The Society for engineering in agricultural, food, and biological systems

*Paper Number: 021150*
*An ASAE Meeting Presentation*

# Elements of a Dynamic GPS Test Standard

Timothy Stombaugh
Assistant Extension Professor
tss@uky.edu

Scott A. Shearer
Professor

John Fulton
Engineer Associate

Department of Biosystems and Agricultural Engineering
University of Kentucky

M. Reza Ehsani
Assistant Professor
Food, Agricultural and Biological Engineering
The Ohio State University

**Written for presentation at the**
**2002 ASAE Annual International Meeting / CIGR XVth World Congress**
**Sponsored by ASAE and CIGR**
**Hyatt Regency Chicago**
**Chicago, Illinois, USA**
**July 28-July 31, 2002**

***Abstract.*** There has been much advancement in GPS receiver technology in recent years. GPS accuracy, especially the dynamic (moving) accuracy, is very important in precision agriculture for collecting data and controlling variable rate inputs. Typical applications of GPS receivers in agriculture include yield monitoring, parallel tracking and variable-rate application of fertilizer. Perhaps more important is the relevance of existing tests (primarily static tests), and the inability to compare receivers because of a variety of reporting formats. This project evaluated several different receivers. Test results showed that different performance reporting techniques make it difficult to evaluate and compare the performance of receivers. Also, the static performance of receivers was not indicative of dynamic performance. A proposed framework for a dynamic test standard for agricultural GPS receivers is presented.

**Keywords.** Global Positioning System, GPS Testing, GPS Test Standard

The authors are solely responsible for the content of this technical presentation. The technical presentation does not necessarily reflect the official position of the American Society of Agricultural Engineers (ASAE), and its printing and distribution does not constitute an endorsement of views which may be expressed. Technical presentations are not subject to the formal peer review process by ASAE editorial committees; therefore, they are not to be presented as refereed publications. Citation of this work should state that it is from an ASAE meeting paper. EXAMPLE: Author's Last Name, Initials. 2002. Title of Presentation. ASAE Meeting Paper No. 02xxxx. St. Joseph, Mich.: ASAE. For information about securing permission to reprint or reproduce a technical presentation, please contact ASAE at hq@asae.org or 616-429-0300 (2950 Niles Road, St. Joseph, MI 49085-9659 USA).

## INTRODUCTION

The Global Positioning System (GPS) is one of the key technologies that have made precision agriculture (PA) possible. Research conducted as early as 1929 outlined the merits of spatially sampling field parameters and applying inputs at variable rates (Linsley and Bauer, 1929). The development of GPS over the last two decades is probably the key element that has made real-time spatial management possible.

There have been many GPS innovations in the last couple years. An example of one innovation that has had a significant impact on PA is the Wide Area Augmentation System (WAAS). Initiated by the Federal Aviation Administration, WAAS is a free satellite-based differential correction service that has facilitated development of very low cost receivers that have potential for use in PA.

The introduction of WAAS as well as rather bold accuracy claims from some GPS manufacturers have sparked interest in GPS testing and accuracy reporting methods. Most manufacturers report accuracy as a single number representing the results of a static test of the receiver, but nearly all PA field operations are dynamic. Consequently, there are many questions about the accuracy of the position information used to create maps or control variable rate application equipment.

## OBJECTIVES

The overall goal of this project was to evaluate current GPS receiver test and reporting standards to determine if they are adequate to describe receiver performance in agricultural situations. This goal was accomplished through the following specific objectives:

1. Identify current standards for GPS receiver testing and accuracy reporting.

2. Summarize current GPS testing protocols implemented by different organizations.

3. Offer a suggested framework for standardized static and dynamic GPS receiver testing for agricultural applications.

## BACKGROUND

The accuracy of GPS receivers is dependant on a number of parameters including the inherent satellite signal accuracy, signal transmission errors, and receiver hardware and software limitations. The errors in satellite signals coming to a receiver could be affected by factors such as satellite orbit perturbations or hardware health. The US Department of Defense, which oversees the maintenance of the GPS system, has committed to a minimum level of service availability, reliability, and accuracy (Department of Defense, 2001). These minimum commitments include a guaranteed achievable position accuracy of no worse than 36 m horizontal and 77 m vertical (95% confidence) anywhere on the globe. This means that the most inexpensive GPS receiver should be able to achieve at least these minimum position accuracies. The receivers used in PA utilize a number of hardware and software enhancements (including differential correction) to achieve accuracies close to 1 m or less.

Several considerations exist that must be addressed when evaluating GPS position accuracy. The first consideration is appropriate error reporting method. Most manufacturers report horizontal receiver accuracy as a single distance number (e.g. 1 m). That number usually

represents the combined horizontal (circular) accuracy of the receiver, and is usually based on one of a number of statistical inferences or confidence intervals (Van Diggelen, 1998; Table 1). To illustrate the interpretation of these inferences, consider a receiver with reported 1 m Circular Error Probable (CEP) accuracy. The implication is that the error in the receiver output will be less than 1 m at least 50% of the time. To compare receivers from manufacturers who use different reporting methods, the user must perform a numerical conversion (Table 1).

The second main consideration when comparing receivers is the way in which the test data were obtained. Most accuracy specifications are computed from a 24-hour stationary test of the GPS receiver. Often there is little information given about test conditions such as receiver configurations, satellite constellation configuration, signal strength or atmospheric conditions, all of which can affect receiver performance.

A third major consideration is the way that the position error is computed. Is the error specification based on the predictable (absolute) or repeatable (relative) accuracy (Fig. 1)? The predictable or absolute accuracy represents how well the position solution reflects the true position of the antenna based on a survey relative to an accepted coordinate system. The repeatable accuracy represents how well the position solution relates to previous solutions at the same location (Department of Defense, 1995). In other words, the repeatable accuracy represents the error between a particular position solution and the average of many positions measured while the receiver was at the same location. Predictable error is measured relative to the true absolute location of the antenna. Repeatable error of GPS receivers is often much smaller than predictable error, especially for shorter test periods; therefore, a receiver with a small relative accuracy specification can appear to be better than another receiver with a slightly larger predictable error when the opposite is true. In short, it would be desirable if all manufacturers who market to the PA industry would utilize a single static test and reporting standard.

The Institute of Navigation (ION) is the only known organization that has published a standard for GPS receiver testing (ION, 1997). Their document, which heavily references the original Department of Defense GPS Specification documents, outlines detailed procedures for static GPS accuracy tests. This protocol is sufficient to describe the static performance of agricultural receivers, and anyone testing receivers is encouraged to follow and reference this standard.

Since the ION serves a very broad clientele representing space, military, land and marine applications, their standard outlines only a skeletal framework for dynamic test standards. Specific dynamic test conditions are left to the discretion of each sub-discipline. No detailed procedures currently exist for agricultural or similar applications.

There are several different groups and organizations that are actively involved in dynamic GPS testing. The protocols used by these groups can be classified as either on-vehicle comparison testing or fixture testing.

On-vehicle comparison testing involves placing several GPS receivers on a vehicle and driving the vehicle through a pre-described path. Han (2002) used this approach to test several receivers simultaneously. He mounted 8 receivers plus a highly accurate Real Time Kinematic (RTK) GPS receiver and an inertial measurement unit (IMU) on one large machine and drove it through a series of maneuvers. The output from the RTK GPS established the absolute baseline from which to compare the performance of the other receivers. Saunders et al. (1996) published a similar test protocol for comparison testing of GPS receivers. Another group of researchers established a series of georeferenced, marked paths through an open field

(Sullivan and Ehsani, 2002). They mount the GPS receiver on an agricultural tractor and drive it through the marked paths.

There are several advantages to using the on-vehicle comparison methods of GPS testing.

- Typical field operations and maneuvers can be replicated exactly so that comparisons can be reported for actual field conditions.
- All receivers are subjected to the same environmental conditions and GPS satellite configurations.
- Tests can be easily replicated at various locations.
- If RTK GPS is used to measure the actual path, error measurement is relatively simple because of the GPS time stamp that is inherent in the data sets.

There are several disadvantages to using the on-vehicle comparison methods of GPS testing.

- The duration of tests is limited since an operator is required to drive the vehicle.
- Depending on the test set-up, the results could be affected by the skill of the vehicle operator.

A fixture testing approach to GPS receiver testing involves placing the GPS receiver antenna in a mechanical fixture that is designed move it through a predefined path. The authors have developed a rotating arm that moves a receiver in a circular motion, thus subjecting it to constant acceleration. Some manufacturers, who have chosen not to publish results, have utilized a similar testing apparatus. Researchers at Kansas State University have gained permission to conduct studies using a section of abandoned railroad track.

There are several advantages that can be realized through implementation of a fixture approach to GPS testing

- The path of the receiver is accurately known and can be replicated repeatedly.
- Tests can be conducted for an extended time period.

There are several disadvantages to a fixture approach.

- It may be more difficult to replicate actual field operations and maneuvers.
- Fixture construction could be quite expensive.
- Once constructed, the fixture may not be easily transportable to other locations for testing.

## PRELIMINARY TESTING

A series of tests were conducted to illustrate the need for a dynamic GPS test standard. A fixture-based GPS test facility was established on the roof of the Charles E. Barnhart building at the University of Kentucky. This location afforded a clear view of the sky that was relatively

unobstructed by surrounding buildings. The primary test apparatus was a 7.5 m rotating arm (Fig. 2). GPS antennae were mounted either on the end of the arm where they are subjected to a constant acceleration (circular motion) or on top of the center of the arm where static tests were conducted. The receivers, recording devices, and power supplies were mounted in a weather-resistant box located part way out on the arm.

The exact location of the arm was determined using a Trimble AgGPS 214 RTK GPS receiver, which gives position accuracy to within 2 cm. National Geodetic Survey benchmark number AA4602, which was surveyed to level-1 horizontal accuracy, was used as the base station location for the RTK receiver. This benchmark was located 1350 m away from the test location.

Four different GPS receivers were tested in this study. Two of the receivers were handheld units costing less than $500 each. These units are hereafter referred to as HH1 and HH2. The other two receivers are typical of those traditionally used in agriculture costing over $3,000 and are hereafter referred to as PAg1 and PAg2. Static and dynamic accuracy tests were conducted on various configurations of the four receivers. Each receiver was allowed sufficient warm up time before recording data to eliminate any starting or almanac differences between receivers.

## Results and Discussion

### Static Tests

Static accuracy tests were conducted to verify the performance that was reported by each receiver manufacturer. In each test, data were collected for at least 24 hours. A GIS program was used to project all data from WGS-1984 Latitude/Longitude to UTM coordinates (NAD 83, Zone 16N) for linear error measurement.

There were visibly noticeable differences between the performances of the different receivers (Fig. 3). Data from the static tests are summarized in Table 2. The accuracy specifications given by each manufacturer were converted to an equivalent RMS specification using the relationship given by Van Diggelen (1998). The bias was the distance between the mean position computed for the entire test and the actual position. The predictable RMS accuracy was computed by taking square root of the mean squared error between the actual antenna position and each data point. The repeatable RMS accuracy was computed from the error between each point and the mean for the entire data set. Mean HDOP values are also reported so the reader can determine whether satellite configuration might have contributed to accuracy differences.

PAg1 was the only receiver whose predictable accuracy did not fall within or very close to the specification given by its manufacturer. The repeatable accuracy, however, was very close to the manufacturer's specification, which suggests that the manufacturer intended the specification to reflect the relative performance of the receiver rather than the true predictable performance. This example alone illustrates the point that manufacturer specifications may be misinterpreted by end users.

As expected, the repeatable error was smaller than the predictable error in all cases; however, PAg1 had a noticeably larger difference than the other receivers. It was also observed that all receivers had a measurable bias.

Receiver HH2 had the capability to accept an external antenna. The static accuracy was less when using the after-market external antenna than when using the integral antenna. This indicated that the antennas can have an effect on the receiver accuracy.

Dynamic Tests

Dynamic tests of the receivers were conducted using the rotational test apparatus (Fig. 2). The speed during all tests was approximately 4 rpm, which produced a tangential speed of 3.14 m/s (7 mph) at the end of the arm where the antenna was located. In each test, data were collected for at least 24 hours. Test results from the 4 receivers are summarized in Table 3, and figure 4. As with static tests, the bias is the distance between the mean of all measured positions and the actual antenna location. The error for each point in dynamic tests was computed by measuring the shortest distance from the point to the circle describing the path of the antenna, which is commonly referred to as cross-track error. The predictable accuracy is measured relative to the actual antenna path. The repeatable accuracy is measured relative to a 7.5-m radius circle about the mean of the entire data set.

For two of the receivers tested (HH2 and PAg2), the dynamic accuracy was actually better than the static accuracy. PAg1 exhibited a noticeable degradation in dynamic accuracy (Fig. 4), illustrating that the static accuracy specification for a receiver is not necessarily indicative of the dynamic performance. One explanation for the differences in static and dynamic accuracy may be data filtering. A data filter is a software algorithm that attempts to filter out or correct data that are judged to be in error (Franklin et al., 1994). Manufacturers incorporate data filters to enhance performance. These filters can affect the dynamic performance of a receiver. One set of tests were conducted with the filters in PAg2 turned off. The static performance was better with the filter, but the dynamic performance was better without filtering (Fig. 5).

The method that was used to compute the dynamic error of each point underestimates the actual error of that data point. As mentioned earlier, the error was measured as the shortest distance from a data point to the circle describing the antenna path. This implicitly assumes that the antenna location was at that point on the circle when it could have been a few degrees one way or the other (Fig. 6). The distance to the actual location is always greater than or equal to the measurement reported above.

One question that remains regarding the dynamic testing is validity of the rotational test. While this constant acceleration test may be effective at exposing filtering effects, it may not be truly indicative of typical agricultural field motions (e.g., Fig. 4). A test that incorporates parallel swaths and headland turns may be more valid.

In short, most accuracy specifications given by GPS receiver manufacturers are a true reflection of the static performance of the receiver; however, some manufacturers may be reporting relative accuracy instead of absolute accuracy, which could be misleading to some consumers. Additionally, the static performance of a receiver is not necessarily indicative of the dynamic performance. Some receivers perform worse in dynamic tests than static tests; others perform better in dynamic tests. Clearly, a dynamic test standard would be advantageous for agriculturists wishing to purchase GPS equipment

## DYNAMIC TEST STANDARD CONSIDERATIONS

Because both the fixture and on-vehicle comparison test approaches have merit, a list of test standard guidelines and considerations are presented for both. In addition, there are several general considerations that must be addressed by both approaches.

### General Test Guidelines

**Test Scope:** The dynamic test should either replicate or simulate the actual conditions and motions that a vehicle with DGPS will usually encounter under agricultural applications. These motions include at minimum straight line following, headland turns, and contour curve following. Additional maneuvers and motions include starting and stopping, sharp turns, and performance in partial or complete tree cover. The standard should also consider the velocities at which the receivers should be tested.

**Test Duration:** Minimum duration times for the tests should be clearly defined. These durations might be different for the two general test approaches.

**Reporting Requirements:** The standard should specify minimum reporting requirements for the test. Since satellite geometry as well as environmental factors can affect performance, the minimum reporting parameter list should include date of test, time of test, weather descriptions, distance from differential correction beacons (if appropriate) and satellite Dilution of Precision (DOP). The receiver configuration, including firmware version and all configurable settings, should also be recorded.

**Datums and Computations:** To insure equitable error comparisons, the standard should explicitly outline the datums and projections to be used for distance computations. Error computation methods and confidence intervals to be used should also be defined. In particular, error computations at each point should be based on distance to actual antenna location, not just cross-track error. Specifications should also be made about minimum standards for establishment of the location of the actual path.

**Antenna Separation:** In cases where multiple receivers will be tested simultaneously, the antenna location could be critical. If antennae are too close to each other, there could be interference between units; if they are too far apart, the antennae could be subjected to different environmental conditions, especially if operated near treelines or other obstructions. The specification should give maximum and minimum separation distances.

**Reference Standard:** Minimum guidelines should be offered for survey establishment of the absolute location of the test. If another locator is to be used (e.g. an RTK GPS receiver), the accuracy of that locator should be greater than the expected precision of the tested receiver. The authors believe that relying on a human operator to follow a pre-described marked path is not sufficient to achieve adequate path accuracy.

### On-Vehicle Comparison Test Guidelines

**Test Path:** The test path parameters, including the path configuration, path lengths, elevation changes, and replication sequence, should be clearly defined. In addition, guidelines about separation from obstructions such as tree lines and power lines should be offered.

### Fixture Testing Guidelines

**Fixture Design:** The standard should define the configuration of the fixture(s) to be used for testing. The authors suggest that a rotary mechanism should be included in the fixtures since the constant acceleration is effective in exposing filter issues and since it is representative of the motion encountered in a contour path. Another fixture, such as an oval track (Fig. 7 a.) is needed to simulate the minimal straight paths and headland turns. The authors suggest a minimum straight path length of 200 ft. to insure that data filters are given sufficient time to settle. Oval width should be at least 40 ft. to be representative of larger application machines as well as smaller planters and harvesting equipment. A figure-8 path (Fig. 7 b.) could also be considered since it provides two straight paths at different orientations. A more complicated path (Fig. 7 c.) could also be considered to incorporate additional maneuvers such as sharp turns.

The authors suggest the following as a possible test sequence for the fixture testing:

One 24-hour test will be divided into 12 2-hour blocks. Three velocities and two directions will create 6 different treatments or test conditions. If the duration of each treatment is 2 hours, then each treatment can be replicated twice in one 24-hour test. The treatments will be randomized in order.

## CONCLUSIONS

Several key conclusions can be drawn from the analyses conducted in this study.

1. The Institute of Navigation (ION) has developed a test standard that is sufficient to characterize and describe the static performance of agricultural GPS receivers; however, there is not a sufficient published standard to characterize dynamic receiver performance.

2. Inconsistent accuracy reporting methods as well as data filtering and unusual dynamic performance of some GPS receivers warrants the development and implementation of a dynamic test standard.

3. Two techniques could be employed for dynamic receiver testing – on-vehicle comparison testing or fixture-based testing, with the fixture-based method being preferable because of repeatability.

**References**


Department of Defense. 2001. Global Positioning System Standard Positioning Service Performance Standard.

Department of Defense. 1995. Global Positioning System Standard Positioning Service Signal Specification.

Franklin, G. F., J. D. Powell, A. Emami-Naeini. 1994. Feedback Control of Dynamic Systems, 3ed. Addison-Wesley Publishing Co., Reading, MA.

Han, S. 2002. Dynamic evaluation of GPS Positioning Accuracy. Oral presentation at the ASAE Agricultural Equipment Technology Conference, Kansas City, MO, Feb. 20-23.

Hurn, J. 1993. Differential GPS Explained. Trimble Navigation, Sunnyvale, CA.

*Institute of Navigation Standards*. 1997. ION STD 101, Recommended test Procedures for GPS Receivers. Alexandria, VA:ION

Linsley, C. M. and F. C. Bauer. 1929. Test your soil for acidity. Circular # 346, College of Agriculture and Agricultural Experiment Station, University of Illinois, Urbana, IL.

Saunders S.P., Larscheid G., Blackmore B.S. & Stafford J. 1996. A method for direct comparison of Differential Global Positioning Systems suitable for Precision Farming. In Proc. 3rd International Conf. On Precision Agriculture, edited by Robert, Rust and Larson. ASA, CSSA, SSSA, Madison, WI: p. 663

Sullivan, M.and R. Ehsani. 2002. Evaluation of GPS lightbar accuracy. Oral presentation at the Conservation Tillage Conference, Ada, OH, Feb. 26.

Van Diggelen, F. 1998. GPS accuracy: lies, damn lies, and statistics. *GPS World*, 9(1)41-45.

Table 1. Comparison of GPS Accuracy Measures (adapted from Van Diggelen, 1998)

| Accuracy Description | Probability (%) | Conversion Factors | | | |
|---|---|---|---|---|---|
| | | **CEP** | **rms** | **R95** | **2drms** |
| **CEP** – Circular Error Probable | 50 | 1 | 1.2 | 2.1 | 2.4 |
| **rms or 1 Sigma** – 1 standard deviation | 63-68 | | 1 | 1.7 | 2 |
| **R95** – horizontal 95% accuracy | 95 | | | 1 | 1.2 |
| **2drms or 2 Sigma** – 2 standard deviations | 95-98 | | | | 1 |

Table 2. Results from Static Accuracy Tests

| Receiver | Mfgr. RMS Spec. | Bias | Predictable RMS Accuracy | Repeatable RMS Accuracy | Mean HDOP |
|---|---|---|---|---|---|
| HH1 | 3.5 | 0.726 | 3.503 | 3.427 | 1.12 |
| HH2 | 1.8 | 0.736 | 1.376 | 1.163 | 0.88 |
| HH2 with external antenna | N/A | 0.851 | 2.164 | 1.989 | 0.90 |
| PAg1 | 0.3 | 1.033 | 1.076 | 0.303 | 1.20 |
| PAg2 | 1 | .427 | 1.06 | .973 | 1.18 |

Table 3. Results from Dynamic Accuracy Tests

| Receiver | Mfgr. RMS Spec.* | Bias | Predictable RMS Accuracy | Repeatable RMS Accuracy | Mean HDOP |
|---|---|---|---|---|---|
| HH1 | 3.5 | 2.034 | 1.875 | 1.219 | 1.10 |
| HH2 | 1.8 | 0.942 | 0.738 | 0.360 | 1.05 |
| PAg1 | 0.3 | 1.181 | 3.320 | 3.255 | 1.25 |
| PAg2 no filter | 1 | 0.062 | 0.424 | 0.421 | 1.21 |
| PAg2 with filter | 1 | 0.173 | 0.685 | 0.671 | 1.16 |

* The manufacturer's specifications are not intended to be dynamic specifications and are included in this table only for comparison.

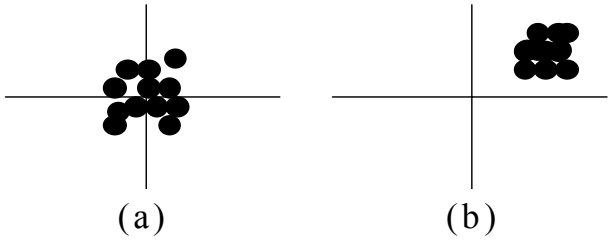


Figure 1. Typical receiver performance illustrating predictable (a) and repeatable (b) accuracy.

Figure 2. Rotational GPS receiver test apparatus at the University of Kentucky.

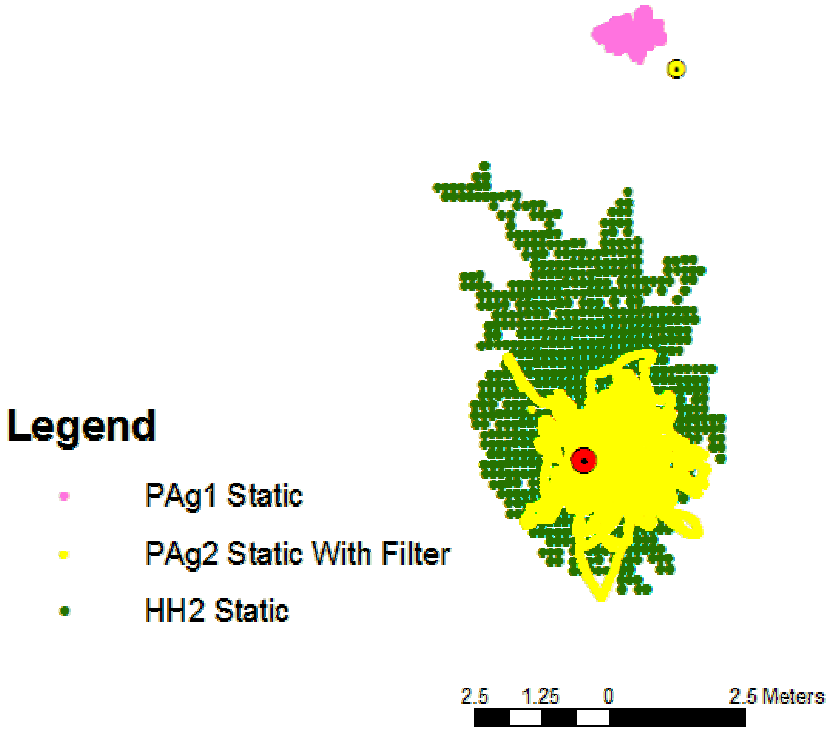


Figure 3. Representative data from static receiver tests. Note that PAg1 was tested at a different location as shown.

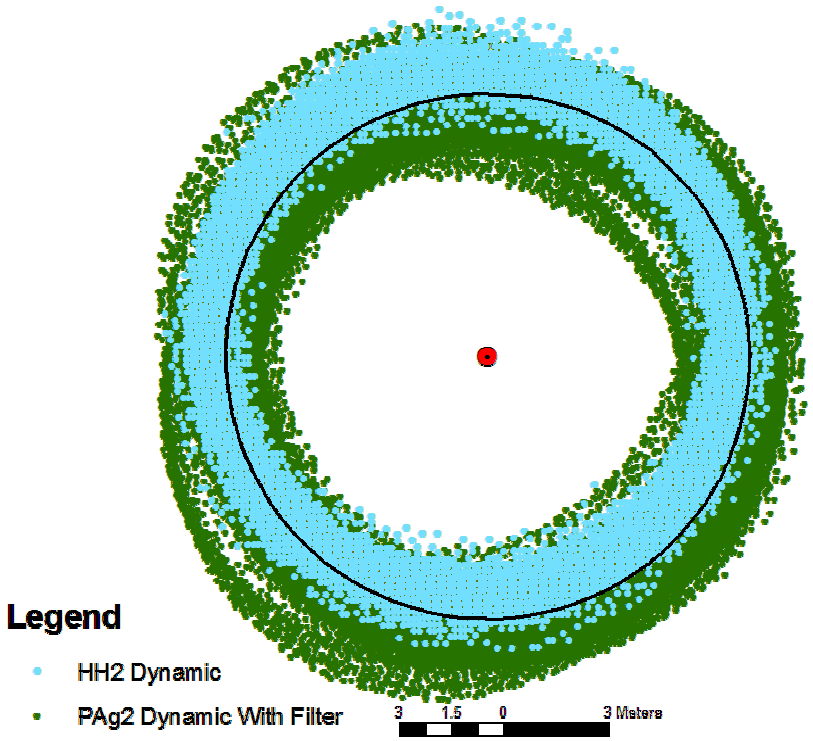


Figure 4. Representative data from dynamic receiver tests.

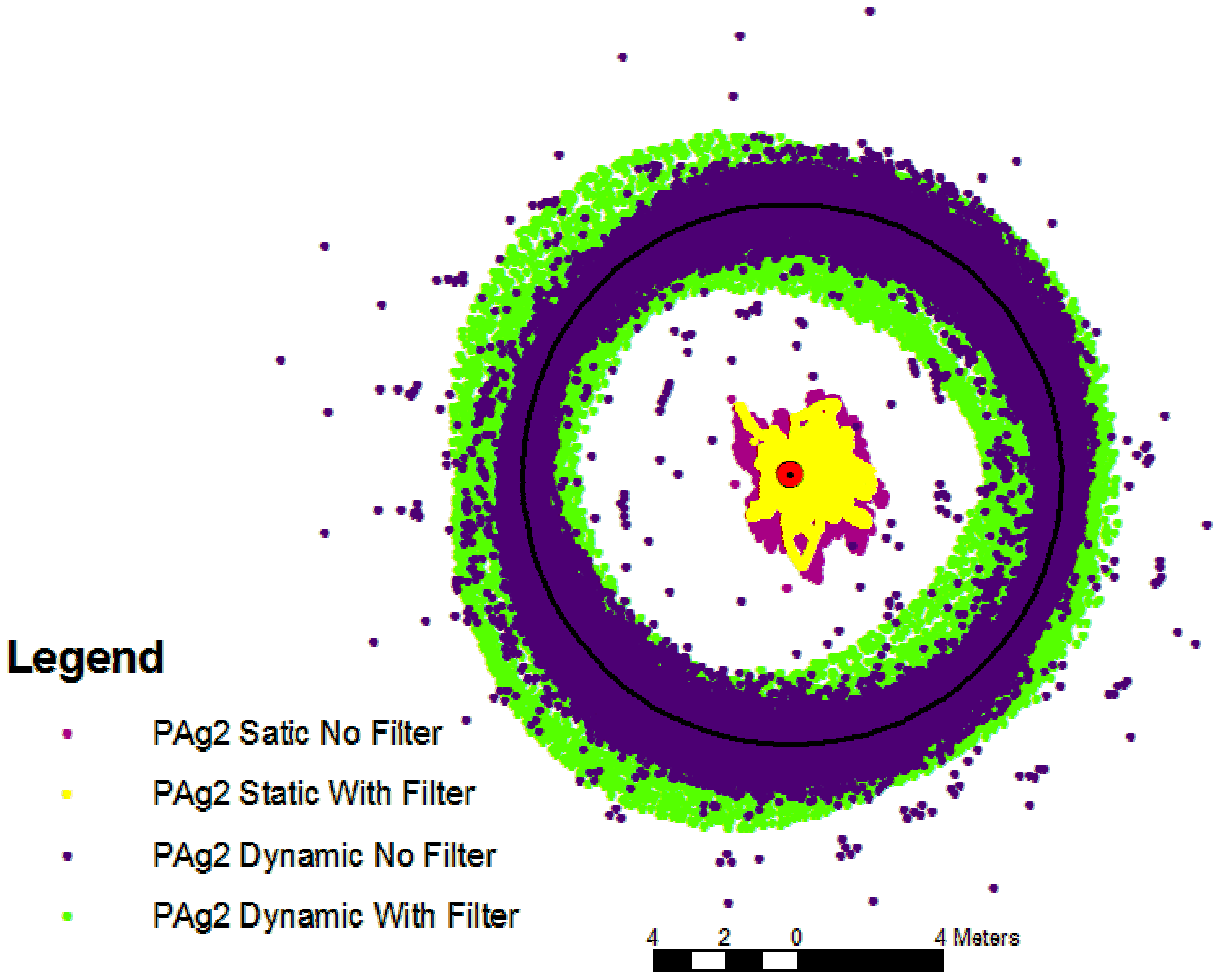


Figure 5. Static and dynamic performance of a GPS receiver with and without data filtering.

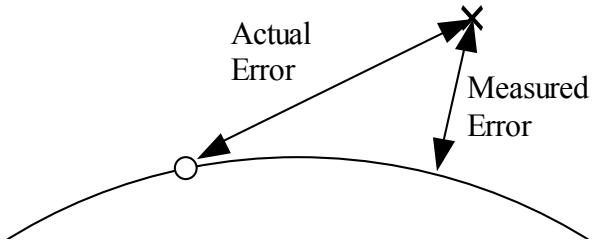


Figure 6. Difference between actual and measured error.

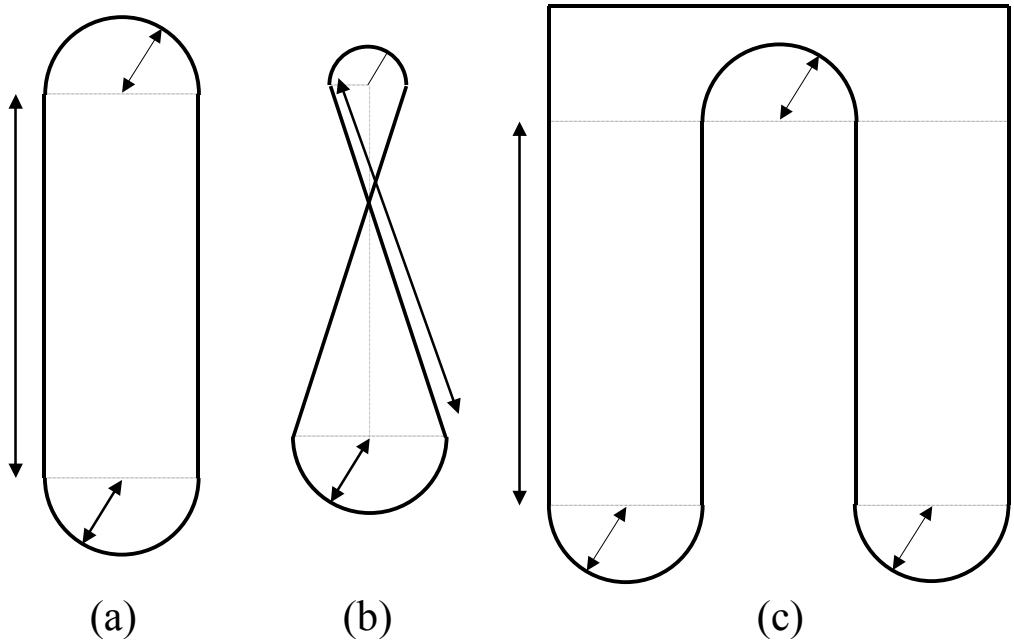


Figure 7. Suggested dynamic test fixture paths: a) oval path , b) figure-eight path, and c) headland turn path.