A study of GeoXT antenna performance

Trimble Navigation Limited, 7403 Church Ranch Blvd, Suite 100, Westminster, CO 80021, USA

Introduction

GeoXT™ handhelds are totally integrated—offering a high level of convenience by placing everything required to record GPS positions in the palm of your hand. GeoXT handhelds also allow you the option to add an external antenna for improved performance.

Using productivity and accuracy as the key measures of GPS performance, this study looks at how three antennas—the internal GeoXT antenna, the Hurricane antenna and the Patch antenna—perform in both static and dynamic testing, under open sky and canopy environments.

Convenience of use is also considered with regard to how antenna mounting options may affect overall fitness for purpose. This paper aims to provide guidance for those who are unsure about which antenna best suits their needs.

Is an external antenna needed?

An external antenna can improve the performance of the GeoXT handheld in a vehicle, under canopy or in difficult urban environments. In contrast to the integrated GPS antenna in a GeoXT handheld, an external antenna can easily be raised above your body, or the body of the vehicle, to minimize interference and the blocking of signals. This typically results in a higher number of positions and less degradation of accuracy.

Internal antennas are always subject to some degree of interference from the adjacent digital electronics of the integrated handheld. While the GeoXT handhelds use advanced anti-jamming and noise reduction techniques to minimize this effect, GPS signal strength can be improved with an external antenna.

In open sky environments, the signal strengths from the internal antenna are more than adequate for best performance, whereas in canopy or difficult urban environments, signal strength becomes a key factor in determining accuracy and productivity.

If operators need to put their GeoXT in a pocket so they can be hands-free to traverse difficult terrain while logging, then an external antenna mounted on a backpack or baseball cap may be required. The external antenna will maintain a steady antenna position that also ensures minimal interference and blocking of signals.

As the following test results show, if you are working in a vehicle, under canopy or in a difficult urban environment, or if you need to be hands-free, then an external antenna will improve your GPS performance.

Scope of study

The study examined all three antenna options—the internal antenna, the Hurricane antenna and the Patch antenna—for the GeoXT handhelds.

The GeoXT handheld, which includes EVEREST™ multipath rejection technology, was chosen for the study because it is designed for optimal performance in the difficult GPS environments where an external antenna is typically needed.

Canopy and urban environments provide challenges for GPS receivers due to multipath and signal strength degradation. Multipath occurs when the signal picked up by a GPS antenna has been reflected off a surface such as a tree trunk or building, rather than received direct from a GPS satellite. Because the signal is delayed, it introduces an error into the GPS position calculation. Signal strength is degraded by reflection or by partial blockage from tree foliage and other obstacles.

Antenna technology is one of the key ways to reduce the negative effects of multipath and low signal strength. This study was conducted in a tree canopy environment, where many GeoXT users work, to best highlight the relative strengths of the three antenna options. A static, open sky environment was used to produce a reference dataset to aid in the analysis.

Difficult urban environments were not tested in this study. However, as multipath interference is the predominant source of error in these environments, it is reasonable to expect results for canopy testing to be applicable in urban environments.

Methodology

Two different aspects of GPS performance—accuracy and productivity—were studied to determine the influence of antenna selection.

Measuring accuracy

The integrated GPS receiver in the GeoXT handheld calculates its position once every second. Because each measurement is subject to introduced errors, each position is slightly different from the previous one, even if the receiver is static at one location.

Over time a 'scatterplot' of GPS positions is built, from which a measure of the receiver's absolute accuracy can be derived using a Root Mean Square (RMS) calculation. RMS is the standard statistical measure for specifying GPS accuracy.

This study focuses on horizontal accuracy, therefore horizontal RMS (HRMS) has been used. The HRMS value represents the horizontal distance from truth (a fixed location where coordinates have been accurately measured using survey techniques) within which 63% of the recorded positions fall.

The smaller the HRMS value, the more accurate the antenna configuration. It should be noted that although derived from large data sets, the HRMS value represents the accuracy you could expect 63% of the time even if you only logged a single position.

To test dynamic accuracy, multiple runs over the same course were recorded, creating a series of lines. The GPS performance was measured by the degree to which the lines matched. This is referred to as relative accuracy.

To measure relative accuracy, the lines recorded with each antenna configuration were sampled at fixed intervals and the spread across the series of lines was measured. The resulting HRMS values represent the distance within which 63% of the GPS positions would fall. The smaller the HRMS value, the better the relative accuracy.

Measuring productivity

Productivity is the second aspect of GPS performance studied. For the purposes of this study, productivity is defined as the number of positions recorded as a percentage of the total number of positions that could have been recorded during the time period. Thus if GPS is logged at 1 second for 100 seconds, and only 75 positions are recorded due to obstructed GPS signals, 75% productivity is achieved.

Creating comparable data sets

To compare the performance of GPS receivers with different antennas, the receivers would ideally be recording data at the exact same time with the antennas on the exact same location. Practically, while multiple receivers can log concurrently, the antennas cannot be in exactly the same position at the same time.

In the open environment, the effect of using neighboring antenna locations when comparing performance is negligible, as satellite visibility is practically the same at adjacent locations. To establish an open, static performance baseline for this study, truth points located on a building roof top were surveyed in to centimeter-level accuracy, using a Trimble 5800 GPS receiver. The GeoXT handhelds were mounted on brackets, with the antennas centered over truth points. Note that the GeoXT internal antenna was not shielded (by an operator's body) as it would be in normal field use.

In canopy environments, small differences in location can have a significant impact on satellite visibility. To emulate a scenario where GPS data was recorded at the same time and location for static canopy tests, receiver and antenna combinations were rotated through a series of truth points (surveyed in using a Trimble optical Total Station), in close proximity, on consecutive days. This ensured that data sets were recorded with the same satellite configurations.

For dynamic canopy tests, four configurations of antennas—a GeoXT internal antenna, hand held in a normal operating position; a Patch antenna, worn in a baseball cap on the head; a Patch antenna with a groundplane and a Hurricane antenna, both mounted on a backpack—were logging concurrently while a technician followed a prescribed path under trees.

Static performance under open sky

Over 30 hours of data, totaling approximately 120,000 positions were collected under open sky with a GeoXT internal antenna, a Patch antenna, and a Hurricane antenna.

In open sky conditions, all receiver and antenna combinations are equally productive. At default Trimble GPS mask settings (see Appendix), you can expect to achieve 100% productivity with any of the antennas, with good satellite constellations at the location. The favorable

GPS conditions under open sky result in scatterplots that are typically tightly distributed around the truth location, as displayed in Figure 1. The red circle on each scatterplot represents the HRMS value from Table 1.

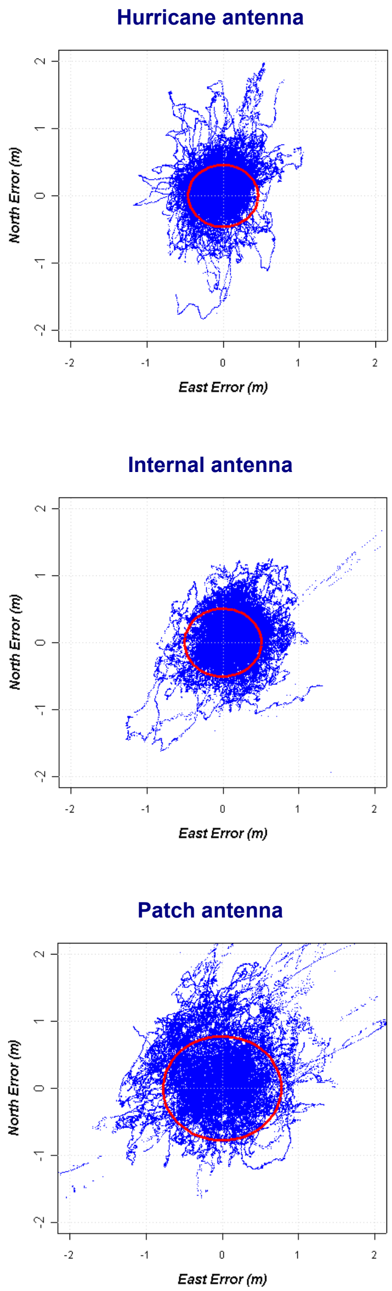

Figure 1: *Open static scatterplots by antenna configuration.*

Table 1 shows the accuracy results achieved in static testing of the GeoXT handheld with the different antenna configurations in open sky conditions. All configurations achieve sub-meter HRMS values, however the lower values achieved with the internal and Hurricane antennas reflect their more sophisticated hardware.

The Hurricane and internal antennas both use similar technology, including a built-in groundplane, and are optimized for multipath rejection. However the larger built-in groundplane, and reduced noise of the Hurricane antenna allows improved satellite tracking, which in turn contributes to better horizontal positioning. This is borne out in the results, where the Hurricane antenna shows 10% improvement in horizontal accuracy over the internal antenna.

Antenna configuration	HRMS (63%)
Hurricane	46 cm
Internal	51 cm
Patch (on groundplane)	78 cm

Table 1: *Static accuracy by antenna configuration in open sky conditions.*

Static performance under canopy

As canopy conditions introduce a great deal of variability into GPS reception, static canopy results are based on a larger data set to offset that variation. Nine sessions of data collection, totaling over 130 hours or 480,000 possible GPS positions, were recorded with the GeoXT internal antenna, the Patch antenna and the Hurricane antenna.

The testing was conducted under moderate mixed canopy. In this type of environment, scatterplots are typically more widely spread in a “star” pattern, containing radiating lines of outliers caused by multipath, as illustrated in Figure 2. Here the difference in the spread of positions is due to the relative performance of the antenna types in high multipath environments.

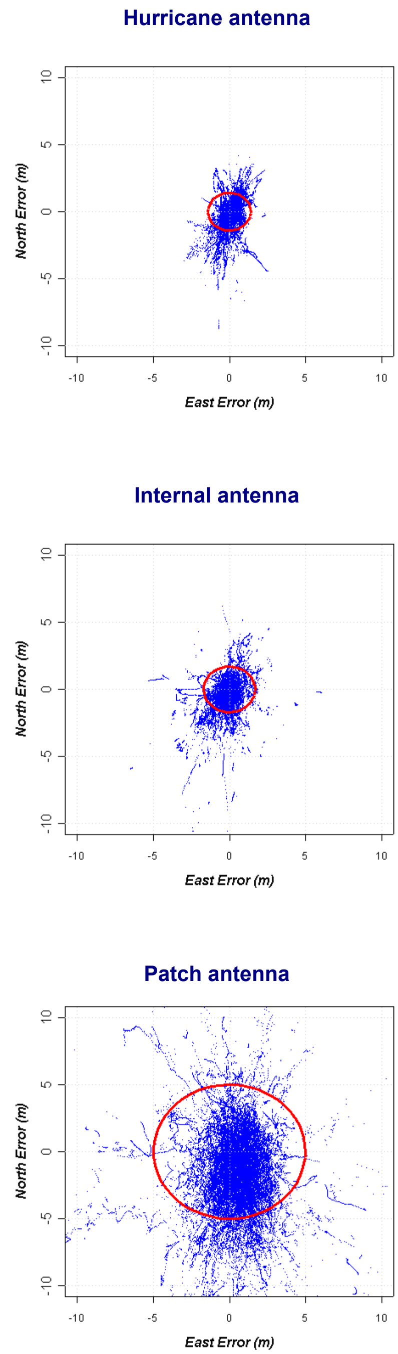

Figure 2: *Example canopy static scatterplots by antenna configuration*

Table 2 shows the accuracy results achieved in static testing of the GeoXT handheld with the different antenna configurations under canopy. The Hurricane antenna shows a 3% improvement in horizontal accuracy over the internal antenna in canopy conditions, compared to the 10% improvement observed in the open.

As detailed earlier, the Hurricane antenna is designed to better track GPS signals. However, in canopy conditions, low elevation satellites that contribute to better horizontal positioning are typically blocked entirely or degraded in accuracy due to canopy interference, so they do not contribute to improved performance.

Note that in this test set-up, the GeoXT handheld was not shielded by a body as it would be in normal field use, so test data for the internal antenna may be slightly better than in real usage.

Antenna configuration	HRMS (63%)	Productivity
Hurricane	2.03 m	48%
Internal	2.09 m	43%
Patch (on groundplane)	3.94 m	63%

Table 2: *Static accuracy and productivity by antenna configuration under canopy.*

In terms of productivity, the Patch antenna shows the highest productivity of the three configurations under canopy. Both the internal and Hurricane antennas are designed for optimum performance with EVEREST multipath rejection technology. As a result, receivers with these antennas will reject signals that are affected by multipath whereas receivers with the Patch antenna will use those same signals to calculate positions.

As the test results in Table 2 show, inclusion of these additional positions results in decreased accuracy overall. Hence increased productivity comes at the expense of accuracy.

Dynamic performance under canopy

To assess dynamic performance under canopy, GeoXT handhelds with four different antenna configurations were compared in eight runs on a 450 meter winding route through parkland. As with the static data sets, data was recorded concurrently to enable valid comparisons and analysis. The canopy was light to moderate cover, with a mix of conifers and deciduous trees.

Table 3 shows that data recorded with the Hurricane antenna had the best relative accuracy of the four antenna configurations tested—almost twice as accurate as the next best antenna, the Patch antenna mounted on a groundplane.

Antenna configuration	Relative accuracy HRMS (63%)	Productivity
Hurricane	2.47 m	86%
Patch (on groundplane)	4.45 m	91%
Patch (in baseball cap)	8.14 m	60%
Internal	8.31 m	64%

Table 3: *Dynamic precision and productivity by antenna configuration under canopy.*

Relative accuracy is illustrated in Figure 3, where the repeated path of the Hurricane antenna appears to be smoother and more precise, compared to the Patch antenna mounted on the groundplane.

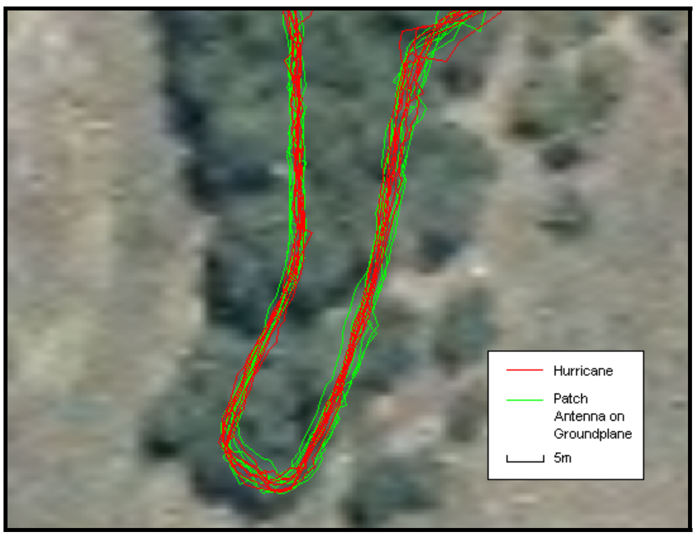

Figure 3: *Dynamic accuracy—a detail of line features recorded with Hurricane antenna and Patch antenna on groundplane.*

The lower productivity of the GeoXT internal antenna relative to the Hurricane antenna can be attributed to the realistic placement of the internal antenna in this test, with the GeoXT held at the usual position in front of the operator. In contrast, in the static test the internal antenna was mounted on a bracket and was not shielded by the operator's body.

Further analysis shows that due to the lower productivity of the internal antenna in the dynamic test, large sections of the path are not recorded. This gives the appearance of corners that are cut off, as illustrated in Figure 4, introducing significant inaccuracies into the data. This was also seen on the baseball cap-mounted Patch antenna, which has similar productivity to the internal antenna under these dynamic canopy conditions.

The degree of curvature in the test path highlights the impact of low productivity on accuracy when working under canopy. In a real use scenario this can be managed by waiting for GPS signal reacquisition before continuing, to ensure that corners are accurately mapped.

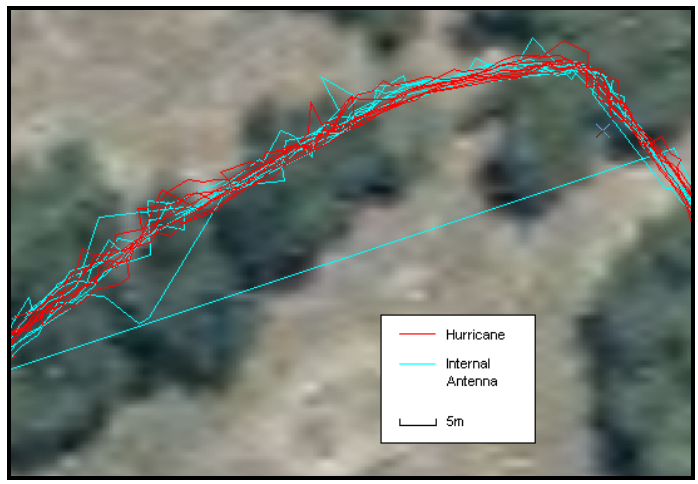

Figure 4: *Dynamic accuracy under canopy—a detail of lines recorded with Hurricane antenna and internal antenna, displaying corner cutting due to low productivity.*

Other considerations

The ergonomics of the different antennas should also be considered in selecting the best antenna option. The integrated antenna is the most convenient as no additional hardware is required—everything you need can be held in your hand. In contrast, both external antennas need to be mounted in a stable position and must be cabled to the handheld.

The Patch antenna has an integrated magnetic base, so it can attach directly to the roof of a vehicle. For work on foot, there are three options for mounting the Patch antenna:

- specially designed baseball cap
- groundplane on backpack
- groundplane on range pole

The baseball cap is the most convenient option for providing hands free operation, but as dynamic test data shows, productivity from the Patch antenna mounted in the cap is lower than when used with a groundplane and only comparable to that of the internal antenna when working under canopy.

For mounting the Patch antenna on a backpack or range pole, Trimble provides a metal groundplane with an integrated screw thread. The groundplane screws to the pole or backpack and the Patch antenna magnetizes to the groundplane.

The Hurricane antenna has a built-in screw thread that allows it to be conveniently mounted directly on to a range pole or a backpack. For vehicle operation, the Hurricane antenna can be screwed on to a magnetic mount, which then attaches to the roof of the vehicle.

While it may be less convenient to wear a backpack or hold a range pole, this clearly gives the highest degree of productivity in the canopy tests. As many workers already carry a backpack in field operations, this may not be an additional burden.

Conclusions

GeoXT handhelds have a high quality integrated internal antenna, with the option to add either the Hurricane or Patch external antennas. The internal antenna is the most convenient antenna to use as it requires no additional cables or mounting equipment.

Under testing in the open (see Table 1), the accuracy of the internal antenna was very similar to that of the Hurricane antenna and significantly better than the Patch antenna. And in the open, all antenna options show equivalent productivity. It is therefore suggested that the internal antenna will give you the best overall performance, unless:

- you require hands-free operation
- you work in a vehicle
- you work under canopy or in difficult urban environments

Where an external antenna is required, there is a choice between the Hurricane antenna and the Patch antenna. The Hurricane is a high quality antenna, designed to resist signal interference and multipath. The Patch antenna is a less sophisticated but highly portable and convenient option for hands-free use.

In both static and dynamic testing under canopy (Tables 2 and 3), the Patch antenna mounted on a groundplane provided the highest productivity of all antennas tested, and is therefore recommended for use in canopy where maximum productivity is required.

The Hurricane provided the most accurate data of the three antennas in all environments, almost twice as accurate as the Patch on a groundplane, in both static (Tables 1 and 2) and dynamic (Table 3) tests. These results confirm it as the best choice for use in canopy where GPS accuracy is the main requirement.

Of the two external antennas, the Hurricane antenna provides the best performance overall, with productivity very close to that of the Patch, and considerably better accuracy.

In summary, this study concludes that:

- In the open, the GeoXT with its integrated internal antenna is recommended, for its convenience and accuracy.
- If you need an external antenna (because you need to be hands-free, you work from a vehicle or under canopy), the Hurricane will provide the greatest accuracy, and the Patch antenna on a groundplane the greatest productivity.
- If accuracy and productivity are both important to you, and you need an external antenna, the Hurricane antenna will deliver the best overall GPS performance.

Appendix

- Data was logged at one second intervals using GeoXT handhelds with GPS firmware versions 1.04 and 1.05.
- Files were collected in TerraSync™ software, version 2.40, using default settings as follows:
  - PDOP mask = 6;
  - SNR mask = 4;
  - Elevation mask = 15°;
  - SuperCorrect = On
- All files were differentially corrected using GPS Pathfinder® Office software version 3.00, using Trimble base stations, with near-zero baseline.