High-Precision Localization for the Autonomous Sensor Suite

The autonomous future requires highly-accurate sensors for precision navigation. Autonomous systems are no longer in the distant future—these systems are navigating around our streets and within our neighborhoods today. Despite their increased prevalence, autonomous vehicles have technological hurdles to overcome when ambiguity or unforeseen circumstances bring them to a standstill. A key to addressing these challenges is improved sensor synthesis within the autonomous sensor suite that mitigates the limitations of individual sensors.

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The Autonomous Sensor Suite

The autonomous sensor suite is comprised of one, or often many, of the following sensors: Cameras, LiDar, Radar, Inertial Measurement Units (IMUs) and Global Navigation Satellite Systems (GNSS). However, many technologies that support relative positioning and heading fall short of the cost, accuracy, robustness and size requirements necessary to support autonomous system mass adoption.

CAMERAS
Monitor surroundings, read traffic lightsand localize

LiDAR
Uses laser technologyto generate a high-resolution 3-D map of the surrounding area

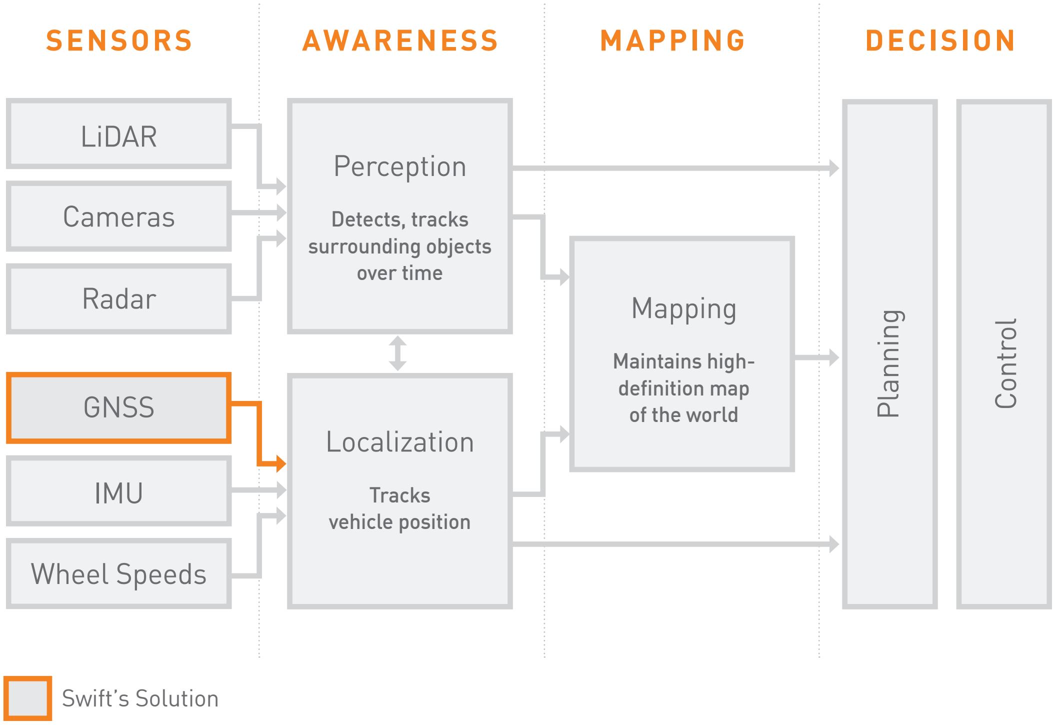
Inertial Measurement Unit (IMU)
Senses rotational and linear motionof the vehicle

Radar
Determines distance and speed in relation to obstacles, even in darkness and fog

Global Navigation Satellite System (GNSS)
Reads GNSS datafrom multiple satellite constellations to determine absolute position, timeand velocity of the vehicle

Optical sensors—LiDAR and cameras—used for relative positioning have difficulties performing in adverse weather conditions such as rain and snow. LiDAR—a leading sensor in autonomous driving—can be very costly and difficult to package and produce in volume. Infrared sensors—which are less commonly used—look for heat differentials and can be impacted by environmental factors such as high and low temperature variants.

Sensors used for heading—such as magnetometers—are prone to magnetic effects. Gyroscopes can drift and require calibration. Gyrocompasses identify True North but are expensive and mechanically bulky. Magnetic compasses identify magnetic north but are afflicted by interference issues. IMUs experience their own problems, such as bias and latency errors, and can be prone to machine vibrations and require time to calibrate while in motion, leading to drift. Once a vehicle has stopped moving, the sources of error may grow, rendering the relative positioning and heading solutions no longer accurate. These sensors are not sufficient on their own to meet the needs of autonomous systems while others, such as ring laser gyroscopes, are too cost-prohibitive in mass market applications.



On the other hand, GNSS sensors are immune to magnetic interference and can operate in a static setting without requiring motion for initial calibration. Real-time kinematic (RTK) GNSS heading does not require calibration time and the vehicle may be stationary, unlike other systems that require the vehicle to be in motion. GNSS is unique in that it provides the high levels of integrity required by autonomous navigation. This integrity enables Advanced Driver Assistance Systems (ADAS) to have confidence in the position and velocity solutions provided by the positioning system. These characteristics—along with their affordable cost—make RTK GNSS sensors an ideal technology for applications that require precise relative positioning and robust precision heading.

GNSS Technology

To better understand the accuracy RTK delivers, we must first look at GNSS technology in general. A GNSS receiver determines its position by measuring the distance to four or more GNSS satellites. To determine its distance to the satellites, the GNSS receiver measures the phase of unique 'codes' continuously transmitted by the satellites. By comparing the relative phase offsets of the received codes, the receiver can determine the relative distance to each satellite, i.e. the distance to each satellite plus a common offset (the time of the measurement is unknown until solved, leading to a common offset to all the distances).

Once the relative distances to the satellites are known, the receiver can solve for its three-dimensional coordinates and the time of the measurement is solved for via iterative algorithms. Note that there are several satellites in place around Earth that allow global position to be calculated. Satellite constellations that provide this capability include:

- Global Positioning System (GPS), owned by the United States government and operated by the United States Air Force. GPS has been in service since the early 1980s.
- Global Navigation Satellite System (GLONASS), operated by the Russian government.
- Galileo, operated by the European Union, European Space Agency and European GNSS Agency.
- BeiDou Navigation Satellite System (BDS), operated by the China National Space Administration.

GNSS receivers can receive codes from one constellation or from multiple constellations simultaneously. Receivers with multi-constellation capability generally have higher availability of position information due to the greater number of satellites used for position determination.

The phase of the code must be measured very precisely to correctly measure the distance to the satellite. In practice, there is a limit to the precision with which the code phase can be measured. The signal transmitted from each satellite travels at the speed of light, and at that speed, each bit of the code is quite long—about 300 meters in length. The 300-meter-units of the code bits, combined with imprecise code phase measurement, leads to an upper bound on the accuracy with which the distance to the satellite can be measured—generally a few meters.

Another important source of error is ionospheric delay. The ionosphere, a layer of radiation-charged particles surrounding the earth, slows the GNSS signals as they pass through it. This delay is difficult to estimate and varies by time and location, leading to a few more meters of error in the measurement of the distance to the satellite.

After exiting the ionosphere, satellite codes accumulate additional errors as they travel through the troposphere, with weather patterns containing water vapor and dust particles. Further errors accumulate as the signal passes through the environment on the Earth's surface. Foliage and man-made structures such as tall buildings with reflective glass interfere with the path of satellite codes, causing multipath errors. Orbit and clock errors in the satellites themselves further compound the magnitude of GNSS signal errors.

RTK Accuracy

RTK GNSS systems achieve much higher positioning precision by mitigating all of the sources of error described above. In addition to measuring the code phase, an RTK GNSS receiver measures the phase of the carrier wave upon which the code is modulated. The carrier has a wavelength of about 19 centimeters. This makes it possible to measure to a much greater degree of accuracy than the 300-meter code.

However, there are an unknown number of whole carrier wavelengths between the satellite and receiver. Clever algorithms are required to resolve this "integer ambiguity" by checking that the code and carrier phase measurements lead to a consistent position solution as the satellites move through space and the geometry of the solution changes. During this time period of "integer ambiguity," an RTK receiver is considered to be in RTK Float Mode and horizontal accuracy can range from 20 cm to 200 cm (RTK Float Mode can last for seconds or minutes depending on varying factors including the specific receiver and the environment it's operating in). Once the ambiguity is resolved, the RTK receiver will report that it is in RTK Fixed Mode and horizontal accuracy can be 1 cm to 5 cm.

Also, an RTK GNSS receiver is able to reduce the ionospheric error with the help of an additional reference receiver at a known position. When the two receivers are located relatively close to each other on Earth, the ionospheric delay will be approximately the same for both receivers. If the two receivers measure their distances to the same four satellites, and the two receivers have a communication method to one-another for exchanging their individual observations (such as a radio or cellular network), each receiver can communicate its relative distance to the other receiver without the ionospheric delay.

The most common use case for RTK involves two RTK GNSS receivers: a base station and a rover. The base station is typically a stationary GNSS receiver at a known position that is configured to send out RTK corrections (often through a radio link). The rover GNSS receiver is configured to receive these RTK corrections sent by the base station, and applies these corrections to solve for a centimeter-accurate level vector between the units.

RTK requires two independent GPS / GNSS receiver modules to be linked with a robust communication link so that the primary (base station) unit can send RTK corrections to the secondary (rover) unit. The rover receives these RTK corrections and solves for a 'vector' ΔX, ΔY, ΔZ that is accurate to within 1-2 centimeters with reference to the base station unit. If the base station unit has accurately-surveyed coordinates, then the rover uses these base station coordinates to solve for its position in the global reference frame.

Beyond the Base Station

Swift has evolved its expertise in RTK GNSS to create Skylark, a one-of-a-kind cloud-based GNSS corrections network that delivers the benefits of RTK while eliminating the complexity of deploying and maintaining GNSS networks. Skylark runs on a modern cloud software stack, based on data collected from Swift's hundreds of GNSS reference stations around the globe. By moving the service to the cloud, Skylark creates a platform for high-precision GNSS navigation of autonomous vehicles, via Internet connectivity. Skylark offers a plug-and-play user experience that delivers fast convergence times measured in seconds, not minutes. It uses cutting-edge positioning algorithms to provide a continuous stream of data to individual devices from the cloud. This data stream allows for quick and robust positioning and high reliability and availability, even in challenging environments.

Skylark eliminates the complexity of deploying and maintaining a traditional radio-connected base station and rover GNSS network and provides a connected GNSS solution that is able to overcome the accuracy limitations that have traditionally hindered GNSS used for localization. Skylark is a scalable, secure and highly-available cloud service delivering a continuous stream of real-time corrections. With its full contiguous United Stations (CONUS) coverage, Skylark is the only positioning network designed and built from the outset to support next-generation GNSS applications, connected car, V2X and advanced driver assistance systems (ADAS).

Conclusion

As an industry, we are at a technology inflection point. All the enablers for high-precision localization are here today: multi-frequency, automotive-grade GNSS receivers have emerged at affordable price-points that can support OEM-level adoption; all future vehicles will be equipped with cellular connectivity; and Swift offers an affordable precise positioning corrections service.

Learn more at about Swift's end-to-end automotive localization solutions at swiftnav.com/automotive.