White Paper

Applanix IN-Fusion+™: the Ultimate Solution for Enhanced Spatial Intelligence

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Spatial Intelligence and Spatial Knowledge

Spatial Intelligence is the ability to derive insights and information about your surroundings and objects in those surroundings. Good Spatial Intelligence is required by many industries in order to make the right decisions to streamline business processes, reduce environmental waste and maximize productivity. These industries include but are not limited to Forestry, Agriculture, Mining, Construction, Emergency Response, and Transportation. Good Spatial Intelligence itself is not possible without relevant, up-to-date, and accurate *spatial knowledge*.

Spatial knowledge can be defined as knowing the exact location or position of an object, its motion and direction of motion, the direction it is pointing (orientation), how quickly its motion is changing, and other metrics at a specific time. This information is used by applications that create or enhance spatial intelligence, including: Mobile Mapping (creating maps using sensors such as cameras, echosounders, and lasers mounted on automobiles, crewed aircraft, uncrewed airborne vehicles (UAVs), ships, and other moving platforms), Navigation, Guidance and Control of Autonomous Vehicles (AVs), Asset or Fleet tracking (continuously knowing the location of mobile assets), Mobile Surveying (measuring the geometry or examining specific features of land-based objects such as bridges, roads, tracks, and other features while moving), Remote Sensing (collecting information about something while moving around, over, or through it), and other similar activities.

Regardless of the application, the common requirement for spatial knowledge data is that it must *always be there*. Since the objects can be moving, any gaps in the data will result in a loss of spatial intelligence, which can have a myriad of consequences ranging from increased costs through reduced productivity, loss of an asset, or something more catastrophic such as an accident if the AV does not react or is not tracked properly.

The Applanix solutions guarantee highly accurate spatial knowledge in all types of environments, *without interruption*. This is achieved with the "inertial-centric" Applanix IN-Fusion+ engine, a highly advanced multi-sensor integration technology that always produces a spatial knowledge solution, and one that is always the most accurate based upon the sensors available.

At the heart of the Applanix IN-Fusion+ technology is the concept of "Aided-Inertial Navigation". Here, data from inertial sensors (accelerometers and gyros) are run through a navigation algorithm and are then "aided" or "fused" together with information from other sensors such as GNSS and odometer (Distance Measurement Indicator or DMI) to produce highly accurate, high-rate three-dimensional measurements of the position, velocity, and orientation of a platform as it moves. These measurements provide the continuous dynamic state of the platform and can be used to directly georeference any attached sensors, such as cameras or lasers, and subsequently create a map of the surrounding environment. The measurements are continuous since they are derived from the inertial sensors and are only "aided" by the other sensors; if the other sensors are blocked from providing measurements the inertial-based solution is still produced.

The Applanix IN-Fusion+ technology provides the highest level of navigation sensor integration producing measurements with an unequaled level of accuracy and robustness. It incorporates several advanced technologies, including Trimble® ProPoint™ GNSS, a fifth generation high-precision processing engine that leverages the modernized GNSS infrastructure and Trimble's advanced GNSS receiver hardware, and the Applanix SmartCal™ sensor calibration technology. It also incorporates leading edge GNSS correction services in the form of the Applanix SmartBase™, a post-processed virtual reference station (VRS) module, the Trimble Centerpoint® RTX™ real-time correction service, and POSPac® Post-processed Trimble CenterPoint RTX (PP-RTX). Trimble RTX technology enables cm-level positioning anywhere on the Earth without base stations.

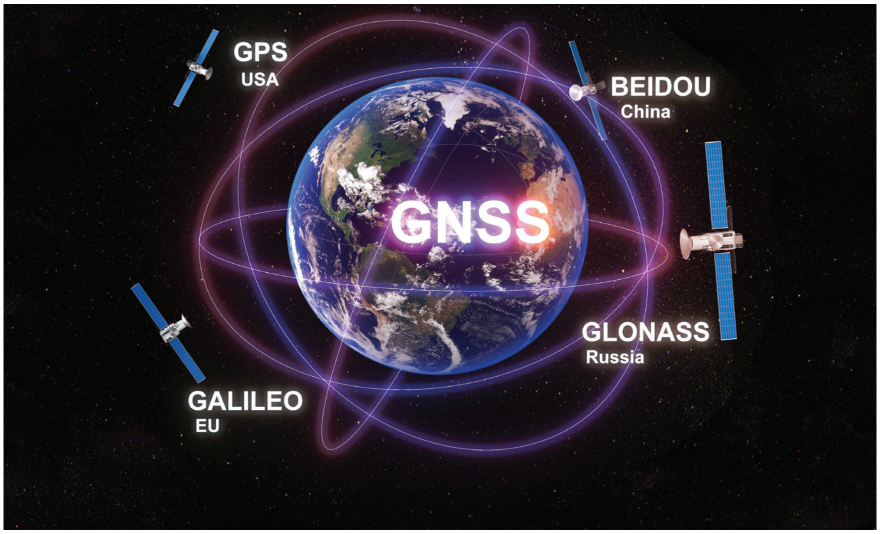
Applanix IN-Fusion+ enables mobile mapping and positioning to be done efficiently in all types of environments where accurate GNSS positioning is often marginal or even impossible. This includes urban canyons, inside buildings or mines, and during high-banked turns of an aircraft. It is one of the reasons why Applanix is the market leader in products and solutions for spatial knowledge.

Measurement Technologies

In order to understand the power of Applanix IN-Fusion+ technology, it is necessary to first understand what types of technologies are commonly available today for measuring spatial knowledge.

Global Navigation Satellite Systems (GNSS) Positioning

A satellite-based positioning system is referred to as a Global Navigation Satellite System (GNSS). Today there are five such systems in operation: the Global Positioning System or GPS (United States), GLONASS (Russian Federation), Galileo (European Union), and the Beidou Navigation Satellite System or BDS (People's Republic of China). Japan has deployed the Quasi-Zenith Satellite System (QZSS) comprising four satellites in geostationary orbit to supplement GPS in Japan and surrounding regions.



GNSS Satellite Constellations

To improve the reliability and achieve the highest accuracy possible from GNSS, the solution must use a combination of signals from all satellites in view. Thus, a GNSS receiver designed to support surveying and mapping applications must track all signals and frequencies from GPS, GLONASS, Galileo, Beidou, and QZSS. The Applanix products achieve this using the advanced hardware and software innovations referred to as Trimble Maxwell™.

Position and velocity measurements are obtained using GNSS through the triangulation of ranges measured from the antenna mounted on a vehicle to each satellite. The ranges are computed by measuring the time-of-flight of information transmitted from the satellites on the radio signals to the receiver. The accuracy of the position is determined by the accuracy of the range measurements and the geometry of the triangulation defined by the distribution of the satellites in view. The more satellites and frequencies tracked (enabled by Trimble Maxwell), the more accurate the geometry, and the faster and better that atmospheric delay errors can be estimated and corrected for. The highest accuracy range measurements are computed using measurements of the signal phases and correcting these measurements using independent ground-based measurements. These correction techniques are referred to as "Differential GNSS", RTK, or Precise Point Positioning (PPP).

If two antennas are mounted on a vehicle, the vector between them can be computed in the Geographic frame. This vector can then be projected into a true heading measurement from North, meaning a dual antenna GNSS receiver can produce position, velocity, and heading.

Advantages

GNSS is a well-proven technology for mobile positioning and has the advantage of being able to produce cm-level absolute position measurements tied to a Global Reference frame. The two-antenna heading measurement is ideal for determining which way a vehicle is pointing for guidance purposes. A third and equally important benefit of GNSS is its ability to produce a very precise global time reference which is used to synchronize the sampling of all sensors to a common time base. This is critical for mobile applications where the position and orientation from the georeferencing system must be accurately interpolated to the exact time that data from a sensor (LiDAR, camera) is sampled. If the times are not in the same time base or are not accurate, the georeferencing solution will be generated at a different location, introducing large errors correlated to the motion of the vehicle.

Limitations

Since GNSS positioning relies on measuring the ranges to the satellites using radio signals, it is highly susceptible to interruptions in the radio signals. For a mobile application, this occurs when moving through trees, under bridges, through tunnels, around buildings and other structures, or if the signals are jammed by other sources. During this time, the position, velocity, and heading measurements are simply not available or are reduced in accuracy.

Distance Measurement Indicator (DMI or Odometer)

For land-based wheeled vehicles, a distance measurement indicator (DMI), also called an odometer, measures incremental distance traveled using the rotations of the instrumented wheel. Continuously integrating the DMI along with a heading measurement enables the location of the vehicle to be determined. Additionally, the incremental distance traveled provides an accurate speed measurement of the vehicle.

Applanix vehicle with DMI on back wheel.

Advantages

A DMI has the advantage of being self-contained to the vehicle and can produce highly accurate, uninterrupted measurements of distance traveled and speed. It can also be used to precisely indicate when the vehicle is stationary.

Limitations

Wheel slippage will introduce errors in the DMI measurements, which is why they are only suitable for on-road vehicles. As well, changes in the tire pressure will introduce a scale factor error.

Magnetometer

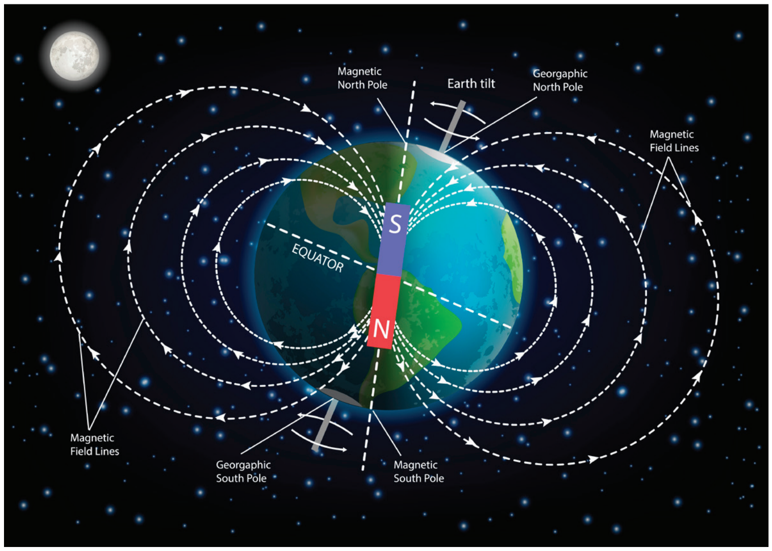
A magnetometer measures the vector component of the Earth's magnetic field, and therefore can be used to derive both heading and the inclination of an object.

Advantages

A magnetometer is low-cost, self-contained, and can produce high-rate measurements of orientation and changes in orientation.

Limitations

The Earth's magnetic field is quite weak and is easily disturbed by magnetic fields from other sources, such as large metal



Earth's magnetic field.

objects, electronic and electric motors, and anything else that can produce a magnetic field. This means that in order to produce reasonably accurate measurements, a magnetometer must be calibrated immediately after it has been installed in a vehicle to remove any influences of the vehicle itself. However, even after calibration, measurements from a magnetometer will still be impacted by local magnetic fields as the vehicle moves through them, greatly increasing noise and reducing its accuracy.

Visual Odometer (VO)

A visual odometer is a solution that provides three-dimensional changes in position and orientation measurements (referred to as delta POSE) using optical measurements. The optical measurements can be from active or passive devices mounted on a vehicle (ie. cameras or LiDAR). The basic concept behind VO is to match stationary features in overlapping images or LiDAR scans and use the known and fixed geometry of the imaging sensors to compute the change in position and orientation of the vehicle between each image or scan.

Applanix vehicle with mounted LiDAR

Advantages

Unlike a DMI, a VO system produces a three-dimensional incremental position measurement plus change in orientation. It is also not restricted to on-road land vehicles; it can be used on any type of mobile platform..

Limitations

Limitations of VO include low update rates which are an issue for fast moving vehicles, a generally higher level of noise versus a traditional DMI, and inaccuracies, or even outages, due to the inability to match features in poor lighting conditions, when there is homogeneous scene content, or if there are high vehicle dynamics.

Map Based Localization (MBL)

An MBL system uses optical sensors to match features in captured imagery or LiDAR scans against an existing georeferenced database of features (ie. a map). This process is also referred to as "map aiding". Once features are matched, the system can then use the a-priori locations of the features and geometry of the optical sensors to compute the position of the vehicle relative to the map. If the map is accurate and georeferenced with respect to a global coordinate system, the resultant vehicle positions are also accurate and georeferenced with respect to the global coordinate system. If a map does not exist, the most sophisticated MBL solutions can build a local map from the imaging sensors while the vehicle is driving, and then determine the vehicle's relative position within that map. Such a process is referred to as Simultaneous Location and Mapping or SLAM.

Autonomous vehicle using sensors for mapping.

Advantages

An MBL solution can produce cm level accurate measurements of a vehicle's absolute and relative position. It can do so anywhere (including indoors), and from any type of vehicle.

Limitations

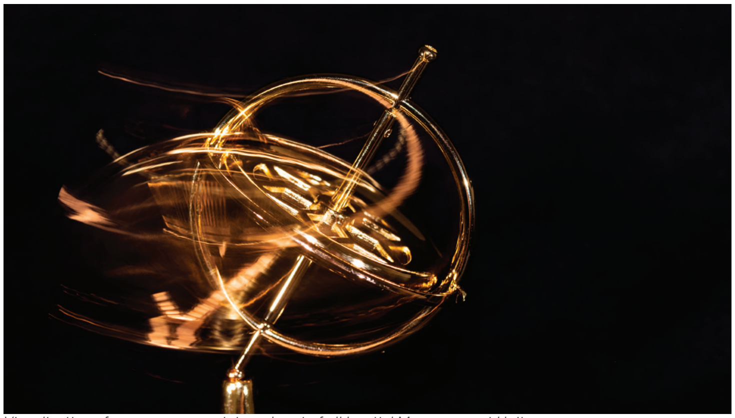
Absolute position accuracy from MBL is limited to the accuracy of the globally reference map it is using in its database. If the a-priori map does not exist, an MBL solution can only produce a relative position measurement. The ability to correlate features in the imagery or LiDAR data with the map database is also limited to the geometry of the surroundings that the vehicle is moving through. If there are no strong features or the scenery is completely homogenous, just like VO, the MBL measurements will be inaccurate or not produced. Also, like VO, MBL can suffer from lower data rates and inability to correlate features during high vehicle dynamics.

Inertial Navigation System (INS)

An inertial navigation system, or INS, starts from a known position (latitude, longitude, and altitude), velocity, and orientation (roll, pitch, and heading) with respect to the North and Down directions. Using accelerometers and gyros contained in an Inertial Measurement Unit (IMU), it measures changes in velocity and orientation angles up to 1000 times per second, and then sums these with the original solution to compute the current position, velocity, and orientation at any point in time on the Earth.

Advantages

An INS produces complete 6 degrees of freedom spatial knowledge of a vehicle's state at a very high rate. This means it is ideal for use on even the fastest moving vehicles. It also operates completely independently of its surroundings, which means it can always produce a solution in any environment, including indoors or under water.



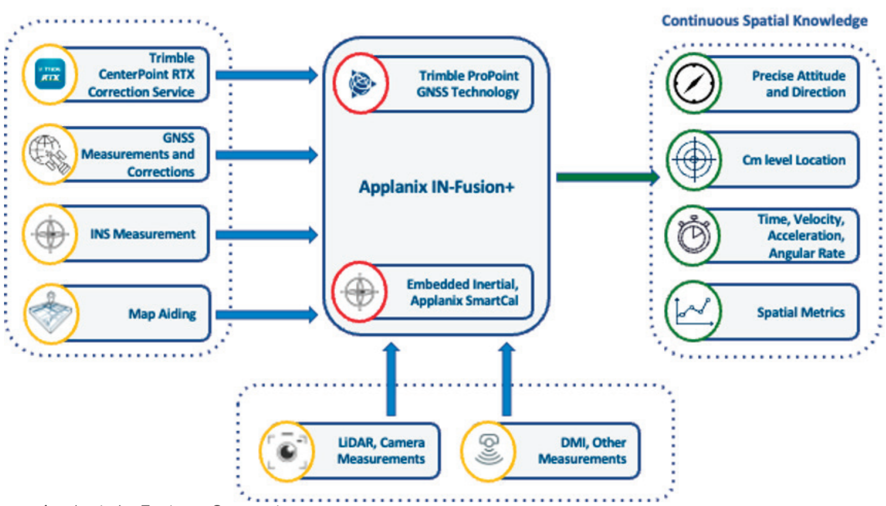
Visualization of a gyroscope, an integral part of all Inertial Measurement Units

Limitations

As with any summation process, an INS will accumulate position and orientation errors over time due to imperfections in its accelerometers and gyros. An INS used in a commercial aircraft contains highly accurate ring-laser gyros and pendulous accelerometers, and with these it can navigate with an uncorrected position error rate of one nautical mile per hour, which is the equivalent of 0.5 meters per second velocity error. While this is adequate for guiding a commercial transport aircraft across the ocean, it is not acceptable for mobile mapping applications which require sub-meter accuracy..

Applanix IN-Fusion+ Technology

The Applanix IN-Fusion+ technology is an advanced version of an "aided-inertial" navigation system or Aided INS. An Aided INS is an INS that uses other sources of information to continuously correct or "aid" the INS errors. Such an approach means that the INS errors no-longer grow unbounded, allowing the use of a less accurate and hence smaller and less expensive IMU (ie. using MEMs sensors), while still obtaining sufficient position and orientation accuracy for mobile mapping applications. It also is an optimal method of "blending" or "fusing" the information of all measurement systems into a single solution. This advanced technology takes the *advantages of each measurement technology* and *eliminates or significantly reduces their limitations*. The net result is the most accurate and robust spatial knowledge solution for the highest level of productivity in mobile mapping and positioning.



Applanix In-Fusion+ Concept

At the heart of the Applanix IN-Fusion+ technology is an advanced Kalman Filter architecture that incorporates sophisticated inertial and aiding sensor error models developed using the Applanix SmartCal technology, as well as the latest in GNSS measurement processing and correction methodologies called Trimble ProPoint GNSS, Trimble Centerpoint RTX, and Applanix

SmartBase. The Applanix IN-Fusion+ supports a variety of the most common aiding sensors including GNSS, DMI, VO, MBL, and Magnetometer, and uses sophisticated vehicle dynamic models to enhance overall performance.

Applanix SmartCal

Applanix SmartCal is a proprietary method of characterizing and calibrating inertial sensor errors and aiding sensor errors. It allows Applanix to achieve exceptional performance from inertial measurement units (IMUs) manufactured specifically for mobile mapping applications.

The Applanix IN-Fusion+ Kalman filter contains a linearized set of differential equations that describe the errors in the navigation solution which are driven by the inertial sensor errors (gyros and accelerometers). It also contains the aiding measurements which enable these errors to be observed and corrected for.

The Applanix SmartCal technology allows the Applanix IN-Fusion+ to achieve unparalleled performance from IMUs built specifically for mobile mapping and positioning. By understanding the requirements on the inertial sensor errors to achieve a specific level of performance in an Aided-Inertial architecture for mobile mapping and robotics use, Applanix can compensate for the inertial sensor errors in a unique way for those applications. Compensation is applied as calibration parameters to the IMU data and through the Kalman filter. A key element of achieving performance is characterizing the errors over all types of motion dynamics and temperature profiles. This is done using a combination of rate table calibrations and vehicle calibrations.

The error models for aiding sensors such as GNSS and MBL are developed through an extensive system identification process resulting in a high-order parameterization that enables unparalleled accuracy.

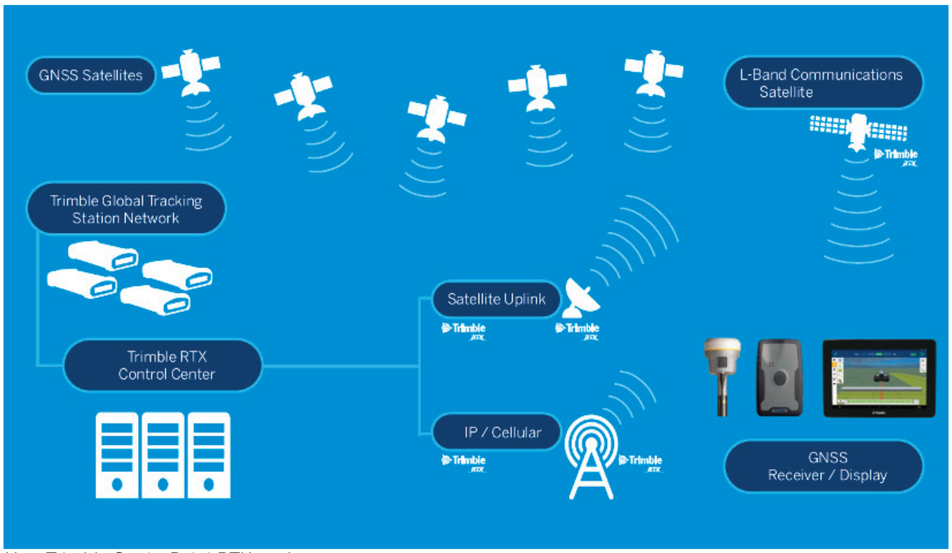
Trimble ProPoint™ GNSS

Trimble ProPoint GNSS is the fifth generation high-precision GNSS positioning technology from Trimble. It leverages the latest developments in GNSS signal infrastructure and Trimble's high-precision Maxwell 7 receiver hardware to deliver improved positioning performance in challenging environments.

Trimble ProPoint GNSS supports data from all GNSS constellations (GPS, Galileo, GLONASS, BeiDou, QZSS) and all frequencies. Its advanced algorithms enable robust GNSS positioning performance under harsh tracking conditions where satellite line of sight can be impaired, such as under tree canopy and highway overpasses, and in dense urban areas, while its sophisticated signal filtering and error modeling means better protection against jamming, spoofing, and multipath interference.

The Trimble ProPoint GNSS is tightly integrated in the Applanix IN-Fusion+ allowing it to achieve extremely robust high-rate Aided-INS position output at the cm level under all types of signal environments.

Trimble CenterPoint® RTX™

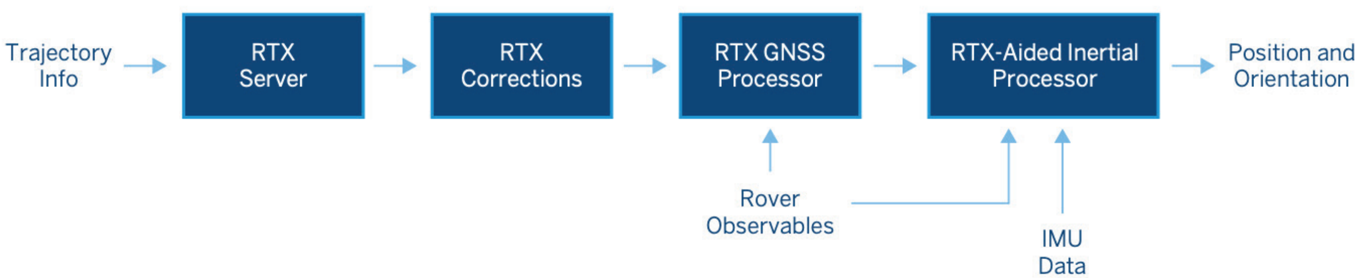


How Trimble CenterPoint RTX works

The Trimble CenterPoint RTX is an innovative multi-frequency GNSS positioning technology that combines the high accuracy of reference station-based Differential GNSS with the highly productive wide-area coverage of global satellite corrections. It employs its own dedicated precise ephemeris correction service and derives integer level ambiguities for accuracy approaching that of RTK. It supports GPS, GLONASS, Galileo, BeiDou, and QZSS.

The Trimble RTX GNSS correction services provide users with real-time and post-mission, high-accuracy positioning via satellite or Internet, worldwide without the need for terrestrial infrastructure such as cellular networks, radios, or modems, and without the need for base stations.

POSPac™ Post-processed Trimble CenterPoint RTX (PP-RTX™)

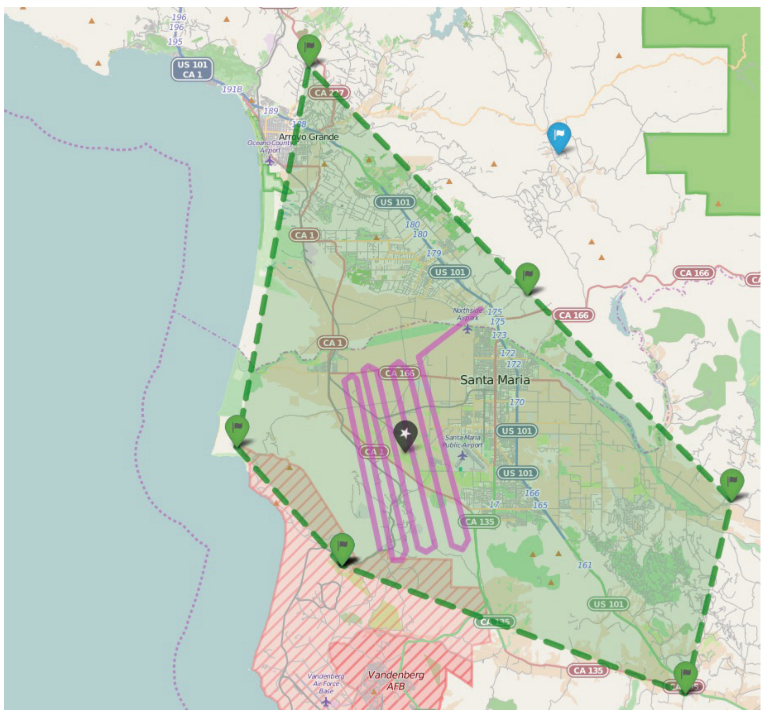


PP-RTX concept

POSPac PP-RTX is a cloud-based global GNSS correction service as part of the patented Applanix POSPac MMS post-processing software that utilizes Trimble's RTX technology to provide cm-level post-processed positioning accuracy without base stations. Trajectory information logged during the mission is sent to the Trimble RTX server by POSPac MMS. This information is used to generate a set of RTX corrections unique to the mission, which are then transmitted back to POSPac. POSPac processes the corrections, along with the raw GNSS and IMU data in its IN-Fusion+ engine, to generate a solution with cm-level accuracy, all without the need for local reference stations.

Applanix SmartBase

Applanix SmartBase is a post-processed version of the GNSS Virtual Reference Station concept designed to work in land, airborne, and marine mobile mapping and positioning applications. Based upon the industry-leading Trimble VRS™ technology, the Applanix SmartBase software has been optimized for large changes in altitude by the rover and extended to work with reference stations separated over very large distances. It has also been tightly integrated into the Applanix IN-Fusion+ technology.



Applanix SmartBase Example

Applanix SmartBase processes the raw GNSS observations from a network of 4 to 50 reference stations to compute the atmospheric, clock, and orbital errors within the network. These are then used to correct for the errors at the location of the rover receiver at each epoch, as it travels throughout the network.

A key benefit of Applanix SmartBase is that it enables the same position accuracy as using a dedicated reference station without the restriction of remaining within a 30 km range. Furthermore, when integrated with the POSPac IN-Fusion+ technology, it is also possible to achieve this accuracy both immediately before and after GNSS signal disruptions due to bridges, tunnels, foliage, and high banked turns in an aircraft.

Conclusion

When creating spatial intelligence via Mobile Mapping, Navigation, Guidance and Control of Autonomous Vehicles (AVs), Asset or Fleet tracking, or Mobile Remote Sensing, the state-of-the art Applanix IN-Fusion+ technology provides the most robust, accurate, and continuous measurements of spatial knowledge. It optimally "fuses" the measurements from individual sensing systems and produces the best possible solution without interruption, under all types of conditions.