FieldGenius Technical Notes
GPS – Position Accuracy

Positioning Errors

GPS observations are influenced by a great number of systematic error sources and blunders caused by the user. Through careful user procedures, some intuitive position computation methods and insightful signal processing many of these errors can be reduced or eliminated. The principle of differential positioning to achieve higher accuracy assumes the same errors are being experienced at both the reference station and rover station. The following table provides an insight into the systematic errors involved with GPS positioning and gives the user an appreciation to following correct procedures.

Error Description	**Possible Magnitude**	**Reduction Methods**
Broadcast ephemeris orbits	25 m	Apply differential corrections, use precise ephemerides
Satellite clock	10 m	Apply differential corrections, use computed clock corrections
Ionospheric and tropospheric propagation	2 – 150 m	Apply differential corrections, use dual frequency sensors, baselines kept within reason otherwise modeling is required, avoid periods of high solar activity
Selective availability	50 m	No longer exists
Receiver noise	0.0002 m – 1.5 m	Use identical sensors for reference and rover pairs
Receiver clock	10 m	Apply differential corrections
Signal multipath	0.001 m – 20 m	Antenna ground planes, changing environment, signal analysis

Table 1. Systematic GPS Errors

User errors are not predictable and therefore cannot be removed by mathematical modeling. But they can be identified and eliminated by redundancy, keeping equipment in good order and by understanding the principles satellite navigation with regards to surveying.

1. Antenna Heights
   The measuring of antenna heights is a common source of errors and fortunately it can be easy to prevent. Antenna phase centers cannot be measured directly and therefore require the use of horizontal and vertical offsets and application of Pythagoras' theorem. Measuring distances in units of both meters and feet with conversion to one of the two for comparison can eliminate recording errors. Fixed height tripods and range poles at the reference and rover stations respectively can be a wise investment to avoid measurement errors.

2. Antenna Centering
   Antenna centering refers to the precision of positioning the GPS antenna horizontally over a feature or monument. A well maintained tribrach with antenna bracket at the reference station is suggested. GPS antennas are normally placed high above the ground surface for improved signal reception and due to the long lengths of range poles any degree of miss-leveling can cause considerable horizontal error. Ensuring range poles are kept straight and leveling devices are accurate will minimize errors.

3. Reference Coordinates
   Any error in the reference station's coordinates will be directly translated to the rover station; therefore care should be taken in entering coordinates. The datum of the reference station coordinates need to be taken into account and the use of non-geocentric datums avoided. Further information on datum issues can be found in the Coordinate Systems technical notes.

4. Baseline Distance
   Baseline distance refers to the computed vector from the reference station GPS antenna to the rover station GPS antenna. Differentially derived position solutions depend on similar conditions at the reference station and rover stations to reduce errors such as tropospheric propagation. RTK positioning is recommended to be kept within 10 km of the reference station to maintain accuracy and to minimize computation time to establish an RTK Fixed position solution.

5. Geoidal Modeling
   As the name modeling implies, interpolated geoidal undulations will have inherent errors for determining orthometric heights. Constraining GPS observations to vertical benchmarks are recommended to minimize vertical biases. Depending on the density and quality of the geoid model and user procedure, the best achievable vertical accuracy of orthometric heights determined by GPS will at best approach second order spirit leveling observations. For a further explanation on geoidal modeling see the technical notes on coordinate systems.

FieldGenius Rover Parameters

Careful application of the following parameters will aid the user in achieving high quality positions by eliminating erroneous positions and using statistical redundancy. An important item to remember for positioning (not just with GPS) is that higher accuracy translates to higher equipments costs, longer completion times and higher overall project costs. Therefore parameter selection requires a balance between required project accuracies and minimizing resources.

Masks define the minimally accepted values for recording positions for statistical analysis and tolerances define the statistical minimums for a collection of positions to be logged as a single position. For example the parameters shown in Figure 1 dictate that in order to collect positions for a statistical population, the solution must be RTK Fixed or better, all observed satellites must be 15º above the horizon, the PDOP less than 4.5, a minimum of 5 satellites must be observed and differential corrections can be received from any reference station. Once a population of one or more positions has been collected, the presented tolerances must all pass prior to the feature being logged with a position. In this case the horizontal and vertical RMS must be better than 3 cm and at least 10 position observations collected over a minimum of 10 seconds.

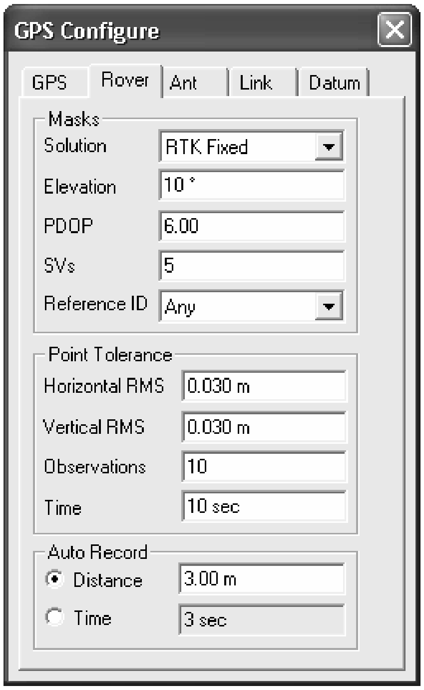

Figure 1. GPS Setup – Rover.

1. Solution Mask
   Solution refers to the computation method used to derive the position and will usually involve differential corrections. Accuracy is dependant on the use of differential corrections and the resolution of the observables which can either be pseudoranges or carrier phase, therefore selection of the solution mask will drive your achievable accuracies.

Solution Mask	**Description**	**Attainable Accuracy**
Autonomous	Independent position derived from pseudorange (C/A code) observations	20 m
WAAS	Pseudorange (C/A code) differentially derived position. Free corrections are obtained from geostationary communication satellites and reception is dependant on sensor model.	1.5 – 3.0 m
DGPS	Pseudorange (C/A code) differentially derived position.	1.0 – 2.0 m
RTK Float	Pseudorange and carrier phase differentially derived position. Integer ambiguities have not been resolved.	0.2 – 1.0 m
RTK Fixed	Pseudorange and carrier phase differentially derived position. Integer ambiguities have been resolved.	0.03 m

Table 2. Position Solution Masks

2. Elevation Mask
   Satellites which are low on the horizon from the observing position will have more errors induced into their observations. These errors are due to the signal having to travel through more of the ionosphere and troposphere as opposed to a satellite situated near the zenith. Suggested elevation masks are between 10 and 20 degrees.

3. PDOP Mask
   Geometry of the satellites has a direct effect on accuracies. A measure of satellite geometry is called dilution of precision (DOP). Dilution of precision can be represented in a variety of dimensional states with the most common being in 3D position (PDOP), 2D horizontal (HDOP) and 1D vertical (VDOP). Figure 2 describes the difference between good DOP and poor DOP conditions. DOP’s are unit-less and lower values denote superior satellite geometry. Recommended mask settings are between 3 and 6 depending on desired position accuracy. The use of mission planning software can help in predicting periods of time when the satellite geometry will be at optimum levels for positioning.

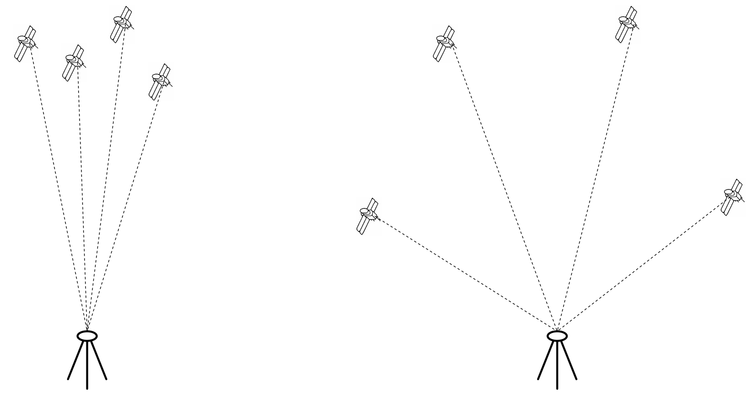

Figure 2. Satellite Geometry (DOP).

4. Satellites (SVs) Mask
   A minimum of four satellites are required for a three dimensional position. There are four unknowns to be determined, latitude, longitude, height and time (required due to range measurements) thus at minimum four satellites are required for minimally determined position solution. Observing beyond four satellites increases redundancy and improves the confidence of the position solution.

5. Reference ID Mask
   Reference stations have the ability to transmit an identification number with their generated correction messages. Rover stations can be configured to accept correction messages from a specific reference station. This feature eliminates the possibility of blunders caused by correction messages being received from unknown sources. Alternatively rover stations can also be configured to receive corrections from the first identified reference station selecting “Any”.

6. Horizontal and Vertical RMS Tolerance
   The horizontal (2D) and vertical (1D) RMS (root mean square) values describe the desired position precision. The term RMS is often used interchangeably with standard deviation (a slight difference does exist but will not be discussed) and represents normally distributed residuals of a population with a probability of one sigma (1 σ). A one sigma probability has an associated value of 68.3% which essentially means that approximately 68% of the measured positions will have the desired position tolerance. Table 1 can be used as a guide for determining suitable values for the RMS tolerances. Do not expect 3 cm accuracies if doing positioning with autonomous solutions.

7. Observations and Time Tolerance
   A population of suitable size is required in order to successfully obtain the precision of a position. Population size is defined by a combination of time and observation number and both must be satisfied for a position to be accepted. For most RTK

applications it is recommended to set the observation number and time to identical values of between 5 and 20.

8. Auto Record
   Auto record measurements allow the user to automatically record positions at a periodic interval of distance or time. Examples of applications can include measuring the center line of a road or the perimeter of a water body. Keep in mind that correction messages are received and positions generated at a one second rate, therefore it may be necessary to restrict the speed of the rover station to correspond to the position update rate. Consideration must be given for achievable accuracies because of observation latency and care in positioning the antenna.

Monitoring GPS Quality and Accuracy

FieldGenius provides information of the GPS receiver station and position state with the use of the GPS toolbar as shown below. The buttons on the GPS toolbar can act as information fields in addition to being controls. The following sections describe each button starting from the left with the GPS Solution button.

Figure 3. GPS Toolbar.

1. RTK Fixed GPS Solution Button
   As a status indicator this button will denote the current position solution state of the connected GPS receiver. Possible states include No Position (No Position), Autonomous (Auton), WAAS (WAAS), DGPS (DGPS), RTK Float (RTK Float), RTK Fixed (RTK Fixed) and No Link (No Link). A description of each state is listed in Table 2. Use of this button as a control will provide the options of accessing the GPS configuration for start up or shutting down the GPS receiver.

2. 6 Show SkyPlot Button
   The number of satellites being used in the position solution will be denoted on this button. Pressing the button will toggle the display between a skyplot of the satellite constellation and the map.

3. PD 2.2 GPS DOP Button
   A dilution of precision (DOP) value of the satellite geometry being used in the position solution is shown. Pressing the button will toggle its display state between PDOP (PD 2.2), HDOP (HD 1.7) and VDOP (VD 3.5).

4. GPS Information Button
   Selection will produce a property sheet with several pages which include GPS receiver information, a skylist of the satellite constellation and datum information.

5.  GPS Coordinates Button
   Toggles the display of GPS coordinates on the heads up display (HUD) of the map. Possible states include geodetic coordinates (latitude, longitude and ellipsoidal height), cartesian coordinates (northing, easting and orthometric height), and position RMS (Hrms and Vrms).

6.  GPS Position Pan
   A single press on this button will pan the current GPS position to the center of the map display. A double tap to the button will toggle the panning into a continuous mode.

Starting the measurement of a feature with GPS positioning will present a dialog as shown in Figure 4. In addition to having attribute entry fields, the dialog has a GPs position status and RMS fields. The Status field will indicate the condition of the position population based on the user selected masks and tolerances and the RMS field shows both the horizontal and vertical root mean square values for the population of positions at the current feature. Possible status values are shown in Table 2. Once all of the observations which have been filtered by the masks meet the tolerances, new observations will cease, the status field will denote Accepted and the OK button will be enabled to allow the feature's position to be stored.

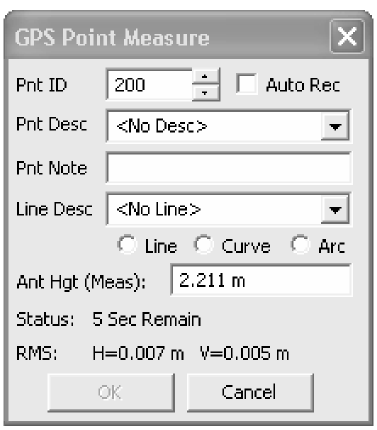

Figure 4. GPS Point Measure Dialog.

Status messages of High RMS can be an indication of a poor RTK fixed solution (ambiguities incorrectly resolved) or instability of an antenna supported by a range pole. If excessive RMS values are observed and are not converging to within the tolerance values, it may be necessary to cancel the point measurement and restart the measurement process. Additionally it may be necessary to re-initialize the RTK fixed solution by inverting the GPS antenna.

Status Value	Description
Poor Solution	Current solution type quality is less than defined mask
Deficient SVs	Insufficient number of satellites used in solution
High PDOP	PDOP value is greater than value defined in mask
Invalid Ref	Correction messages are being received from incorrect reference station
No Link	Correction messages are not being received (if solution mask type requires corrections)
High RMS	Horizontal and/or vertical RMS exceeds tolerance
n Sec Remain	Denotes number of n seconds remaining for tolerance
n Obs Remain	Denotes number of n observations remaining for tolerance
Accepted	All masks and tolerances have passed and feature position is ready to be stored

Table 3. GPS Point Measure Status.

Recommended Procedures

The masks and tolerances which are used in FieldGenius will not guarantee reliable positions alone. Additional steps involving quality control are required by the user to further improve the reliability of positions and help eliminate many of the user errors mentioned in the previous section.

1. Control Points
   Immediately after the reference station has been setup, commenced operation and prior to surveying new features, it is strongly recommended to occupy an adjacent control point with published coordinates. The adjacent control points need to be on the same datum and adjustment as which the reference station is occupying. A comparison between the published coordinates and measured coordinates of the control point will enable blunders to be detected and provide an indication of the positioning accuracy. Identifiable blunders include antenna heights at the reference and rover stations and reference station coordinates.

2. Repeat Observations
   This method involves re-observing features which had been previously measured using the same method. Ideally the re-observation should occur when there has been a significant change in the satellite constellation and the reference station and rover station have been dismantled and re-assembled. A change in the constellation occurs in varying degrees from one to five hours. Keep in mind that satellites have an orbiting period of 12 sidereal hours and the constellation configuration repeats itself every sidereal day (1 Solar Day ≈ 0.997 Sidereal Day). If a repeat measurement must be done immediately to a feature immediately due to logistical difficulties, it is recommended that the GPS antenna be inverted briefly to lose satellite signal lock. This procedure will reset the ambiguity resolution algorithms and also the signal processing methods which perform multipath effects reduction.

Surveying repeat points without re-assembling the reference and rover stations will not provide a means for detecting blunders in antenna heights or reference station coordinates.