GNSS ACCURACY
Specification versus Reality

Global Navigation Satellite System (GNSS) accuracies have been debated since surveyors began using the systems over twenty years ago. Some of the descriptions surrounding GNSS accuracies are common to other measurement techniques and some are unique to satellite based measurements. This article will attempt to explain GNSS specifications and what is reasonable to expect from GNSS measurements in terms of accuracy under various conditions.

A typical GNSS receiver specification that is used in Machine Control resembles the following:

Kinematic surveying

Horizontal……………………….10 mm + 1 ppm RMS
Vertical………………………….20 mm + 1 ppm RMS
Initialization time……….……. typically < 10 seconds
Initialization reliability…….……..typically > 99.9%

Regardless of the measurement technique, there is always some error in each measurement. This is called the given error. The given error in GNSS real-time kinematic (RTK) measurements is typically 10 mm (0.033 ft.) horizontally and 20 mm (0.065 ft.) vertically as noted above. The reason that vertical accuracy is worse than horizontal is because the GNSS receiver cannot see below the horizon. With horizontal measurements, the receiver has satellites visible across all quadrants of the horizontal plane which produces strong geometry for horizontal calculations. However in a vertical sense, the GNSS receiver can only track satellites in two quadrants of its vertical plane which does not provide the same strength of geometric calculations.

Machine Control relies on a kinematic approach to GNSS measurements. Kinematic implies that the conditions will change. There will be times when the GNSS antenna has a complete view of the sky, times when the sky may be partially blocked, times when it is motion and other times when it is static. Most GNSS specifications contain a footnote to the effect that…*"Accuracy and reliability may be subject to anomalies due to multipath obstructions, satellite geometry, and atmospheric conditions…"*

When a manufacturer writes a specification about the accuracy of their GNSS receiver, they generally want to impress the potential buyer with the highest degree of accuracy possible. All of the testing is therefore conducted in perfect conditions. (Imagine a grassy field on flat ground for as far as the eye can see in all directions.) In perfect conditions, there is 10 millimeters of error horizontally and 20 millimeters vertically that are floating around on every measurement. The answer can be anywhere within this egg shaped ovoid standing on its edge and still be considered to be within specification.

Then there is an accumulation of given error depending upon the distances between the rover and its base station. 1 Part Per Million (PPM) means that for every kilometer the rover goes away from the base, another millimeter of given error is added to each measurement. Let's imagine a situation where the rover is 10 miles from its base station. There is already one centimeter horizontally and two centimeters vertically given plus the PPM accumulation. 10 miles equals about 16 kilometers. At 1 PPM, this contributes another 1.6 centimeters of given error both horizontally and vertically making the accuracy specification at 10 miles in perfect conditions 2.6 cm (0.085 ft.) horizontally and 3.6 cm (0.12 ft.) vertically.

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The next aspect of the specification defines the confidence that can be assumed behind each measurement. Root Mean Square (RMS) roughly means that the average of all measurements will fall within this egg shaped ovoid of given error. Some of the measurements will be nearly perfect, but others will fall completely outside of the range. Another way to express this confidence is by sigma. One sigma equals about 68%. In measurement theory, that means that 68 out of 100 shots will fall within the specification while 32 of that hundred will not.

The final aspect of a GNSS receiver specification relates to the amount of time it may take to get to a desired level of accuracy. This time to converge is a balance between meeting accuracy requirements and time budgets. In the world of Machine Control, the solution is needed quickly and accurately. With good geometry of satellites, moderate baseline lengths, a clear view of the sky and no atmospheric disturbances or multipath influences, the receiver specified above will achieve a one to two centimeters level solution within 10 seconds (typically) and the solution will meet the horizontal and vertical specification more than 99.9% of the time.

Actual performance should not be limited to the specification. In many situations, the performance of a GNSS receiver exceeds the specification. But there are also times when the users' expectations are unreasonable based on the local or current conditions. For instance, GNSS technology needs sky. The more sky that is visible, the better the equipment will perform. Unfortunately, there is no instrument that measures the percentage of sky occlusion and the definition of "clear sky" is different when speaking to someone from Phoenix versus Philadelphia. If your base station is within a few miles of your rover, performance is going to be better than if it is 40 miles away. Is the firmware of the receiver up to date? Most times, firmware updates provide performance enhancements. Depending upon the levels of accuracy being sought, attention to these details may be needed to get the desired results.

Many times, the word "accuracy" is used when in fact the word "precision" might be more appropriate. Accuracy refers to some truth about a position. There must be a frame of reference against which the precise position is truthed. In Machine Control, these are the grid files and control points around which the project is designed. Precision refers to repeatability. Sometimes, it is more important to be able to repeat a measurement over and over than to be accurate. On a perfect job site, these two concepts are synonymous. However, many times it can become difficult to tell whether a site is being graded accurately or with precision, or both.

A good way to illustrate this difference is to consider a marksman aiming at a target. If all of the shots are scattered around the target, he is neither precise nor accurate. If all of his shots are grouped tightly together but they are all high and to the right of the bulls-eye, he is precise, but not accurate. If he has a tight grouping of shots and they are all on the bulls-eye, he is both accurate and precise.

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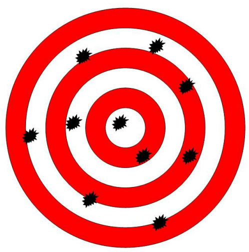		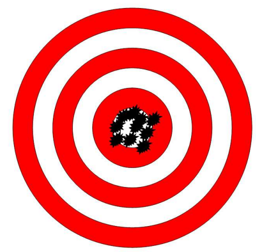
Neither precise nor accurate	Precise, but not accurate	Precise and accurate

There are still other factors that affect GNSS accuracy including solar activity, upper atmospheric disturbances and satellite signal interference by local radio transmissions. But these other error sources are more exceptional than normal and modern GNSS receivers are designed to mitigate many of these effects. The dynamics of Machine Control and GNSS accuracies introduce even more variables than can be named in this article such as vibrations, user interfaces and the actual configuration of the hardware. Understanding the specification, recognizing the strengths and limitations of GNSS technology and having realistic expectations based on these can enable a GNSS end user to configure the system that best meets their needs. GNSS technology and Machine Control are married to each other. The practical use of GNSS technology to position heavy equipment is evolving and improving. MachineControlOnline.com will continue to be there and keep you informed.