapid	orbits	~2.5 cm	17 - 41 hours	at 17 UTC daily	15 min	CDDIS(US-MD) IGS CB(US-CA) SOPAC(US-CA) IGN(FR) KASI (KOREA)
	Sat. & Stn. clocks	~75 ps RMS ~25 ps SDev			5 min	
Final	orbits	~2.5 cm	12 - 18 days	every Thursday	15 min	CDDIS(US-MD) IGS CB(US-CA) SOPAC(US-CA) IGN(FR) KASI (KOREA)
	Sat. & Stn. clocks	~75 ps RMS ~20 ps SDev			Sat.: 30s Stn.: 5 min	

Table 2

OPUS GPS Surveys

NGS OPUS (Online Positioning User Service) provides access to high-accuracy National Spatial Reference System (NSRS) coordinates. To process an OPUS position the user uploads a static data file collected with a survey-grade GPS receiver and obtains an NSRS position via email. For ODOT, the primary applications of OPUS static would be to establish initial control in remote locations where CORS/ORGN stations are not readily available or to update coordinates of a passive mark. Another option would be to obtain an OPUS solution on a mark at either end of a project tied together by a terrestrial network. OPUS would not be used to establish the entire network because the points would have no direct baseline measured between them, therefore a least squares adjustment would not be possible. Visit the OPUS website for recommendations on establishing and accepting a quality mark.

Shared solutions within NGS OPUS provide an easy way to update the coordinates of a mark into the future. The service will automatically update the coordinates of the point as the NSRS changes realizations of NAD 83 through time. When uploading a 4hr+ GNSS data file to OPUS select "share my solution" and fill out the required details of the mark along with photos. NGS will store and update the coordinates of the mark through time and will use it to strengthen future models.

OPUS Projects is another online service provided through the NGS that allows baseline processing, least squares adjustment and publishing of multiple stations over multiple days. Because of the complexity of the service, access is limited to those who complete an OPUS-Projects Manager's Training workshop.
http://www.ngs.noaa.gov/OPUS/

Summary of GNSS Static Project Control Specifications

Specification	**Static**
-Network-	
Minimum number of horizontal reference stations for control (CORS, ORGN)	2
Number of verified vertical reference stations for control	1
Minimum ties coming into each station	2
Minimum number of independent occupations per station	2
Minimum time between station occupations	N/A
-Equipment-	
Minimum number of receivers	2
Antenna Setup	tripod
-Field Procedure-	
Minimum satellite elevation mask	10°
Epoch interval for observations	5"
Minimum number of observed satellites	4
Maximum GDOP/PDOP value during station observations	GDOP 8 PDOP 6
Minimum observation time: Baselines <5km	20min*
Baselines 5km to 10km	30min*
Baselines 10km to 15km	45min*
Baselines 15km to 30km	1hr*
Baselines >30km	2hr*

Table 3

Recommended times. Additional time may be needed to fix integers.

Real-Time Kinematic

Single-Base Station RTK Surveys

Conventional RTK GPS surveys are kinematic (moving) surveys that are performed with a data transfer link via cellular data or radio between a reference GPS unit (base station) and rover unit(s). The rover coordinate is differentially corrected based on the known coordinates of the base. A solution is derived as a product of a single baseline vector from the base station to the rover. Baseline length between base and rover is limited to a maximum of 10km to avoid increased atmospheric error. An ORGN station can be used as a single RTK base, thus avoiding the expense and possible errors of a temporary base; however, the 10km baseline limitation still applies. Initialization is needed at the rover to fix the integer ambiguities of the baseline between the base and rover. Typically only a few seconds is needed for initialization, then real-time coordinates can be used in the field for jobs such as construction staking, topo collection, and monument search.

The proper location of the base receiver is critical to a successful single-base survey. It should be located in an area that is mostly free of multi-path and has good visibility with at least three clear quadrants of sky. The radio link is also important to maintain and may involve a tall antenna mast or location that is generally higher than the area surveyed. In certain sites a repeater may be necessary to maintain radio contact, especially in areas with varied topography.

The base can be started over known control or has the ability to take a single epoch “here” position that provides Latitude, Longitude and ellipsoid height for the point. The “here” position is good enough to begin RTK work. Static data is logged at the base while RTK work is underway for later post-processing.

Double measurement of the base height is required to ensure blunders are avoided. The base should also be differentially leveled where the vertical component is required The rover setup uses a locking fixed height rod, usually 2m in height, and is equipped with a bipod if double occupations are to be collected.

Multi-Base Real-Time Network Surveys (MAX)

In addition to single-base RTK surveys, real-time surveys with the Oregon Real-Time GPS Network can offer a multi-base network solution. This multi-base network solution (Master AuXillary) is the preferred way to use the ORGN. The ORGN active stations send measurement data to the central server system, which processes the data and monitors the integrity of the network. This also allows for modeling of GPS errors over the entire network

area. Network error modeling virtually eliminates the distant dependent error in a single–base RTK survey, thus allowing for a 35km base-rover distance when using the ORGN. The Rover unit contacts the central server system via the internet by cellular link and receives a unique correction based upon its location in the network. Efficiency is gained when using a real-time network because the only required equipment is a properly equipped rover.
http://www.theorgn.net

The coordinates of the ORGN are derived by aligning to the National Spatial Reference System (NSRS) maintained by the National Geodetic Survey (NGS). They are referenced to the NAD 83 (2011) Epoch 2010.00 datum/adjustment as of March, 2013. This is the same datum/adjustment coordinate base that OPUS produces. NAD 83 (2011) Epoch 2010.00 is the current "realization" of NAD 83, meaning that the coordinates related to the datum shifted slightly from the previous realization [NAD 83 (CORS 96) epoch 2002.00] to account for improved CORS coordinates, tectonic plate movement, and more refined GNSS observations on existing marks. Though the coordinates may shift through realizations, the datum remains fixed as defined by the GRS 80 ellipsoid.

The quick ambiguity resolution (initialization) that RTK offers is not infallible. Local electromagnetic effects and multipath, though rare, can cause an incorrect position to be calculated. An accepted best practice with both methods of RTK is a check shot. Checking in to a known (3D) point before and after the survey helps validate that the reference (base) and the rover are configured properly.

In the case of the RTN, formal "check–in-marks" should be established for the life of the project. An online form is available through the ORGN website that allows users to establish and track their own high quality marks in convenient locations and gives the option to *share solution* within OPUS.
http://www.oregon.gov/ODOT/HWY/theorgn/Pages/Check-in_Mark.aspx

The current ODOT GPS rover receivers used for RTK are GLONASS capable. GLONASS is a Russian constellation of satellites that in certain configurations can augment the solution from the U.S. GPS constellation. The future and stability of the GLONASS system is in question, which is why ODOT has not fully adopted its use as part of their standards. There are cases where GLONASS can improve initialization times and help maintain lock in less than ideal GNSS conditions. In order to use GLONASS with RTK the base sending correctors must be GLONASS enabled. Currently the ORGN does not fully support GLONASS, though some stations are enabled and usable with a single base solution.

http://www.oregon.gov/ODOT/HWY/theorgn/Pages/Glonass.aspx

Again, using a single base solution does not provide the user the advantages of a network solution and has the same limitations as that of a single-base RTK survey.

Summary of RTK/RTN Specifications

Specification	Single Base	RTN (MAX)
Base		
Atmospheric modeling	No	Yes
Base antenna setup	Tripod*	N/A
Base height measured meters and feet	Yes*	N/A
Base satellite mask	10°*	N/A
Rover		
Fixed height pole (2m)	Yes	Yes
Maximum distance to base	10km (6mi)	35km (22mi)
Observe 3D check point	Yes	Yes
Maximum GDOP/PDOP during observation	8GDOP/6PDOP	8GDOP/6PDOP
Epoch interval	1 second	1 second
Single Point Position quality (horizontal)	1cm (.03’)	1cm (.03’)
Single Point Position quality (vertical)	2cm (.07’)	2cm (.07’)

Table 4

**N/A if an ORGN station is used as the single-base*

Calibration (localization)

When site calibrating the surveyor must go through a process of deciding which points are outliers by assessing point deltas. This process can be hard for a retracing surveyor to duplicate. It is therefore very important for data continuity to avoid using different calibrations on the same site. For that reason, it is recommended as an alternative to site calibration to utilize as much as possible the Oregon Coordinate Reference System (OCRS) as a horizontal coordinate base. However, a vertical calibration may be required when using the OCRS.

Site calibration is the *transformation* of GNSS WGS 84 coordinates that originate from the satellites to project specific grid coordinates. The project area is calibrated by occupying several monuments external to the project perimeter on the WGS 84 coordinate base. Grid coordinates for these points are loaded into the data collector or office software as control, and then the software performs a rotation, translation and scale to come up with a best fit solution. This best fit solution can be viewed and the deltas at each calibration point assessed.

A vertical calibration is performed similarly and can be used to convert WGS 84 ellipsoid heights to orthometric heights, either with or without the geoid model. The vertical calibration may be a simple vertical shift to match a single elevation or a best fit to four or more benchmarks surrounding the project. Using four benchmarks will show residuals necessary for quality control.

Types of Points

Network

Project control network points are of a durable quality permanently set on the project and are the basis for all future survey work within the project. Monuments set are 5/8″ x 30″ iron rods or rebar with a 1-1/2″ brass cap stabilized horizontally and vertically. In the case where the network is set to reference the centerline, the points must also be witnessed by a carsonite marker or post and paddle. See ODOT Monumentation policy for further details. They form a local network and are typically spread out along the project so that surveyors can set up directly on them to perform their work and infill control from the network. In order to place the network on a geodetic datum, several points are tied to geodetic control stations surrounding the project.

The static observation method is used for establishing network control. See static guidelines in section 1, Pg. 9.

Controlled Strategic

Controlled strategic points are set for the purpose of providing a total station instrument location for mapping, terrain modeling, and monument ties. A controlled strategic point can also be occupied with a total station to propagate control to the strategic point level and should also be of durable quality.

The criterion that qualifies a point to be controlled strategic is that it must be “double tied.” The second tie of the point is to serve as a quality check for the initial tie. A second tie must be executed under unique conditions that serve as an independent check. An independent check is more easily accomplished with a total station that has the ability to occupy, or tie into, separate network control for verification of the initial tie.

Due to the nature of RTK GNSS, an independent check is less clearly defined. With a single occupation there may be a blunder or multi-path in the solution. The surveyor needs to strive to observe a unique satellite constellation to detect the multi-path in the initial tie. GPS satellites complete an orbit in approximately 12 hours, which mean that they pass over any point on the earth about twice a day. A second tie at the 24 hour mark would then be essentially duplicating the conditions of the first. Anywhere between those two time periods there would be a unique constellation available.

The guidelines for double occupation that follow (Table 5) recognize the need for production in the field and allow for enough change in the constellation to detect multi-path. Care must be taken to assess GNSS conditions as a whole. It falls on the surveyor to recognize the amount of multi-path in the solution and decide if a GNSS tie will be sufficient for the mark.

Specification	Double tie RTK
Occupation time under accepted DOP values	10 epochs
Minimum time between observations under accepted DOP values	30 mins
Maximum GDOP/PDOP value during station observations	8 GDOP/6 PDOP
Rover Satellite mask	15°
Single Point Horizontal precision (CQ)	.03′
Single Point Vertical precision (CQ)	.07′
Maximum horizontal difference between occupations	.07′
Maximum vertical difference between occupations	.09′

Table 5

Other points that can be observed with double-tie RTK include:

- Photo pre-marks
- Instrument location for Scan control
- Property boundary, right-of-way monuments
- Government corners including Public Land (PLSS) corners and DLC corners.

Topographic

Topographic points are used to create Digital Terrain Models (DTMs) and tie 3D features for base maps. With a proper RTK survey in place where known points have been checked and point qualities assessed, a single epoch may be taken to collect topo data. Terrain that is considered a “hard surface” is not normally collected using GNSS unless the end product is 2D mapping. Generally, this method is used for bulk collection of terrain data where the position does not have to be re-occupied.

Staked

Staked points are temporary marks used to guide construction activities such as earthwork, grading, and paving and limited inspection. A single epoch occupation is acceptable for these activities, but should not be used for major structure points, final grade stakes and pavement elevations. Use a check-in mark for quality control.

Strategic

This point class cannot be set using GPS. A double tie is necessary when setting all RTK GPS control which is defined by the Controlled Strategic procedure.

Confidence

Currently, confidence points cannot be collected using GPS. See Route Surveying Manual for discussion on Confidence Points.

Project Vertical Control

Normally, project control points receive an orthometric height by means of differential leveling to a nearby bench mark. In cases where there are no bench marks near the project, it may be more efficient to bring in vertical control using GNSS. Due to the inaccuracy of GNSS with regards to the vertical, special guidelines must be followed.

If the nearest bench mark is deemed to be impractical for differential leveling, then GNSS can be used to bring in an elevation. Only one verified bench mark can be used for this purpose so be sure that it's suitable for satellite observations. It is required to verify the bench mark against another by differentially leveling or taking a static observation on the mark and applying the geoid separation to the GPS-derived ellipsoid height as a check. Once verified, using stated static network procedures, a single project control point will receive the GNSS derived orthometric height. That height will be the basis for all other elevations on the project.

Two baselines need to be established between the bench mark and the project control point, with a minimum of 2hours between each session. If the second session falls on a different day make sure it's observed at a different time than the initial session. The ellipsoid heights obtained from the two baselines must agree within +/- 0.1' (3cm). Finally, use the correct geoid model to determine the geoid separation to compute the orthometric height of the project control point. Again, follow previously stated procedures for static occupation.

The geoid is a mathematical model in relation to gravity that simulates a mean sea level surface. GPS receivers as a default, give heights above the reference ellipsoid (WGS84). These are not orthometric heights meaning that water may not flow from one point to another using ellipsoid height alone. When post-processed to get on the NAD 83 (2011) epoch 2010.00 realization, the GEOID12A model can then be applied. A Geoid "separation" can be calculated between the ellipsoid and the geoid to give true ground (orthometric) heights (Figure 4). When the geoid model is applied, heights will be consistent with the NAVD 88 vertical datum. GEOID12A is the most current model and is required on projects on the NAD 83(2011) epoch 2010.00 datum. GEOID09 and 03 should be used with the NAD 83 (CORS 96) epoch 2002.00 realization to achieve NAVD 88 elevations. Understanding the correlation between the Geoid model and datum realization is critical to achieving correct GPS derived heights.

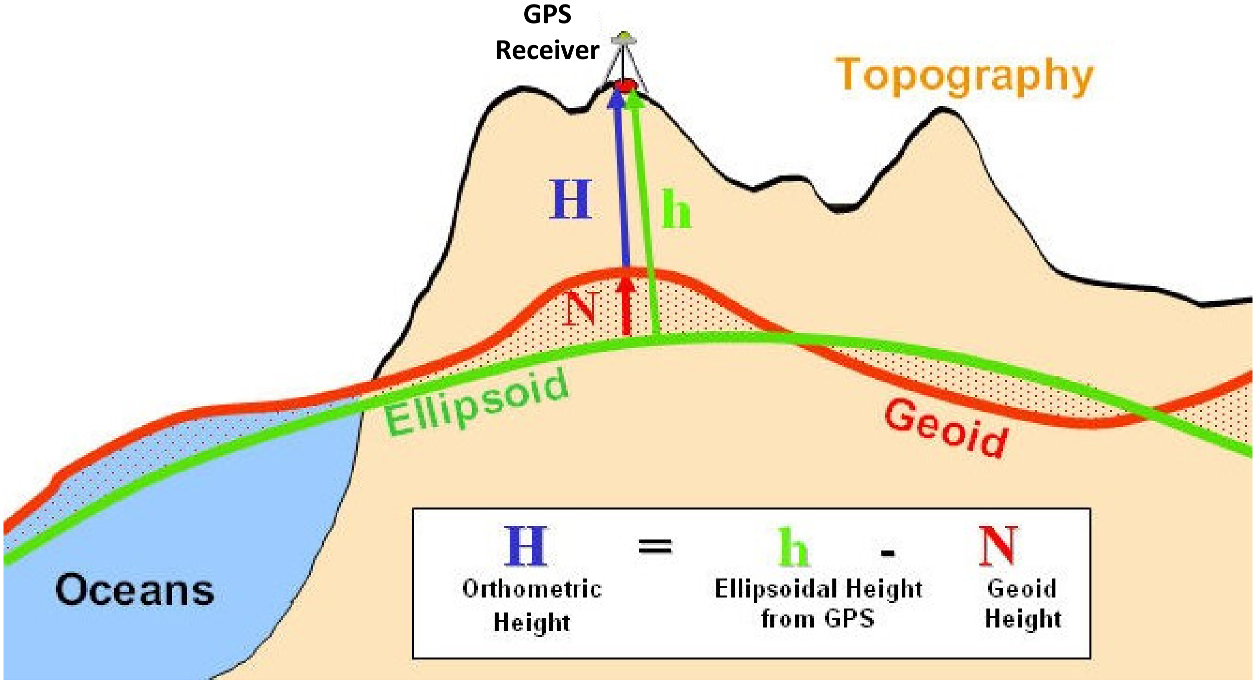


Figure 4

Online References

http://water.usgs.gov/osw/gps

http://www.ngs.noaa.gov/OPUS/about.jsp

http://onlinemanuals.txdot.gov/txdotmanuals/ess/ess.pdf

https://connect.ncdot.gov/resources/Location/Manual%20Documents/Location%20GPS%20Guidelines%202010.pdf

http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.1.pdf

Conversions

1 inch = 25.4mm (international)
1 international foot = 0.3048m
1 mile = 1.6093 km

1 inch = .08 foot
1 minute of latitude ~ 6,076 feet
1 mile = 5280 feet

Glossary

Note: the definitions found below are adapted to fit the intent of this document and may not be as fully complete as those found in the NGS Geodetic Glossary.
http://www.ngs.noaa.gov/CORS-Proxy/Glossary/xml/NGS_Glossary.xml

A

Almanac: A data file that contains the approximate orbit information of all satellites, which is transmitted by each satellite within its Navigation Message every 12.5 minutes. It is transmitted from the satellite to a receiver, where it facilitates rapid satellite signal acquisition with the receiver's by providing the receiver an approximate search area to acquire the satellite's signal

Ambiguity: Carrier phase measurements are made in relation to a cycle or wavelength of the L1 or L2 carrier waves. While the receiver can tag the partial cycle after locking on to a satellite, it cannot directly know the whole number of cycles preceding that tag. This ambiguity of whole cycles must be solved in order to correctly calculate the distance from the satellite.

Antenna Calibration: An antenna calibration is the act of determining the point of reception of the GNSS carrier phase signals. NGS publishes coordinates using a particular set of antenna calibrations. NAD 83 (CORS96) epoch 2002 and earlier datum use a relative calibration. NAD 83(2011) epoch 2010 is defined using absolute antenna calibrations.

> Absolute calibration: Antenna offsets and phase center vartiations are computed independent of a reference antenna.
>
> Relative calibration: Antenna phase center offset (PCO) and phase center variations (PCV) are computed with respect to a reference antenna.

Antenna Phase Center: The electrical point, within or outside an antenna at which the GNSS signal is measured

Antenna Reference Point: The point on the exterior of the antenna to which NGS references the antenna phase center position. It is usually the bottom of the antenna mount.

Autonomous Positioning: A single receiver position relative to a GNSS datum as realized by the satellites. A current civil user can expect better than 10m accuracy under normal conditions autonomously.

B

Baseline: A baseline is a computed 3D *vector* for a pair of station for which simultaneous GPS data have been collected. It is mathematically expressed as a vector of Cartesian Earth Centered Earth Fixed (ECEF) X,Y,Z, coordinate differences between the base and the rover or unknown station

Broadcast Ephemerides: The orbital position sent in the navigation message base on the predicted position of the satellite. This is the orbit information used in all Real Time surveys. Broadcast orbits are the least accurate (1mm for 10km). In order of ascending accuracy, the ultra-rapid, rapid and the final post-fit precise orbits are available after about 10 days.

C

Carrier Phase Ambiguity: The unknown number of integer carrier phase cycles (or wave lengths) between the user and the satellite at the start of tracking.

Constellation: Refers to either the specific set of satellites used in calculation a position or all the satellites visible to a GNSS receiver at one time.

Cycle Slip: A discontinuity of an integer number of cycles in the carrier phase count resulting from a loss of lock in the tracking loop of a GPS receiver.

D

Datum (Geodetic): Simply stated, a geodetic datum is defined by a reference surface, an origin, gravity and a scale. NAD 83 is defined by the Geodetic Reference System 1980 (GRS80) ellipsoid, at an origin near the center of the mass of the earth, with axes oriented through the pole, equator and at right angles, with a scale unit based on the International Meter. The realization of the datum is through monumentation of some sort on, above or below the earth.

Differential Correction: Requires a base station. The base station receiver calculates its position based on satellite signals and compares this location the known location. The difference is applied to the GPS data recorded by the roving GPS receiver.

Dilution of Precision (DOP): An indicator of the effect of satellite geometry on positioning errors. Positions derived with a higher DOP value generally yields less accurate measurements.

GDOP: Uncertainty of all parameters (latitude, longitude, height, clock offset)
PDOP: Uncertainty of 3D parameters (latitude, longitude, height)

Double-Difference: A data processing procedure by which the pseudo-range or carrier phase measurements made simultaneously by two GNSS receivers are combined (differenced) so that, for any measurement epoch the observations from one receiver to two satellites are subtracted from each other to remove that receiver's clock error (or bias) and hardware error. Two receivers to one satellite eliminate that satellite's clock errors and hardware errors. The difference of these two single differences is then the double difference.

E

Ephemeris: The file of values giving a particular satellite's position and velocity at any instant in time.

Epoch: A specific instant in time. Real Time GPS carrier phase measurements are made at a given interval or epoch rate.

G

Geoid (model): The equipotential (homogenous gravitational acceleration value) surface that most closely approximates global Mean Sea Level.

H

Height (Ellipsoid): Height above or below a mathematically defined ellipsoid (GRS80 or WGS84) that approximates the surface of the Earth at the geoid.

Height (orthometric): The Orthometric Height is the height of a point – usually on the earth's surface, measured as a distance along the curved local plumb line and normal to gravity from the reference surface to that station.

L

L1/L2: For the ranging codes and navigation message to travel from the satellite to the receiver, they must be modulated onto a *carrier* frequency. GPS utilizes two frequencies; one at 1575.42 MHz called L1 and a second at 1227.60 MHz called L2.

Least squares: A mathematical method for the adjustment of observation, based on the theory of probability. In this method, the sum of the squares of all the corrections or residuals derived for the observed data is made a minimum.

I

Ionosphere, Ionospheric Delay: The Ionosphere is the band of atmosphere extending from about 50 to 1000km above the earth in which the sun's radiation frees electrons from the gas molecules present creating ions. The free electrons affect the speed and direction of the GNSS signals.

M

Multipath: Interference caused by reflected GPS signals arriving at the receiver, typically as a result of nearby structures or reflective surfaces. The reflected signal is delayed causing an apparent longer distance to the satellite. Usually the noise effect on the Real Time positioning is a few centimeters unless it causes an incorrect ambiguity resolution, which might result in decimeters of error.

N

NAVSTAR: The NAVigation Satellite Timing and Ranging is a navigation and positioning system based on a constellation of 24 satellites, operated and maintained by the Department of Defense.

Noise: An interfering signal that tends to mask th desired signal at the receiver output and which can be caused by space/atmospheric phenomena, man-made or receiver circuitry.

Navigation Message: Contains the satellite's broadcast ephemeris, satellite clock bias correction parameters, constellation almanac and satellite health. A message modulated on the L1 and L2 GPS signal broadcast every 12.5 minutes.

O

Oregon Coordinate Reference System: A grouping of region specific "low distortion" projections that best fit ground distances in Oregon.
http://www.oregon.gov/ODOT/HWY/GEOMETRONICS/Pages/ocrs.aspx

P

Phase Center: The apparent center of signal reception at an antenna. The electrical phase center of an antenna is not constant but is dependent upon the observation angle and azimuth to the satellite. The L1 and L2 phase centers are at different locations.

Precision: The degree of repeatability that a measurement of the same quality displays, and is therefore a means of describing the quality of the data with respect to random errors. Precision is traditionally measured using the standard deviation and therefore is shown in the RMS error on the data collector. It can be thought of as the spread of the positional error.

Pseudo-range: The distance between the antenna phase centers of a GPS receiver and the satellite from which it is receiving signals.

R

Root Mean Square (RMS): The RMS error typically approximates the 68% confidence level in individual spatial components (north, east or up).

RTCM: *Radio technical commission for Maritime Services.* Commission set up to define a differential data link to relay GPS correction messages from a monitor station to a field user.

RINEX: Receiver Independent Exchange format. The GPS file format used for satellite data messages, containing time, carrier phase and pseudo-range observables. To encourage the free exchange of GPS data, it was designed to be compatible with any software package.

S

Signal to Noise Ratio (SNR): The ratio of incoming signal strength to the amount of interfering noise as measured in decibel on a logarithmic scale. Measurements have good reliability if the SNR is 30 or greater.

T

Troposphere: The atmosphere from the earth's surface to around 50km altitude. The wet and dry components of the Troposphere cause GNSS signals to refract and delay. Error can be introduced if the rover is experiencing different weather conditions than that of the base.

W

World Geodetic System 1984 (WGS 84): A global geodetic datum defined and maintained by the Department of Defense. It was used as a reference frame for broadcasting GPS ephemerides beginning in 1987. WGS 84 positions differ from NAD 83 between 1 and 2 meters.