swift NAVIGATION

Continuous GNSS Corrections Along the Coast of the U.S.

Results of a West Coast Drive Test

Swift Navigation's lane-level positioning production solution for autonomous vehicles continually undergoes testing—both as a gauge for internal improvements as well as customer-specific applications. One such test is captured in this paper as the Swift team demonstrates the true breadth of its solution with a test drive that extended beyond standard drives in local, frequently-tested environments to one across the West Coast of the United States. In addition to providing the data from this test drive, Swift summarizes its positioning solution comprised of the Skylark™ cloud corrections service and Starling® positioning engine.

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Skylark

Swift Navigation launched its Skylark Cloud Corrections service in preview markets in spring of 2018. By summer of 2019, Skylark had nationwide coverage across the contiguous United States. This scalable network delivers a continuous stream—via the cloud—of robust, reliable, multi-constellation, multi-frequency GNSS corrections, with the latency, security, precision and reliability required for safety and autonomy.

Skylark is hardware-independent, giving customers a choice in today's rapidly improving and affordable GNSS sensor ecosystem. OEMs are able to benefit from the lane-level positioning Skylark delivers using a host of third-party receivers and microprocessors in addition to Swift's Piksi® Multi and Duro® GNSS receivers.

Skylark Key Features

Fast Convergence Times

- <20s to 10cm*

High-Accuracy Corrections

- <10cm Accuracy*

Nationwide Coverage

- Across the Contiguous U.S.

SSR Ready

- Reduces bandwidth, improves privacy and scalability

Starling

Starling is an advanced, high-precision, receiver-agnostic positioning engine that works with a variety of automotive-grade GNSS chipsets and inertial sensors—making it ideal for autonomous applications. Starling's software is platform-independent and enhances the measurements for commercially available GNSS receivers—geodetic-grade to mass-market—to provide centimeter-accurate results with high integrity.

Starling supports the calculation of precise position, velocity and time (PVT) and when combined with inertial sensor measurements, wheel odometry and other sensor inputs, Starling can assist with vehicle localization, decision and control.

Starling Key Features

Receiver-Agnostic

- Works with automotive and commercial-grade GNSS measurement engines

Centimeter-Level Performance

- Delivering <10cm accuracy when connected to Skylark*

Multi-Constellation / Multi-Frequency (L1/L2/L5)

- Supports GPS, GLONASS, BeiDou, Galileo & SBAS

Navigation Outputs

- Swift Binary Protocol (SBP) & NMEA 0183

Positioning Solution — Skylark + Starling

Together Starling and Skylark deliver a high-accuracy positioning solution. This solution is organized into three main sub-systems: the measurement engine, the corrections service and the positioning engine.

The measurement engine is responsible for outputting GNSS observations. This sub-system is provided outside of the Skylark and Starling positioning solution. Swift's GNSS offering is designed to be measurement engine agnostic, including supporting many third-party providers.

As detailed earlier, the Skylark corrections service estimates high-accuracy corrections which can be used to eliminate the various sources of error in the GNSS signals, while the Starling positioning engine estimates position, velocity and the related protection levels based on both the GNSS observations and the high-accuracy corrections from Skylark.

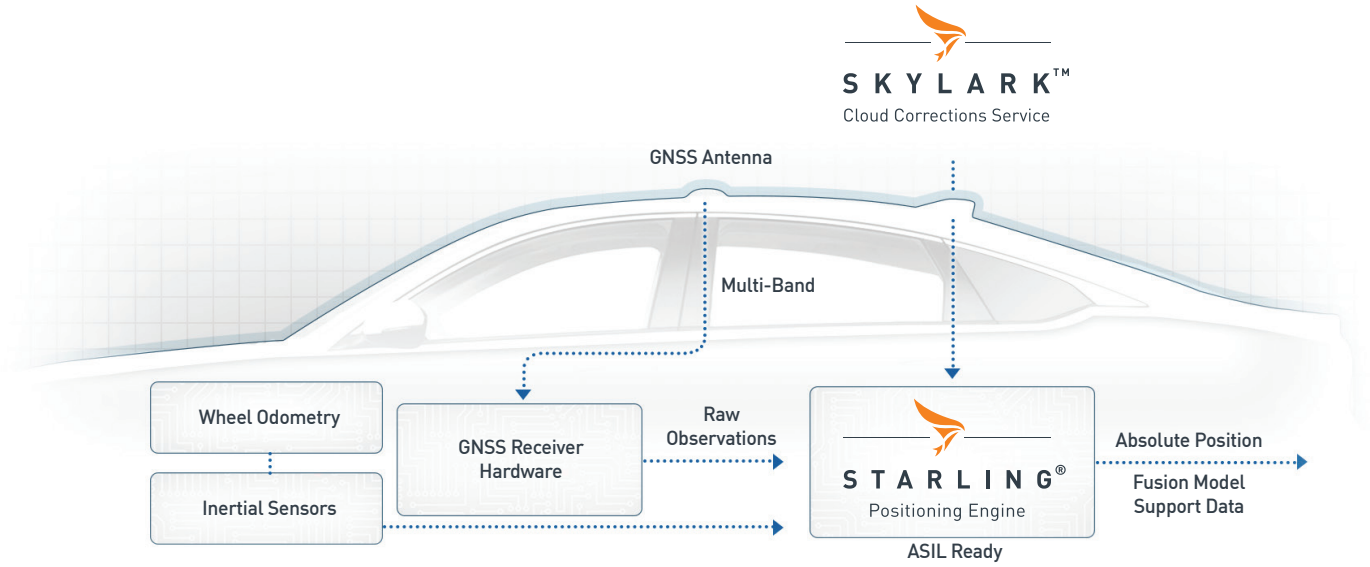

Figure 1 - High-Level Architecture of the Proposed Positioning System

Static Performance of the Skylark + Starling Positioning Solution

Before exploring the performance of Skylark and Starling during a west coast drive test, the team at Swift performed a static test.

Table 1 shows convergence times with Starling in static mode when connected to Skylark (770 cycles of RF signal turned on/off over 24 hours) on a Piksi Multi receiver.

	50th percentile (over 770 reconvergences)	68th percentile (over 770 reconvergences)	90th percentile (over 770 reconvergences)
Convergence time to <10cm error	19 seconds	30 seconds	60 seconds

Table 1 - Convergence Time Performance of Piksi Multi + Skylark Corrections, Static Test

In addition, Figure 2 shows the accuracy of a Piksi Multi receiver performing continuous navigation (no reset) when connected to Skylark. It can be seen that the bulk of the horizontal accuracy distribution obtained is well below decimeter at the 4-5 cm level.

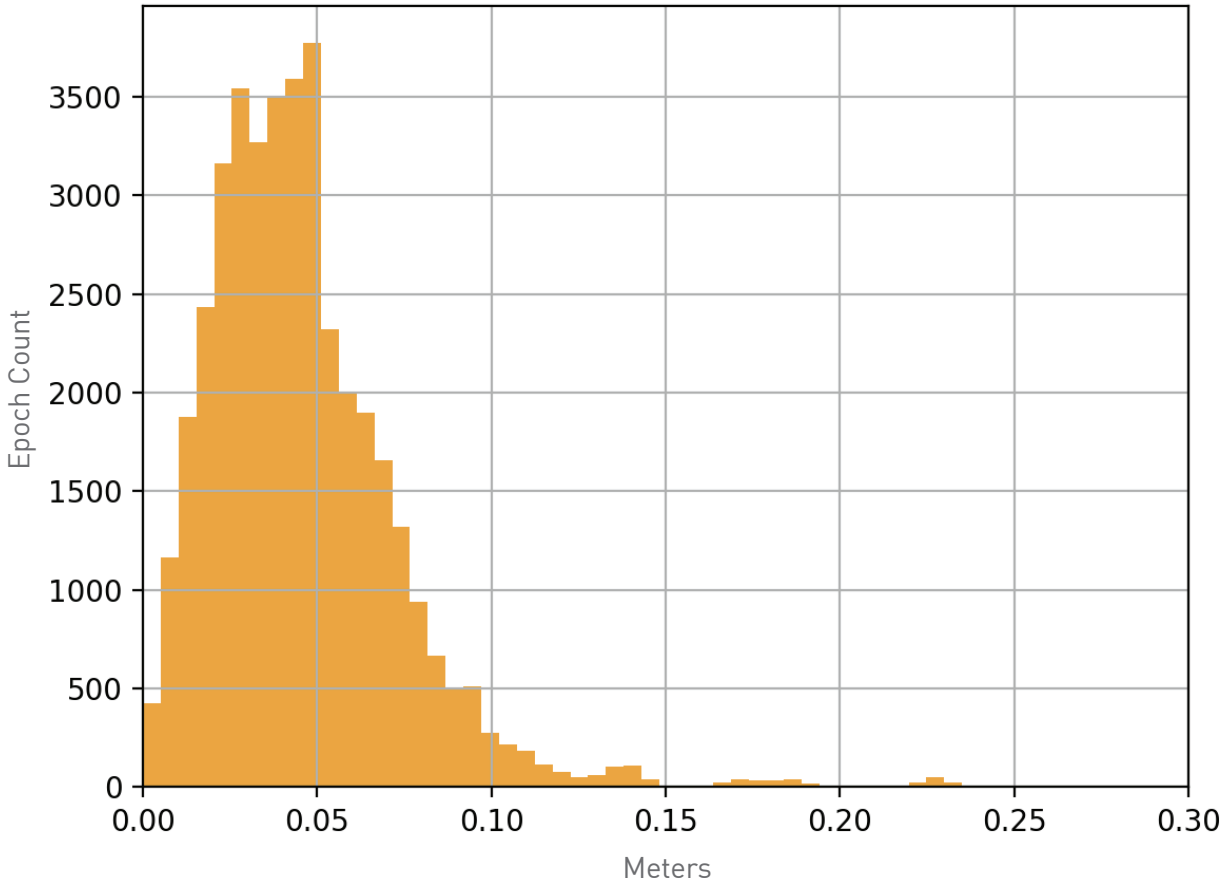

Figure 2 - Histogram of Horizontal Position Accuracy, 24 Hours of Static Data, December 9, 2019

	50th percentile	68th percentile	95th percentile
Piksi Multi + Starling + Skylark	4.2cm	5.4cm	10.3cm

Table 2 - Performance of Starling with Skylark Corrections, Over the 24 Hours of Static Data Collection

The static results are a baseline for what kind of performance we can expect from Skylark and Starling in ideal conditions (open sky, full constellations, averaged over 24 hours, 50th percentile). This gives us a baseline with which to compare the drive test results.

Drive Test

This west coast drive test took our team up the Pacific Coast Highway in California into the Pacific Northwest. The car utilized Swift's Piksi Multi receiver as a measurement engine. The Piksi Multi also included the Starling positioning engine. Corrections were provided from Skylark through a GSM modem connected to a major U.S. mobile network operator.

Measurement Engine	Antenna	Positioning Engine	Correction Service
Piksi Multi	Harxon Antenna	Starling	Skylark

Table 3 - Equipment Set-Up

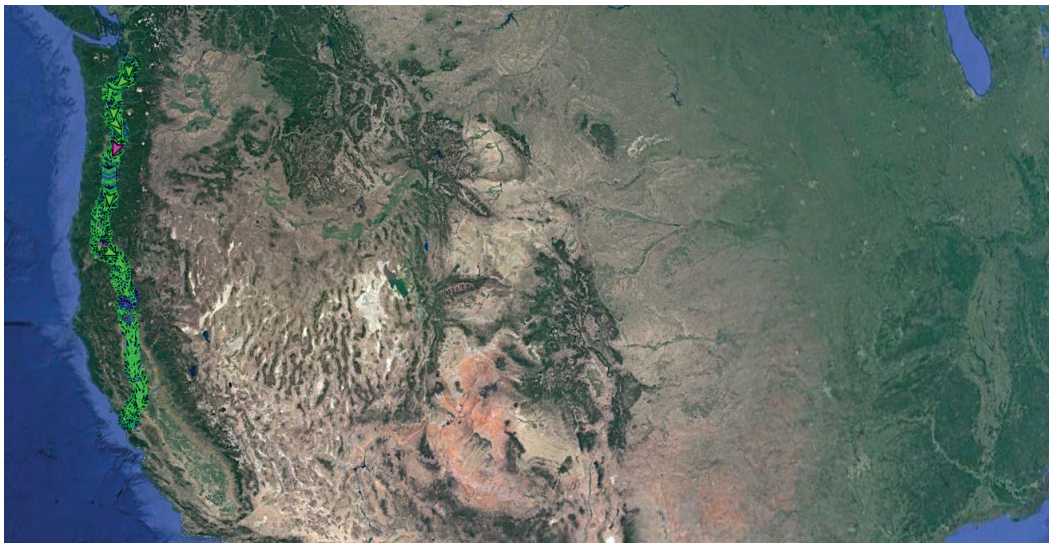

Figure 3 - San Francisco to Seattle Test Drive Route

Drive By the Numbers

- 13 hours of driving
- 800 miles / 1,300 km covered
- Drove across 3 states
- Below 10cm error over 70% of the time

Test Results

The Swift positioning solution delivered the results stated below.

	50th percentile	68th percentile	95th percentile
Piksi Multi + Starling + Skylark	6cm	8cm	35cm

Table 4 - Performance of Starling with Skylark Corrections, Over the 13 Hours of the Drive

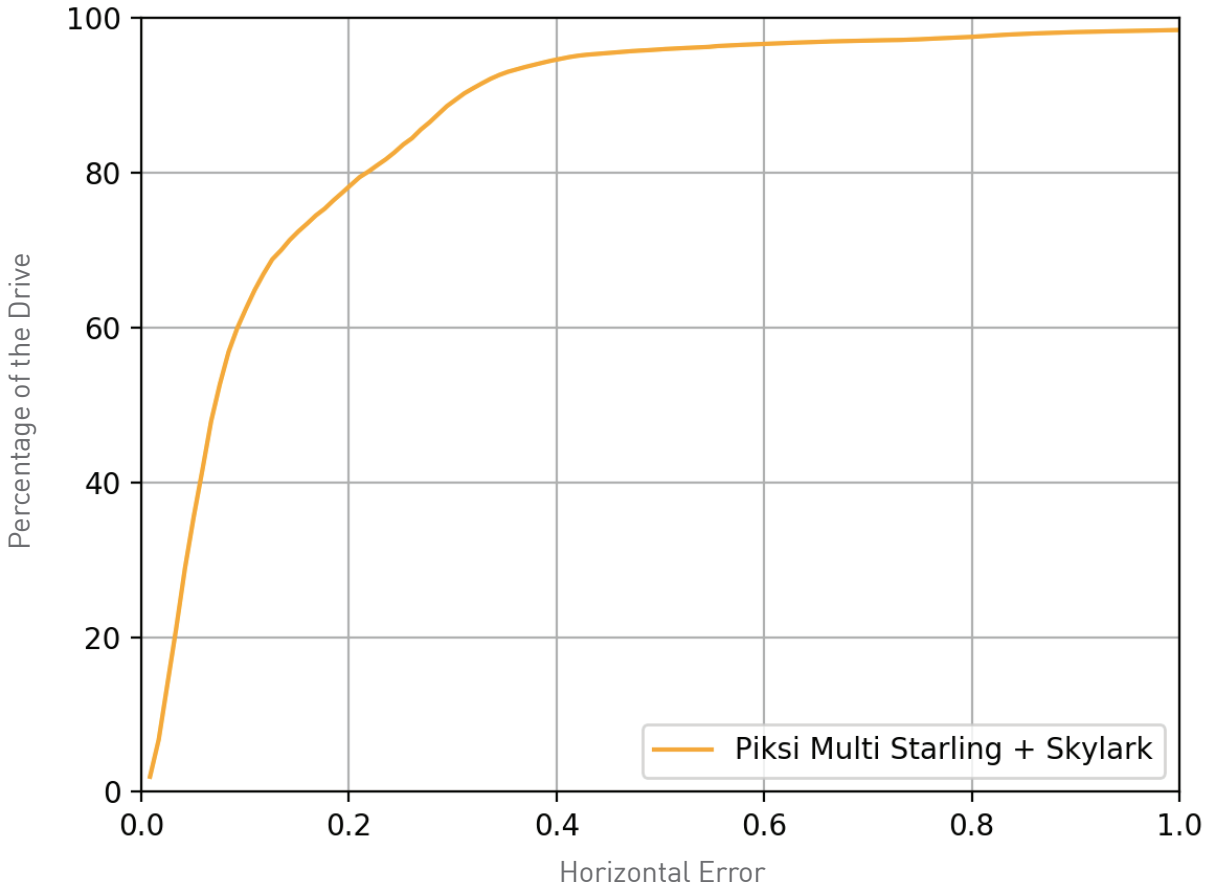

Figure 4 - Drive Test Results Cumulative Distribution

Results demonstrate that Piksi Multi with Starling connected to Skylark achieved less than 10cm of error more than 70% of the time over the 1,300 km driving route, without the aid of an Inertial Measurement Unit (IMU). Note that Swift has the ability to add an IMU sensor fusion solution to GNSS to further improve the availability and accuracy of the solution.

Conclusion

These results demonstrate that Swift's positioning production solution delivers consistent, lane-level accuracy at fast convergence times over a coastal scale. This fast convergence time to a high-accuracy solution has been demonstrated in static tests with different receivers. This translates to a high availability of sub-decimeter level solution in typical drive environments, as exemplified in this drive along the Pacific Coast from San Francisco to Seattle.

Contact Swift at sales@swiftnav.com to arrange your pilot program—that includes a free Skylark trial—get started today!

*Actual system performance may vary, dependent but not limited to: use-case dynamics, receiver and antenna characteristics. 10 cm 50% accuracy measured over 24 hours stationary with a Geodetic set up.