Trimble ProPoint Engine - Next Generation Centimeter Positioning and Orientation

Superior performance under challenging GNSS environments, with groundbreaking measurement management that leverages the latest developments in GNSS and Inertial sensor fusion.

INTRODUCTION

In 1992, Trimble® released the world's first commercial GPS (Global Positioning System) 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 and high update rate, low latency positions. This technical bulletin provides an overview of the Trimble ProPoint™ 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.

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 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

Trimble ProPoint GNSS 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 system which is more flexible and also provides a more accurate solution in challenging GNSS environments. The new Trimble ProPoint GNSS 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 Trimble 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 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 modelling of all error sources

Owing to advances in the GNSS signal spectrum and low power mobile computing technology, Trimble 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. Multi-filter techniques using combiners, such as Trimble's FAMCAR (Factorized Multi-Carrier Ambiguity Resolution) had benefits in reducing processing load with earlier generation CPUs, but ultimately can result in some suboptimal behavior in demanding high multipath environments.

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 individually in harsh tracking environments, to generate that optimal solution.

TECHNICAL PUBLICATION

Dynamic models tuned for application

The ProPoint engine allows selection of a dynamic model that best suits the application. Using data collected in a variety of applications, models have been created that are used as inputs to the engine. Off-road vehicle models that allow for wheel slippage and sideways movement contrast to on-road automotive models which expect the vehicle heading and direction of travel to be the same. The marine model allows for side-to-side motion and lateral drifting.

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

The Trimble ProPoint Engine 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 provides the technology that enables positioning to continue for short periods with centimeter-level precisions. Not only does this eliminate positioning drop-outs, 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 (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 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

To understand the advantages of including the ProPoint Positioning Engine in your application we shall review the key value drivers in terms of accuracy, availability and integrity.

Many position systems can provide some of these attributes but we believe that ticking all the boxes will deliver the positioning and orientation necessary to make your product 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 Trimble ProPoint Engine performed at least 30 percent 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. The Trimble ProPoint Engine 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 100Hz.

Availability

It has long been a goal as a company to deliver centimeter precision for everyone everywhere. Allowing our customers to operate in more difficult environments expands the variety of potential applications and a better return on investment for the end user of the technology. ProPoint in GNSS only and GNSS/INS modes deliver centimeter-level accuracy in denser tree canopy and high rise urban environments where historical 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 that achieved by RTK users that are not leveraging 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 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 precisions. ProPoint precision computation benefits from improved noise models and the ability to adapt these models to the current environment.

PROVEN PERFORMANCE

In order to evaluate the capabilities of Trimble ProPoint, it was essential to conduct field tests which 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.

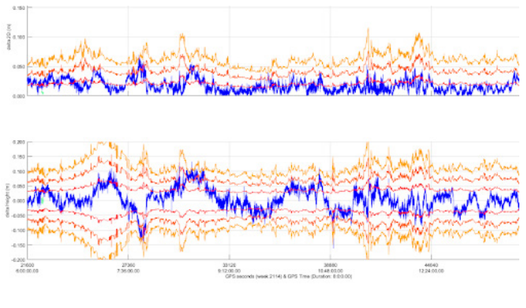
GNSS Performance

The Trimble ProPoint Engine provides superior GNSS-only performance in hostile environments. Looking at RTK data from a stationary 19km baseline with the rover in a suburban environment (5m 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.

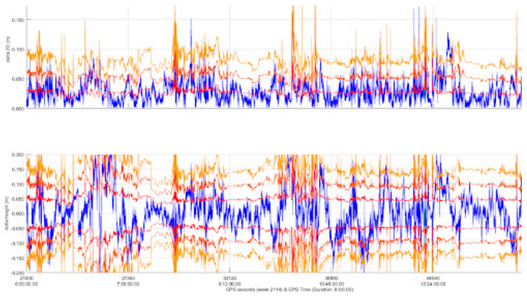
The blue lines indicate the position error from the known coordinate for the survey point. The Trimble ProPoint Engine produces a more accurate and precise solution than the previous generation RTK engine.

The red/orange lines indicate the 1-sigma, 2-sigma & 3-sigma errors estimates output by the receiver in real-time These can be seen to have dramatically improved with the Trimble ProPoint Engine, 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

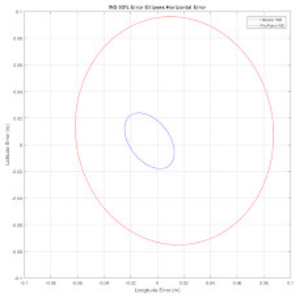


Previous generation RTK positioning

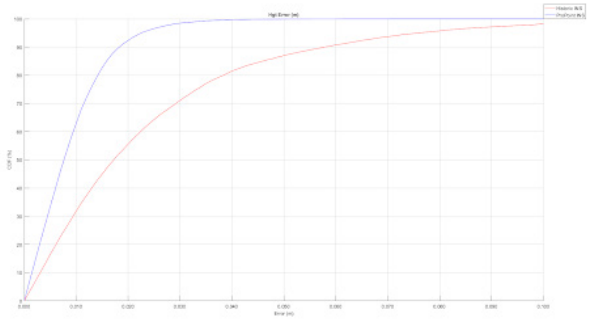


GNSS/INS Performance

The following results are from an analysis of a 13 km suburban environment 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 plot of the error in the height component clear improvements are seen. With the previous generation GNSS/INS engine 95% of the heights (the 95 percentile) fell within 78mm of truth, now with the Trimble ProPoint Engine 95% of the heights fall within 23mm of truth.



CONCLUSIONS

Trimble's 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. When accuracy, availability and integrity are key requirements for your autonomous application then ProPoint is the ideal choice.

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