White Paper

Trimble ProPoint Engine

Next-Generation Centimeter Positioning and Orientation

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Trimble

The Trimble® ProPoint® GNSS engine, housed within a range of Trimble GNSS receivers, provides superior performance under challenging GNSS environments. It features groundbreaking measurement management that leverages the latest developments in GNSS and inertial sensor fusion. Dive into the white paper below to learn more about this industry-leading technology.

Introduction

In 1992, Trimble released the world's first commercial Global Positioning System (GPS) receiver capable of performing centimeter-accurate Real-Time Kinematic (RTK) positioning. Although this first-generation system required the user to position the rover over a known location to initialize the system, it was revolutionary for land surveyors, enabling topographic mapping, stakeout and as-built surveys in real time.

Follow-on applications such as construction machine control and agriculture resulted in positioning engines that have delivered rapid on-the-fly initializations, high update rate and low latency positions. This technical white paper provides an overview of the Trimble ProPoint GNSS engine, the fifth generation RTK/RTX precision positioning engine, engineered to provide positions and orientation from the fusion of GNSS signals, worldwide correction services and measurement data from a variety of sensors.

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System Architecture

Support for the latest constellations and frequencies

The space segment of the world's Global Navigation Satellite System (GNSS) is constantly being modernized with new generations of satellites. These new signals, while improving the performance of user equipment, pose a challenge for receiver manufacturers to support the structure of new signal transmissions. Trimble receivers equipped with Trimble Maxwell™ 7 and ProPoint technology are ready to reap benefits from all current GNSS signals transmitted on all frequencies. These include:

- **GPS:** L1 C/A, L1C, L2E, L2C, L5
- **GLONASS:** L1 C/A, L1P, L2P, L2 C/A, L3 CDMA
- **Galileo:** E1, E5A, E5B, E5AltBOC, E6
- **BeiDou:** B1C, B1i, B2i, B2A, B2B, B3i
- **QZSS:** L1 C/A, L1S, L2C, L5, LEX
- **IRNSS:** S1 C/A, L5
- **SBAS:** L1 C/A, L5
- **MSS:** Trimble RTX, OmniSTAR

ProPoint technology is capable of using all available signal inputs, provided an RTK base receiver is transmitting corrections for the same signals. This has resulted in a more flexible and more accurate solution in challenging GNSS environments. ProPoint technology also allows for flexible signal management, which helps mitigate the effects of signal degradation and provides a GNSS constellation-agnostic operation. For example, when individual frequencies and constellations are spoofed or jammed, the receiver continues to provide positioning using available measurements.

Tight coupling of IMU data with RTK and RTX

The ProPoint engine is designed from the ground up with inertial navigation and sensor fusion in mind. The raw GNSS measurements, together with the gyroscope and accelerometer data, are combined in a single position and orientation solution. The inertial measurement unit (IMU) in most products is an in-house design built on the same circuit board as the GNSS receiver. This tight integration provides a robust solution that maximizes the benefits of GNSS and INS.

Large filter and accurate modeling of all error sources

Owing to advances in the GNSS signal spectrum and low-power mobile computing technology, ProPoint was designed with an improved approach to data signal filtering. By combining all of the measurements together into a single filter and estimating the carrier integer ambiguities simultaneously with an extended set of filter states, an optimal solution is achieved. While more computationally intensive, this approach delivers the most flexible use of all available GNSS signals.

The result of this new approach to signal filtering is that it permits any and all available signals to be used in the RTK position solution, as a variety of traditional methods based on signal combinations have become redundant. Although dual-frequency data is required to account for atmospheric effects on GNSS signals in RTK positioning, the improved filtering technology means that the processor can use any or all of the signals, including individual signals in harsh tracking environments, generating an optimal solution.

Dynamic models tuned for application

The ProPoint engine allows users to select from a dynamic model depending on what best suits their application. Using data collected in a variety of applications, models have been created that are used as inputs to the engine.

Robust estimation techniques for detection of outliers

The ProPoint engine identifies within the received input data any measurement that does not match a stochastic model. For each measurement that doesn't match its stochastic model, the engine will either reject the measurement, adjust the stochastic model assigned to the

measurement or correct the measurement. The method generally enables the provision of a precise position estimation even in the presence of measurements containing one or more outliers.

Positioning modes

ProPoint supports a variety of GNSS-only and GNSS/INS positioning modes. These include the following:

- **Precise positioning:** GNSS-SBAS, GNSS-DGNSS, GNSS-RTK, GNSS-RTX
- **Precise positioning with orientation:** GNSS/INS-SBAS, GNSS/INS-DGNSS, GNSS/INS-RTK, GNSS/INS-RTX

Depending on the availability of differential corrections, the engine will gracefully transition positioning modes to deliver uninterrupted positioning.

Integrated RTK xFill

During periods of radio outage when the base station correction stream is unavailable to support conventional single-base or Virtual Reference Station (VRS) Network RTK, Trimble xFill® correction service provides the technology that enables positioning to continue for short periods with centimeter-level precision. Not only does this eliminate positioning dropouts, it also enables a brief excursion into an area masked from the reference radio signal, yet still visible to the GNSS constellations. To achieve centimeter positioning with GNSS signals, Trimble xFill provides a specialized correction stream broadcast by L-band satellite that is generated using Trimble Real-time eXtended (Trimble RTX®) technology.

The Trimble xFill technology is able to produce RTK positions with precision levels similar to traditional differential RTK because it mitigates the same source of errors. The satellite clock, orbit and measurement biases that are cancelled via differencing in standard RTK processing are modeled and transmitted as part of the Trimble RTX correction stream.

These effects then become known quantities and can be properly accounted for when processing the rover measurements. The atmospheric errors are dealt with by algorithms specifically developed for the Trimble RTX system, reducing any residual effects to an acceptable level for high-accuracy GNSS positioning applications. As a result, the overall Trimble RTX data processing provides modeling of the residual errors on the satellite observations that are comparable to the ones achieved with RTK.

Leverage CPU capacity in modern platforms

As the number of GNSS signals increases, so does the computing power required to process all the measurements. To address this challenge, Trimble has released receiver platforms with upgraded processors and the latest Trimble Maxwell 7 GNSS ASIC (Application-Specific Integrated Circuit).

This allows positions to be delivered to control systems with minimal latency while also reducing overall power consumption.

Benefits of Trimble ProPoint engine

The advantages of including the ProPoint positioning engine in various applications include key value drivers of accuracy, availability and integrity.

Many position systems can provide some of these attributes, but the ProPoint engine delivers the positioning and orientation necessary to make your project truly successful. In head-to-head testing with the previous-generation RTK/RTX engine in challenging GNSS environments, such as near and among trees and built environments, the ProPoint engine performed **at least 30% better across a variety of factors,** including time to achieve centimeter precision levels, position accuracy and measurement reliability.

Accuracy

Open sky guidance and control applications have been benefiting from the centimeter accuracy of RTK for over 20 years. Unfortunately, most real-world, autonomous applications operate in challenging environments where satellite line of sight can be impaired. Trees, buildings, bridges and other obstacles both block and reflect incoming signals. ProPoint in GNSS-only mode, with its flexible signal management and optimal single filter approach, delivers centimeter-level accuracy results under tree canopy where at best, decimeter-level accuracies could be obtained in the past.

For applications where most of the sky is blocked, the integration of IMU measurements into the engine offers the best solution. The ProPoint engine tightly integrates the available GNSS and IMU measurements, delivering centimeter-level accuracy and orientation during these events.

The latency of the computed results is also an important factor in autonomous vehicle control. A position may be very accurate but if it is delayed, then it has little value to system performance and safety. The ProPoint engine produces positions and orientations with less than 20 milliseconds latency at update rates up to 100 Hz.

Availability

It has long been a goal of Trimble to deliver centimeter-level precision for everyone, everywhere. Allowing our customers to operate in more difficult environments expands the variety of potential applications and gives a better return on investment for the end user of the technology.

ProPoint in GNSS-only and GNSS/INS modes delivers centimeter-level accuracy in denser tree canopy and high-rise urban environments where historic engines would struggle. Both on-road and off-road vehicles operating close to buildings or under bridges continue to achieve close to 100% availability of position and orientation.

Users in RTK mode benefit from the integrated xFill technology to allow continued operation when the correction source is lost. This boosts availability over what can be achieved by RTK users who are not leveraging Precise Point Positioning (PPP) technology to bridge loss of corrections from the local base.

Integrity

Providing accurate precision estimates is critical to centimeter-level control of autonomous machines. Applications depend on these horizontal and vertical indicators to know when to trust the position and orientation information. An incorrect estimate can result in damage to the end product, equipment, or at worst, personnel.

Considerable testing of ProPoint in a variety of environments around the world has resulted in estimates that accurately reflect the precision from computation benefits from improved noise models and the ability to adapt these models to any environment.

Proven performance

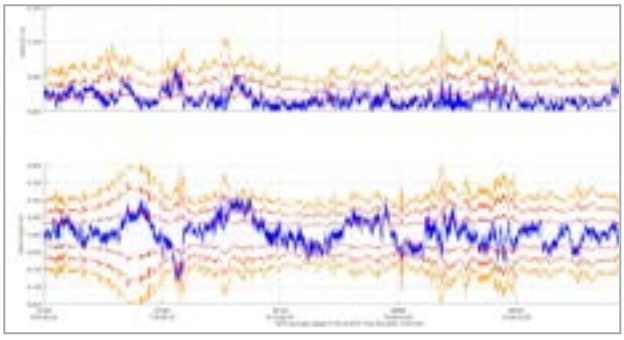
In order to evaluate the capabilities of ProPoint, it was essential for the team to conduct field tests that would closely approximate the types of challenges encountered by customers in the field on a day-to-day basis. To this end, Trimble carried out an extensive testing campaign, employing several different test courses around the world, each comprising different environments characterized by common GNSS obstacles such as trees and buildings. Below are examples from GNSS-only and GNSS/INS RTK tests carried out to compare the previous-generation engine with the ProPoint engine. Similar results are obtained in RTX modes.

GNSS Performance

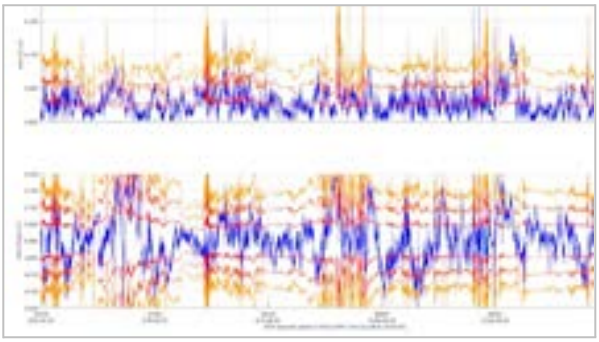
The Trimble ProPoint engine provides superior GNSS-only performance in hostile environments. Looking at RTK data from a stationary 19 km baseline with the rover in a suburban environment (5 m away from a 2-story building with trees in the vicinity) an improvement is seen in both the magnitude of position errors and in the estimation of position errors. In each set of plots the top axis gives the position error in the horizontal while the bottom axis gives the vertical position error.

The blue lines indicate the position error from the known coordinate for the survey point. ProPoint produces a more accurate and precise solution than the previous-generation RTK engine.

The red and orange lines indicate the 1-sigma, 2-sigma and 3-sigma error estimates output by the receiver in real time. These can be seen to have dramatically improved with ProPoint, better estimating the actual position error in these harsh conditions. The error estimates are also less erratic. This will help users better gauge in real time whether or not the position solution meets their accuracy requirements.



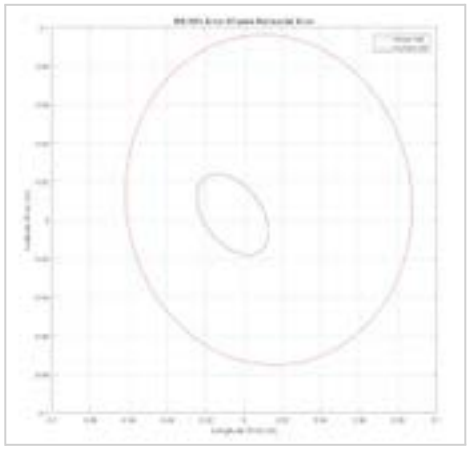
Trimble ProPoint engine positioning

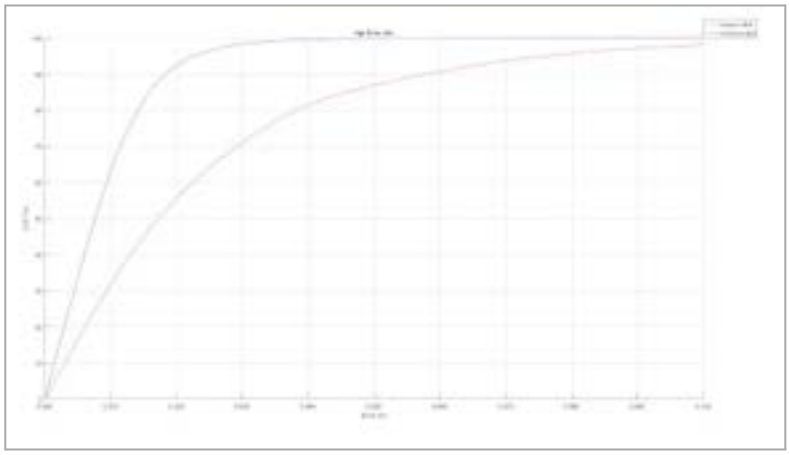


Previous-generation RTK positioning

GNSS/INS performance

The following results are from an analysis of a 13 km suburban drive with the system running in GNSS/INS(RTK), which starts near the base station and ranges out to about 9 km away from the base station. A significant improvement is seen in the 95% error ellipses of the horizontal positioning, shown for ProPoint in blue. This is the difference between the real-time GNSS/INS positions and a high-accuracy, post-processed truth trajectory using an Applanix POSLV system (high-end IMU system).





Similar improvements are seen in the vertical performance. Looking at the Cumulative Distribution Function, clear improvements can be seen in the plot of the error in the height component. With the previous-generation GNSS/INS engine, 95% of the heights (the 95 percentile) fell within 78 mm of truth, now with the ProPoint engine, **95% of the heights fall within 23 mm of truth.**

Conclusion

The Trimble ProPoint engine is an investment in the future, ready to fuse present and future GNSS measurements with inertial and sensor data to deliver premium performance in the toughest of environments. If accuracy, availability and integrity are key requirements for your application, then ProPoint is the ideal choice.

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