WHITE PAPER

H-Star technology explained

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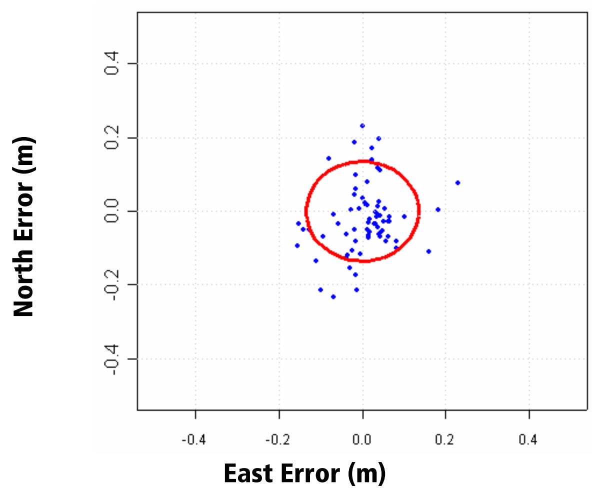
Introduction

A predominant trend in Geographical Information Systems (GIS) is the increase in demand for high accuracy enterprise data. In some instances this demand comes from within the enterprise, with high accuracy providing better efficiencies in asset management and better decision making. Increasingly, however, the demand is driven by legislative requirements.

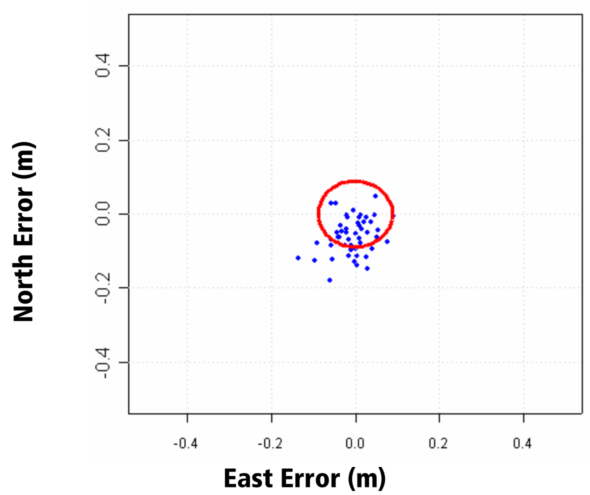
The benefits of more accurate GIS data are especially important in applications such as flow modeling, locating underground assets and establishing land inventory systems in developing nations. Utility applications in many countries have a horizontal accuracy requirement of one foot (30 cm) or better, and many cadastral agencies in developing nations are specifying 20 inch (50 cm) accuracy to enable rapid establishment of land tenure.

Delivering subfoot (30 cm) accuracy, Trimble's new H-Star™ technology provides the ideal solution for the high accuracy GIS sector. H-Star technology—a combination of advanced GPS receiver, field software with sophisticated logging capabilities, and office software with innovative postprocessing capabilities—enables high accuracy GPS data to be logged without the time and cost overheads, and complex workflows associated with traditional high accuracy data collection.

The Trimble GPS Pathfinder® ProXH™ receiver and the GeoXH™ handheld, with H-Star technology, enable subfoot (30 cm) postprocessed accuracy, and when used with an external Zephyr™ antenna, the receivers are capable of 8 inches (20 cm) or better. The following scatterplots show the accuracies achievable with H-Star technology.



GPS Pathfinder ProXH receiver with internal antenna, HRMS 13.5 cm



GPS Pathfinder ProXH receiver with external Zephyr antenna, HRMS 10.5 cm

Figure 1: H-Star data scatterplots.

The H-Star data shown in Figure 1 was collected in 50 two-minute blocks, over 9 hours in an open sky environment, with a GPS Pathfinder ProXH receiver. It was processed against three dual frequency reference stations, between 90 km and 180 km away. The HRMS values for the H-Star data show a high level of accuracy with both the internal and external antenna options for the GPS receiver. This data is considered to be representative of H-Star performance.

How H-Star technology works

Trimble's new H-Star technology utilizes advances in GPS receiver design, and improvements in field and office software to achieve subfoot accuracy.

In the field, H-Star data is collected using Trimble software[1] specifically designed for high accuracy logging. The software's Predicted Postprocessed Accuracy (PPA) indicator clearly shows the accuracy likely to be achieved once H-Star data is postprocessed. H-Star processing is designed to reach subfoot accuracy with no more than two minutes of continuous data. If lock on satellites is maintained, subsequent positions need only minimal occupation times.

Back in the office, with either the GPS Pathfinder Office software or the Trimble® GPS Analyst™ extension for ESRI ArcGIS software, it is simply a case of selecting the H-Star carrier processing option in the Differential Correction wizard. With H-Star processing, multiple reference stations are utilized to reduce errors caused by reference station bias and distance.

The three essentials of the H-Star system are:

1. Quality GPS data
2. PPA-driven workflow
3. H-Star postprocessing

The following sections will consider each of these factors in more detail.

[1] Data for H-Star processing can only be collected with version 2.50 or later of the TerraSync™ software, version 1.10 or later of the GPScorrect™ extension for ESRI ArcPad software, version 1.10 or later of the GPS Analyst extension, or an application developed with version 2.00 or later of the GPS Pathfinder Tools SDK.

1. Quality GPS data

H-Star technology is a system of high accuracy data collection that relies on good quality GPS data collected in the field, using an H-Star receiver with either an integrated antenna or the optional external Zephyr antenna.

The antenna

The antenna's role in GPS data collection is crucial, given that GPS satellites orbit the earth at an altitude of 19,000 km and the signal's initial point of entry is the antenna. A GPS antenna does a similar job to the lens of a camera.

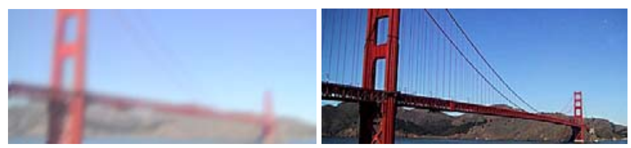


Figure 2: Comparison of low and high resolution images.

As illustrated in Figure 2, a high-resolution camera can take a much more detailed picture than an inferior camera. Similarly, a well-designed antenna can capture signals at a higher resolution, from which higher accuracy GPS measurements and positions can be computed.

Multipath interference occurs when GPS signals reflect off other objects before reaching the antenna. While GPS signals are right-hand circular polarized (RHCP), multipath reflections are reversed to left-hand circular polarized (LHCP). The internal antenna in a GPS Pathfinder ProXH receiver or GeoXH handheld employs an integrated groundplane, EVEREST multipath rejection and antenna tuning to filter out LHCP signals.

It should be noted that multipath introduces less error to H-Star measurements than to code measurements. However, the effect of multipath is still significant because of the higher relative impact of any error on a high accuracy solution.

The optional Zephyr antenna uses these same design principles to ensure high quality measurements. In addition, the Zephyr antenna receives L2 signals, which are required to obtain the best possible H-Star accuracies. L1 and L2 signals carry different information from the satellites. Traditional mapping-grade systems use the L1 signal only. Adding the L2 signal allows the H-Star system to better correct for ionospheric delays, which are a significant source of error.

The ionosphere contains electrons and ions that affect the propagation of the GPS signals. Ionospheric effects vary with sunspot activity, geographic location and seasonal and diurnal cycles.

Standard DGPS systems utilize an ionospheric correction model, transmitted in the GPS navigation message, but this is only modeling the error, not measuring it. By using dual frequency GPS, it is possible to calculate the true ionospheric delays at both the reference station sites and user end, and to correct for this in the solution.

For best results with the ProXH receiver, the GPS antenna should be mounted on a pole or, if necessary, on a backpack. A pole is easier to position exactly over a point, while a backpack is easier to use for dynamic data collection. Both techniques will position the antenna with an unobstructed view of the sky.

For ease of use, the GeoXH can be hand held when used with the internal antenna. For best results with the external Zephyr antenna, the antenna should be pole mounted.

The GPS receiver

The GPS signal is affected by electromagnetic interference commonly referred to as noise. Some of this noise is generated by electronic components within the GPS receiver itself, while other sources of interference may be nearby electronic devices or overhead transmission lines. By the time the signal reaches the receiver circuits, it is buried in noise. A large component of GPS receiver design is concerned with recovering the GPS signal from this noise.

The advanced noise reduction techniques employed in the design of Trimble's H-Star receivers shield both receiver and antenna from electromagnetic interference from adjacent sources.

2. PPA-driven workflow

The Predicted Postprocessed Accuracy (PPA) indicator provided by Trimble field software enables users to log data very efficiently, having confidence that the postprocessed data will meet their accuracy requirements.

A key feature of the H-Star system, the PPA is continually calculated and displayed based on the antenna type, the satellite geometry, the duration of lock on a minimum number of satellites, and the assumption that the reference stations that will be used in postprocessing meet H-Star processing requirements. Several external factors affecting accuracy, such as multipath and ionospheric activity, are not factored into the PPA calculation.

The PPA is an estimated Horizontal Root Mean Square (HRMS) value, representing the horizontal distance from truth within which at least 63% of the recorded positions are expected to fall after postprocessing.

In the screen snap below, the PPA value displayed is 0.21m, meaning that postprocessed accuracy for the current feature should be 21 cm or better. In other words, postprocessed error should be no greater than 21 cm. Note that smaller HRMS values (smaller PPA numbers) indicate higher accuracy.

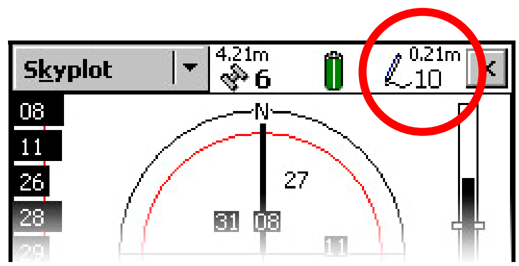


Figure 3: The TerraSync software, showing a PPA value of 0.21 m

The PPA predicts the accuracy that will be achieved after the H-Star postprocessing of all positions logged since carrier lock was acquired. The value of the PPA correlates directly with the length of time spent continuously collecting H-Star data, so if the receiver continues to maintain lock, and the satellite geometry is good, accuracy will improve for all positions since lock was obtained.

H-Star technology relies on data being collected continuously on a minimum set of satellites. This is referred to as "carrier lock". To maintain lock, the receiver must track four or more satellites without interruption when static, and five or more satellites without interruption when dynamic. H-Star measurements can be collected while moving as long as lock is maintained throughout.

Figure 4 shows the effect of carrier lock duration on accuracy with an H-Star receiver. Six hours of H-Star rover data was collected with a ProXH receiver in open sky conditions and processed with a range of carrier lock durations. The files were differentially corrected using three dual frequency reference stations between 20 and 120 km away.

Because H-Star processing uses measurements logged before and after the current position, accuracy depends on the duration of carrier lock. The graph shows that for very short carrier lock durations, very good accuracies can be obtained, with the steep fall of the curve indicating rapid improvement in accuracy. After two minutes, the accuracy still continues to improve with time – but at a much slower rate. The graph also shows the additional accuracy improvement possible with the optional Zephyr antenna.

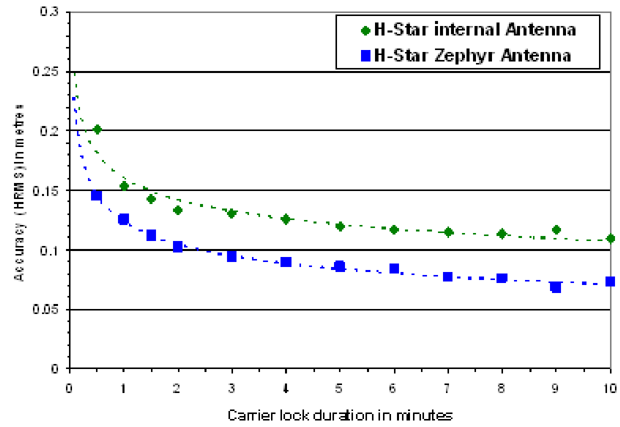


Figure 4: Accuracy v duration of carrier lock for ProXH internal and Zephyr antenna

It is important to note that the accuracy attained is applied to all positions and features logged since carrier lock was acquired. Figure 5 shows how this effect would apply to a hypothetical dataset with three separate periods of carrier lock. The longer the duration of lock, the better the accuracy, with all positions achieving the same level of accuracy for a given duration.

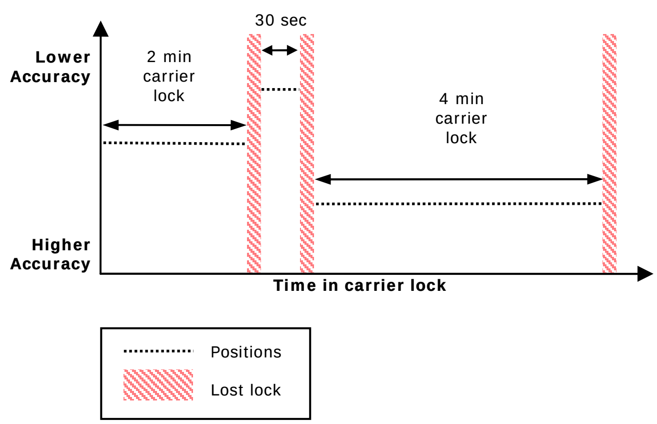


Figure 5: Accuracy as related to periods of carrier lock

Common reasons for losing lock include passing under an obstruction such as a bridge or a tree, lowering the antenna, or returning to a vehicle to drive to another feature.

Data collection practices

Ensuring accuracy

- Log GPS positions until the PPA value reaches the required accuracy.
- For example, to obtain an accuracy of 20 cm, simply remain at the feature and log GPS until the PPA shows 20 cm.
- If lock is lost before achieving 20 cm, it will be necessary to reacquire satellites and remain at the feature until the PPA value reaches 20 cm.
- This is a reliable method for ensuring collection of sufficient data to obtain the required accuracy for point features and averaged vertices. It can be highly productive in open environments.

Maximizing productivity

- In open environments with five or more satellites in view, it may not be necessary to remain at a single feature until the required PPA value is reached. When collecting a series of features with a clear view of the sky, loss of lock is unlikely and it is possible to move between features *before* the required PPA is reached.
- As long as lock is maintained while logging features, and the PPA reaches the required value during the collection of those features, then the postprocessed accuracy for *all* features will meet requirements.
- Provided lock is maintained, this is a highly efficient way to collect field data. However, if lock is lost before the PPA reaches the required accuracy, then you will need to recollect *all* of the features logged since lock was obtained.

3. H-Star postprocessing

An H-Star receiver with single frequency measurements from the integrated antenna can converge on a high accuracy solution very quickly. If there are dual frequency measurements from the Zephyr antenna, the postprocessing engine uses these extra measurements to converge even more quickly on a high accuracy solution.

With L1 data, the postprocessing engine can model and estimate ionospheric delay. With the addition of L2 data, the postprocessing engine achieves even better accuracy by directly measuring the ionospheric delay, thus removing a significant source of error.

Postprocessed accuracy depends significantly on the quality of reference stations used and their distance from the area where data is being collected. The quality of reference stations varies and to enhance quality assurance, Trimble maintains a list of Internet base providers and monitors major providers such as SOPAC and the US Geodetic Survey's CORS, for new base stations. This list is used in Trimble's postprocessing software to automate the downloading of base data.

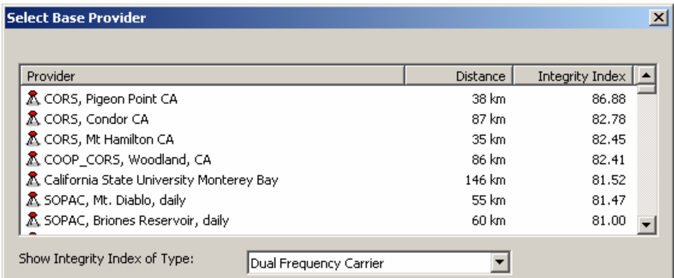
Trimble also calculates a reference station integrity index for each base station on the list.

The reference station integrity index

Trimble regularly re-calculates the integrity index value for each reference station, to indicate the quality of the reference data provided by the reference station. A poor integrity index value indicates that data from a particular reference station will provide less accurate corrections than data from a reference station with a good integrity index.

The integrity index is scaled from 0 to 100, with the best reference stations scoring the highest. The station with the highest integrity index may not necessarily be the closest. This index is calculated using integrity characterizations (bias, precision, and reliability) combined with baseline distance between the roving receiver and the reference station.

In addition to reference station receiver quality, the integrity index may be affected by factors such as station or Web server malfunction, and damage to or movement of a reference station antenna.


Select Base Provider

Provider	Distance	Integrity Index
CORS, Pigeon Point CA	38 km	86.88
CORS, Condor CA	87 km	82.78
CORS, Mt Hamilton CA	35 km	82.45
COOP_CORS, Woodland, CA	86 km	82.41
California State University Monterey Bay	146 km	81.52
SOPAC, Mt. Diablo, daily	55 km	81.47
SOPAC, Briones Reservoir, daily	60 km	81.00

Show Integrity Index of Type: Dual Frequency Carrier

Figure 6: GPS Pathfinder Office software, showing base station list with integrity index column at right

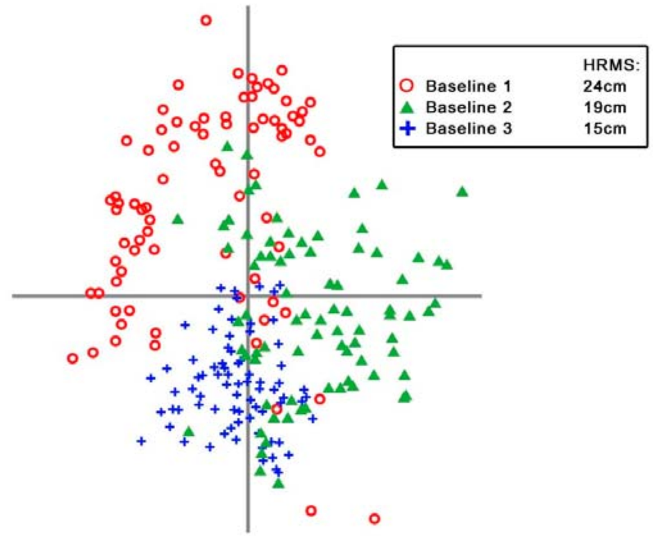
Selecting reference stations

When choosing which reference stations to use, the general rule is to choose stations that are close to the rover and which have a high integrity index.

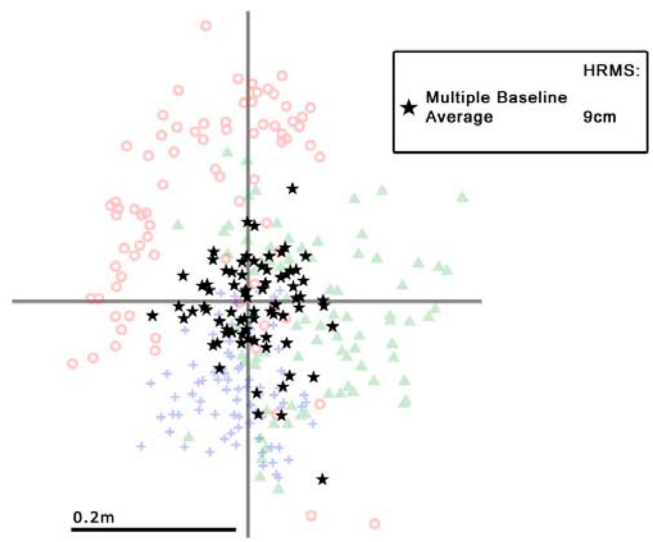
H-Star postprocessing enables the averaging of results calculated from multiple bases. The effect of longer baseline distances can be reduced by averaging with several reference stations in different locations.

Using an averaged result from evenly-distributed reference stations lessens the effect of atmospheric error from any one reference station, and provides a truer picture of what was actually happening at the point measured. A cluster of reference stations in one direction may not improve accuracy.

Figure 7 shows the bias of individual reference stations, each with data clustered in one direction, and the much better accuracy achieved when data from the baselines is averaged, shown by the superimposed multiple baseline average in the second plot.



Plot of three single baselines



Plot of three single baselines overlaid with a multiple baseline average

Figure 7: The effect of averaging multiple baselines.

For optimum results, Trimble recommends choosing a base provider group of at least three well-distributed reference stations, each with a good integrity index. However, it is also possible to achieve very good results using a single reliable reference station in close proximity (within 20 to 30 km). The closer a reference station is to the rover receiver, the less error is introduced due to atmospheric effects.

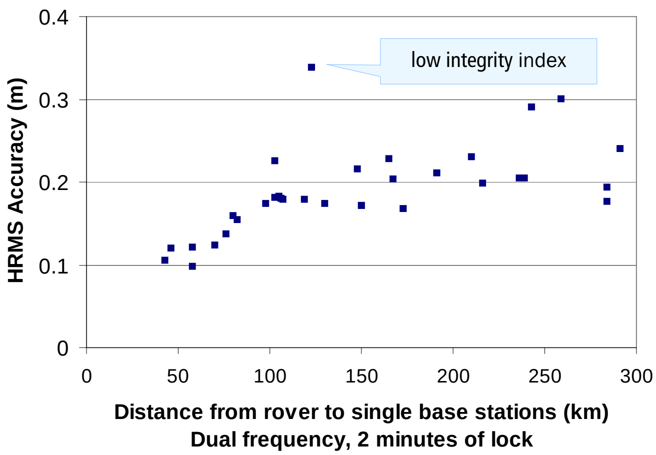


Figure 8: HRMS v distance from rover to base station

Figure 8 shows better accuracy (lower HRMS values) for the positions calculated using reference stations that are closer to the rover receiver and accuracy worsening as distance between rover and reference station increases.

Each data point on the graph represents the same rover file of dual frequency data corrected against a different reference station. The rover file contained 40 positions, each collected with 2 minutes of lock, over a period of 4 hours.

The "low integrity index" station has a significantly worse HRMS value for its relative proximity to the rover. The most likely reason for this is receiver quality, although other factors such as an inaccurate antenna position, atmospheric conditions at the site, or a Web server problem may also play a part.

Errors can also be introduced by mixing different coordinate systems and datums. For example, failure to correctly transform positions between the WGS-84 and NAD 83 datums can introduce errors of up to a meter. It is important to remember that postprocessed GPS positions are in terms of the reference position of the base provider(s) used.

The Trimble reference station list provides all reference positions in terms of the International Terrestrial Reference Frame 2000 (ITRF00). ITRF00 is the international standard for expressing GPS reference positions. However, any reference positions utilized should be regularly monitored, as any change in a base station position may cause new positions to be incompatible with your existing GIS database.

How does H-Star differ from existing high accuracy GPS collection technology?

H-Star technology is simpler to use and more cost-effective than the alternatives that are currently available. Prior to Trimble H-Star enabled systems, the following options were available for achieving subfoot accuracy:

- Survey grade systems, available from both Trimble and other companies. These systems are capable of centimeter level accuracy, either real time kinematic (RTK) utilizing corrections from an RTK reference station, or from a Virtual Reference Station (VRS) system, or postprocessed kinematic (PPK). Capable of a much higher accuracy than typically required in the GIS sector, survey grade systems impose operational overheads unsuited to subfoot applications.

- Traditional carrier phase GPS receivers, available from Trimble and other companies. To achieve subfoot accuracy, traditional carrier phase receivers require lock to be maintained on a set of satellites for extended periods of time.

- The OmniSTAR HP satellite differential service, available today in some parts of the world. The OmniSTAR HP service is capable of delivering accuracy of 10 cm (4 inches). In addition to requiring specific hardware, the OmniSTAR HP service also requires an annual subscription fee and long acquisition times. For example, the Trimble AgGPS® 252 receiver with OmniSTAR HP requires a 30-minute acquisition time before providing 10 cm accuracy.

Conclusion

H-Star technology combines quality GPS data with smart field software and advanced postprocessing techniques in a powerful system that delivers subfoot (30 cm) accuracy. H-Star technology represents a leap forward in GPS technology, with significant advantages over existing solutions. Simple processes enable field crews to collect high accuracy GPS data with short occupation times, significantly increasing productivity.

For subfoot (30 cm) accuracy or better, H-Star technology requires only two minutes of data to be collected: a dramatic improvement in productivity over traditional carrier phase data collection. Reference stations can be up to 200 km away, reducing the need for expensive base station infrastructure. Many locations will be adequately served by freely available base data from the Internet.

H-Star technology uses advanced receiver design and sophisticated processing techniques, but its simple workflow shields the operator from complexity. The same field staff who manage the GIS attribute information can collect high accuracy data, significantly improving the flexibility of the workforce and the productivity of the enterprise GIS.