# Applanix POS AV™ and POSTrack™: Frequently Asked Questions

## 1) What is a "Direct Georeferencing System"?

A direct georeferencing (DG) system provides the ability to directly relate the data collected by a remote sensing device to the Earth, by accurately measuring the geographic position and orientation of the device without the use of traditional ground-based measurements. Examples of where DG systems are used in the airborne mapping industry include: scanning laser systems or LIDAR, Interferometric Synthetic Aperture Radar systems (InSAR), multispectral and hyperspectral scanners, large format digital line scanners, large and medium format digital frame cameras, and traditional large format film cameras The current state-of–the-art direct georeferencing systems are the Applanix POS AV and POSTrack™ products. They use carrier phase differential GNSS measurements integrated with an Inertial Measurement Unit (IMU).

## 2) How Does POS AV Work?

The key component of the POS AV system is the GNSS-Aided Inertial Navigation software. This software runs in real-time on the POS Computer System and in post-processing in the POSPac™ MMS software suite, and performs the integration of the inertial data from the IMU with the data from the GNSS receiver. The software consists of the following components:

- Strapdown inertial navigator
- Kalman filter
- Closed-loop error controller
- Smoother (POSPac MMS only)
- Feed forward error controller (POSPac MMS only)
- In-flight Alignment

***Strapdown Navigator***

The strapdown inertial navigator solves Newton's equations of motion on the rotating earth by integrating acceleration and angular rates sensed by the IMU, producing position, velocity, roll, pitch and heading. Since it is an integration process, the inertial navigator must first be initialized with known position and velocity from the GNSS, and aligned with respect to the true vertical and true North. Alignment with respect to the vertical is referred to as *leveling,* while alignment with respect to North is referred to as *heading alignment*. Once aligned the inertial navigator has established a local-level mathematical frame of reference called the navigation frame, whose heading is known with respect to North, and to which the orientation of the IMU is known, as shown in Figure 1.

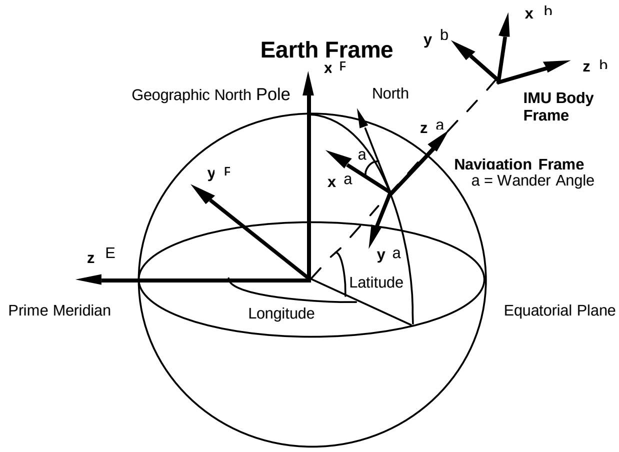



Figure 1. Frames of References Used in Inertial Navigation

The solution it produces is dynamically very accurate; however, due to the integration process, any errors in the accelerometers and gyros will integrate into slowly growing position, velocity and orientation errors. GNSS is an ideal aiding sensor for an inertial navigator since its positional errors are complementary to the inertial navigation errors in the sense that they are spectrally separate: the GNSS position and velocity errors are bounded and noisy, while the inertial navigator errors grow unbounded, but are essentially noise free. The GNSS can thus be used to estimate and correct the errors in the inertial navigation solution.

***Kalman Filter***

In order to use the GNSS to estimate the errors in the inertial navigator, a Kalman Filter is used. The Kalman Filter implements a set of differential equations that model the inertial navigator errors and the IMU sensor errors that drive them. Differences between the position from the inertial navigator and the position from the GNSS are processed in the Kalman filter (typically at 1 Hz), to estimate the slowly growing position error in the inertial navigator. Since this error is a function of both errors in the orientation and errors in the inertial sensors, (as modeled by the differential equations in the Kalman filter), observing the inertial position errors means the orientation errors and IMU sensor errors can also be implicitly estimated.

***Closed-Loop Error Controller***

The closed-loop error control algorithm is used to apply resets to the inertial navigator using the Kalman filter-estimated parameters. Estimates of the inertial sensor errors are also applied to the IMU-measured raw incremental angles and velocities before they are integrated. This has the same effect as calibrating the sensors. The ensuing integrated inertial navigation solution has its position and velocity directly regulated to the absolute accuracy of the GNSS position and velocity, and its orientation accuracy indirectly improved by the calibration of the inertial sensor errors. This is the solution that is computed and output by the PCS in real-time.

***Smoother***

The Smoother is a module that computes the optimal estimates of the inertial navigator and IMU sensor errors, by processing the data backwards in time and then combining it with the estimates from the forward in time Kalman filter. The resulting error estimates are based upon all available information from the past and future, and hence are more accurate. The Smoother is implemented only in the POSPac$^{TM}$ Air software.

***Feed-forward Error Controller***

The Feed-forward Error Control module uses the optimal error estimates from the Smoother and applies them to the integrated inertial navigation solution at the IMU rate, thus generating what is referred to a the smoothed best estimate of trajectory (SBET). The Feed-forward error controller is only used in the POSPac$^{TM}$ Air software after the smoother is run.

**3) What is "Alignment"?**

An important feature of the POS AV system is its ability to align itself (establish initial navigation frame see above) in the air. *Other lower cost systems cannot do this, and are required to be started on the ground. This means if at any time the system needs to be re-started while on a mission, the plane must land!*

The alignment process is comprised of 3 stages: i) Coarse Leveling, ii) Coarse Heading Alignment, and iii) Fine Heading Alignment. Coarse Leveling uses a first-order low-pass filter on the accelerometer data to observe the mean gravity signal in each accelerometer, from which the approximate roll and pitch of the IMU are determined to within 1 to 2 degrees error (see Figure 5).

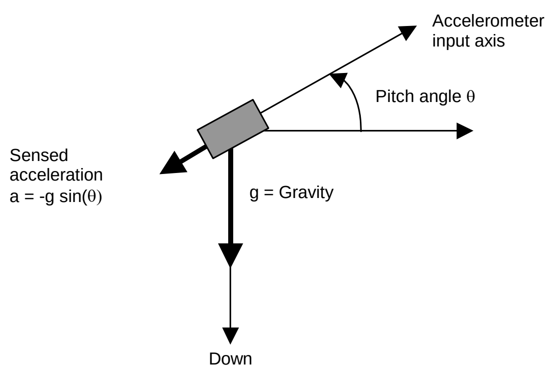



Figure 2. Coarse Leveling Using Accelerometers

At this point, Coarse Heading Alignment is started which uses a Kalman filter error model to describe the initial 180 deg uncertainty in heading. The heading error of the navigation frame will cause the incorrect Earth rate to be removed from the gyro measurements during the integration process, causing an orientation error. This in turn, will integrate into a velocity and position error. If the gyros errors are small enough, the position and velocity error due to the misresolved Earth rate can be detected in the differences with the GNSS, and hence the heading error will be estimated by the Kalman filter (so-called gyro compassing). However, since the gyros themselves can have biases anywhere from 0.03 to 20 deg/hr, usually the error due to the misresolved Earth rate is only sufficient to observe the heading error down to a few degrees at best. Fortunately the heading error also causes the accelerations of the IMU to be misresolved in the navigation frame, which then integrate into very large position and velocity errors that are observable against the GNSS measurements. This allows the Kalman filter to estimate the heading error to fractions of a degree, and as soon as Coarse Leveling is completed a single turn will complete the heading alignment. Once the Coarse Heading Alignment Kalman filter estimates the heading error to less than 10 degrees, the software changes to Fine Heading Alignment, which uses a small-angle error model Kalman filter to continuously estimate and refine the heading error.

### 4) Do I need to do a "figure-eight" to align POS AV in the air?

No, it is NOT necessary to fly a "figure-eight" to do an airstart with POS AV, and Applanix has NEVER trained our customers to do this. You simply need to fly straight-and-level for up to a few minutes while the system finds level, and then execute a change in heading to align the heading (as described above). Any change in heading will do, but a 90 deg turn is usually recommended for robustness on high precision work. This will achieve a change in velocity required to observe the heading error small enough for photos at the beginning of the first line. *This is true for ANY GNSS-Aided INS system*! If you do not do a turn of some sort before the first line, then you are relying on the backwards processing (if post-processing) to reduce the error at the beginning of the line, which it can only do to a certain extent. Conversely, for backward processing, a turn at the end of the last flight will also ensure that the heading error is observed.

### 5) What is the POSTrack and how is it different than POS AV?

POSTrack is the first fully integrated real-time direct georeferencing and flight management system for the airborne geospatial community. The POSTrack system is comprised of a "single box" solution incorporating a POS AV computer system (PCS) module and a FMS computer system (FCS) module built using state-of-the-art real-time embedded computing technology by Applanix. A very low radiation LVDS pilot touch display, GNSS antenna and IMU complete the system. The FCS runs a special modified version of the XTRACK software from TrackAir. The software running on the FCS communicates directly with the POS AV system running on the PCS via high speed Ethernet protocol. In addition to its normal GNSS-Aided INS functions, the POS AV module has been modified to handle the control and triggering of most types and combinations of aerial sensor. The XTRACK system monitors the real-time position and orientation of the sensors computed by the POS AV, then instructs it when to perform certain tasks to control the sensors.

### 6) What is the accuracy of POS AV?

The POS AV and POSTrack products are available in several different models and are primarily differentiated by orientation accuracy (and price). The full POS AV accuracy specifications can be found at www.applanix.com

### 7) How are POS AV products developed?

As with all Applanix products, POS AV products are developed using a rigorous engineering process. First we develop the theoretical error budget for Direct Georeferencing of a particular sensor, and then use this to determine the accuracy requirements for the POS AV. Secondly, using our own highly sophisticated software tools, we perform a simulation study to investigate what types of inertial sensors and GNSS processing would be required to develop the appropriate POS AV. With this knowledge in hand, we then begin working with suppliers to develop and acquire the IMU's we need for the product. The next stage involves integrating these IMU's into the POS AV product, followed by intense investigation of the performance of the product in the lab, vehicle, and aircraft. Lab testing includes temperature testing, shock and vibe testing, EMI testing and burn-in. Vehicle testing includes dynamic evaluation of the product against a know reference, and airborne testing includes flying on the sensor and testing against a Ground Truth.

**8) How do I know what model of POS AV to use for my application?**

At Applanix, we *know* that one size does not fit all. Why should you pay for a system with performance that you do not need and will never take advantage of?

Each model of POS AV has been developed as a turn-key solution with specific Direct Geoereferencing applications in mind. Our flagship product, the POS AV 510, was developed specifically for Direct Georeferencing of large format aerial frame and line scanning cameras, and is also used for high-altitude LIDAR.

Lower altitude applications such as corridor mapping using LIDAR and cameras, or georeferencing of oblique imagery, typically only require a POS AV 410 product, depending upon the sensor and its characteristics.

The POS AV 610 has been developed for specialty applications such as high-altitude SAR and LIDAR. However other specialty sensors such as hyperspectral or multispectral line scanners usually only require a POS AV 410

Applanix has many different hardware and software options that we can use to tailor the exact Direct Georeferencing solution for your needs. Whether you require the smallest, lightest form factor hardware for UAV applications, would like to have dual GNSS cards for redundancy, need custom software modifications, or simply need a standard POSTrack solution for an existing aerial camera, our experts can get you what you need.

**9) What types of IMU's are used by POS AV?**

Applanix uses a number of different types of IMU's for their products. These IMU's are carefully selected, analyzed and often modified to achieve varying levels of performance. Factors such as size, technology, exportability, weight, performance and availability all influence the decision on which IMU is used in a particular product.

**10) I have heard all POS AV systems are difficult to export. Is this true?**

No!. Historically Applanix has used US origin IMU technology that is controlled by the US Department of State in order to achieve the best performance at the best price. However for customers who need the flexibility of moving their systems around the world, Applanix offers IMU's that are classified under the US Department of Commerce, classified under European export regulations, and even those that are export control free. For more details please contact Applanix.

### 11) Why in some cases are different IMU's used in the same product?

Applanix uses different IMU's in the same products for the following reasons:

1. provides insurance against single source
2. increased availability for faster delivery
3. provide options for exportability
4. provide options for custom applications

### 12) I have heard claims that other systems use the same IMU's as Applanix, and hence can achieve 510 performance. Is this true?

You need to be very cautious with claims made about integrated GNSS-Inertial performance. Just because someone might have access to the same IMU, does by no mean guarantee that they can achieve the performance of an Applanix POS AV 510. This is like claiming that since you have the same tires on a Ford as on a Porsche, you can achieve the same handling performance!

Some of our POS AV systems use versions of an IMU called an LN200. These IMU's are manufactured by Northrop Grumman, and are controlled by the US State Department. The standard version of LN200 is offered as an option with our POS AV 410 units. For our 510 units however, we use a very special version of the LN200, designated the "LN200ROM". Applanix worked with Northrop Grumman to develop this IMU in order to achieve the heading accuracy required for Direct Georeferencing. While a standard LN200 (ie our POS AV 410) can achieve excellent Direct Georeferencing results for many mission scenarios, it cannot meet the heading performance required for large format cameras or high altitude sensors over all missions, especially with longer flight lines. An LN200ROM (or equivalent) must be used.

In order to ensure that the LN200ROM can achieve POS AV 510 performance, Applanix has worked with Northrop Grumman to develop a very specific test that checks the quality of certain sensor parameters. This test is ONLY done by Applanix, at our facility. The extra cost of this test is one reason why the POS AV 510 is priced higher than the POS AV 410. However in return, Applanix certifies the 510 performance. *Without this test, it is simply NOT possible to make this guarantee.*

Of course the other key differentiator with our products is the POSPac MMS software. This SW features the Applanix In-Fusion technology and SmartBase module, which together greatly increases the efficiency and accuracy of Direct Georeferencing.

### 13) What cameras and sensors does POSTrack support?

The following is a partial list of cameras and sensors supported by the POSTrack direct georeferencing solution:

1. Intergraph TOP RMK, RMKA Camera
2. Leica RC20/30 Camera
3. LMK 2000 Camera
4. Vexcel UltraCAM
5. Intergraph DMC (POS AV only)
6. Leica ADS40

7. Optech ALTM LIDAR
8. Leica ALS40,50 LIDAR
9. Riegl Q240, Q560 LIDAR
10. Applanix DSS medium format Camera
11. ITRES CASI Hyperspectral Imager
12. FERI Samson Hyperspectal Imager
13. Jenaoptronik JAS150
14. Werhli DAS

Contact Applanix for details and other sensors not listed.

**14) What is a "real-time" solution, and what is it used for?**

The real-time solution is the output from the GNSS-Aided INS software described in 2) running on the POS AV computer system in real-time. This is position, velocity, roll, pitch and heading, output at rates of up to 300 times per second with a delay of less than 5 msec. The real-time solution is extremely important since it is used for the following tasks:

1. Guiding the pilot via the POSTrack pilot display
2. Determining when to trigger a camera to take a picture or control a sensor on or off
3. Provide leveling control of stabilized mounts using the roll and pitch of the mount computed by POS AV
4. Provide automatic drift control of stabilized mounts using the heading of the sensor computed by POS AV
5. Provide status of the GNSS-Aided INS integration to the pilot and operator. By running the GNSS-Aided INS software in real-time, problems with the IMU, GNSS or installation can be detected in real-time instead of flying a whole mission and then finding out
6. Directly georeferencing sensor data in the air, or immediately upon landing for rapid response applications
7. Provide an "instant-align" capability in Applanix POSPac MMS. Here the POSPac MMS post-processing solution is automatically initialized from the real-time solution, so that you do not have to worry about alignment convergence. This applies to either airstart or ground start.

It is NOT sufficient to only have the GNSS position and velocity computed in real-time since this does not provide enough information to determine the health of the system, provide proper mount control, and provide high-performance flight management.

**15) How is POSTrack used to control stabilized mounts?**

POSTrack is used to control stabilized mounts as follows:

1. The roll and pitch from POS AV are sent to the mount in real-time and these are used to provide the leveling reference about which the mount gyros stabilize. This eliminates the typically problems with gyro stabilized mounts being pulled off of level by lateral accelerations
2. The True heading from POS AV is uses to automatically steer the mount to follow either the mean velocity vector of the aircraft over the ground, or to follow a desired heading along the ground set by the mission plan.

3. The gimbal data from the mount is read by the POSTrack to compute the dynamic lever arm between the GNSS antenna and the camera, and to compute the orientation of the aircraft from the orientation of the mount
4. The mount is automatically frozen and un-frozen at the end and beginning of each flight line.

**16) What stabilized mounts are supported by POSTrack?**

POSTrack currently supports the following stabilized mounts:

1. Somag GSM3000: drift, leveling, freeze and un-freeze, gimbal encoder
2. Leica PAV 30/80: drift, leveling, freeze and un-freeze, gimbal encoder
3. Intergraph ZI-Mount: drift, leveling, freeze and un-freeze, gimbal encoder
4. Intergraph T-AS: drift, freeze and un-freeze, gimbal encoder
5. DSS Azimuth Mount: drift, gimbal encoder (no need to freeze)
6. WESCAM: gimbal encoder

**17) Does POS AV support Satellite Based Augmentation Services (SBAS) such as OmniStar and NAVCOM?**

POS AV includes embedded WAAS and EGNOS SBAS support, plus embedded OmniStar XP. Corrections are received via the single GNSS + L-Band aircraft antenna provided with the system. OmniStar XP is activated via a yearly subscription fee purchased locally.

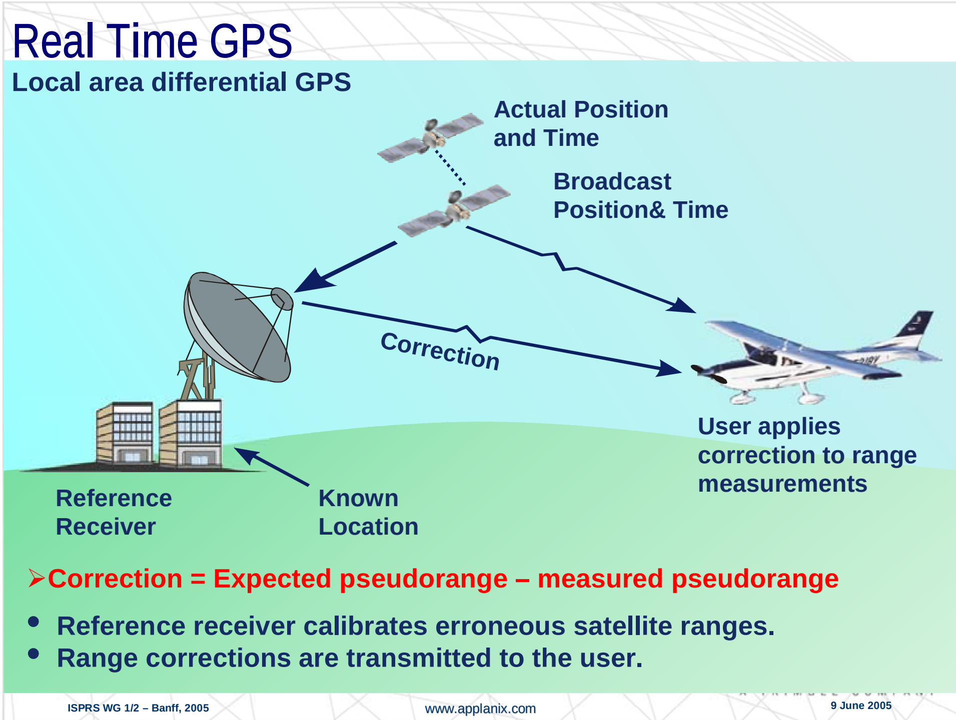
POS AV also supports external Satellite Based Augmentation Services (SBAS) either as a source of RTCM differential correction inputs applied to its internal GNSS receiver, or as auxiliary GNSS inputs (AUX GNSS). Up to 3 SBAS sources can be connected to POS AV at any time: 1 as a source of RTCM differential corrections, and 2 as auxiliary GNSS inputs.

POS AV continuously monitors the accuracy of the AUX GNSS solutions, and automatically uses this in its real-time GNSS-Aided INS solution if it detects that it is more accurate that the internal GNSS solution. The AUX GNSS solution is also logged and can be post-processed through POSPac MMS for improved accuracy.

**18) What accuracy can be obtained using SBAS?**

Current Satellite Based Augmentation Services (SBAS) solutions employ 3 types of technology: standard Code differential correction, precise ephemeris and satellite clock corrections, and floated carrier phase corrections. OmniStar provides services that use all 3 types of technology, while the NAVCOM uses the first 2 types of technology.

SBAS work by deploying a series of GNSS base stations around the world, and then using these base stations to send data to the remote receivers to correct for GNSS errors:




The Code Differential corrections are applied strictly to the CA code pseudoranges (see above Figure), and can reduce the standard CA code positioning error to the 1 m level RMS.

The precise ephemeris approach relies on correcting the satellite clocks and orbits so that the correct ambiguities in the carrier phase can be observed through motion of the satellites. This approach requires time before the solution can reach full accuracy.

The floated carrier phase approach is a typical carrier phase DGNSS solution that also can take up to 0.5 hour to converge, and is of course susceptible to cycle slips and distance from the reference stations.

Both OmniStar and NAVCOM advertise 10 cm accuracy for their precise products. However these specifications were originally developed for slow moving land vehicles (tractors). Experience by Applanix and their customers in the aircraft have proven that the 10 cm specification is NOT reliable, and in particular the floated carrier phase approach (OmniStar HP) is not practical in an airborne environment.

The POS AV currently supports the OmniStar XP service, with a typical accuracy of 0.1 – 0.5 m RMS.

NOTE: Higher accuracy might be possible, but Applanix STRONGLY advises against relying 100% on a SBAS to achieve this. Ensuring that there is a single dedicated base-station in the area or at least some available CORS stations in or around the area will provide the insurance for this.

**19) Do I need to install a separate antenna for POS if I use SBAS?**

It is not necessary to install a separate antenna for an SBAS receiver and POS AV. The POS AV antenna tracks GPS L1/L2 + GLONASS + L-Band SBAS signals.

**20) What is the Applanix POSPac MMS?**

POSPac MMS is a set of post-processing software tools that provide a complete workflow and highest level of accuracy for Direct Georeferencing using POS AV and POSTrack.

POSPac MMS implements a special version of the GNSS-Aided Inertial Navigation software described in 2) to enable the highest accuracy solution possible via carrier phase differential GNSS positioning and forward and reverse processing.

**21) What is POSPac Photogrammetry Tools?**

Photogrammetry Tools is a special module of POSPac MMS that provides the ability to do efficient and accurate Direct Georeferencing of frame cameras. It includes two unique modules called POSEO and CALQC.

POSEO is used to generate the Exterior Orientation (X, Y, Z, Omega, Phi, Kappa) or EO of each image at the exact time of the exposure, in the user's desired local level mapping frame projection and datum.

CALQC is a sophisticated software module that provides the user with the ability to initially calibrate the IMU mounting misalignments with the camera frame (boresight angles), and then for each mission perform a check on the quality of the Direct Georeferencing results. CALQC™ makes us of an automatic tie-point matching module that is super fast and accurate, plus a sophisticated least-squares adjustment module. CALQC is NOT Aerial Triangulation software, and is unique in the industry.

For initial boresighting, CALQC automatically determines the misalignment of the IMU with respect to the camera. These values are then stored for future use.

For mission specific quality control, a small block of stereo images is imported into CALQC. These are then run through the automatic point matching software and adjustment model along with the EO data from POSEO and at least 1 checkpoint to check:

- How well the tie-points fit each other using the EO from POS
- How well the block fits the checkpoints (no datum shift, no GNSS errors)
- The statistics on the boresight values (have they changed?)
- How well the camera model fits (has it changed?)

If all parameters are within specifications, the user simply prints out the report from CALQC™ to deliver with the project and uses the EO for the rest of their project in the mapping process. However, if any parameters have changed but are stable, the user then has the option to apply the corrections to the model or EO for the rest of the mission.

**22) How does Direct Georeferencing apply to Aerial Cameras?**

In this case, Direct Georeferencing (DG) is the direct measurement of the Exterior Orientation (EO) of airborne images at an accuracy level sufficient to:

1. Directly ortho-rectify each pixel on the ground using an existing DEM to an accuracy level that meets applicable mapping standards for the scale of map being produced. Note that this can be done with a single photo or multiple photos without assumption about overlap.
2. Directly extract a DEM from overlapping stereo imagery at an accuracy level that meets applicable mapping standards for the scale of vertical map being produced.
3. Directly setup stereo pairs on a photogrammetric plotter with residual parallax less than a pixel, thus enable operators to efficiently compile vector information from the stereo imagery, at an accuracy that meets applicable mapping standards

**23) What are the benefits using Direct Georeferencing for Aerial Cameras?**

The benefits of Direct Georereferencing include but are not limited:

1. Eliminates the need to do aerial triangulation (AT), which saves costs both through time and labor savings, and by not having to collect extensive ground control points (GCP) to do the AT
2. Enables the ability to map using a single strip, photo or stereo pair, which saves both acquisition and processing time
3. Enables the ability to map in remote locations (islands, reefs, deserts, jungle etc)

**24) What is Assisted-Aerial Triangulation or Integrated Sensor Orientation?**

Assisted Aerial Triangulation (Assisted-AT) or Integrated Sensor Orientation (ISO) refers to the process of using the directly measured EO from a GNSS-Inertial system to “seed” the automatic point matching and bundle adjustment process in aerial triangulation. Such a technique is used when the directly measured EO is not sufficiently accurate to meet the requirements for the scale of map being produced (horizontal or vertical), or the parallax is too large to allow manual stereo compilation. Using the EO in the AT process:

1. Constrains the search area for tie-point point matching algorithms
2. Constrains the bundle adjustment process

The net output of the Assisted-AT process is an adjusted EO that will be parallax free and will meet the map accuracy requirements. Note that if the accuracy of the directly measured EO is already sufficient to meet the desired map accuracy, this process can be run without GCP in a so-called “relative” adjustment just to remove parallax.

**25) What are the benefits of Assisted-AT?**

The benefits of Assisted-AT over traditional AT include:

1. Faster processing
2. More robust and automatic processing (reduced re-work)
3. Higher accuracy
4. No cross strips are required, which reduces acquisition costs

5. Fewer GCP are required, which reduces overall project cost

**26) What EO accuracy is required to do Direct Georeferencing of Aerial Cameras?**

The EO accuracy required to do DG depends upon the scale and type of map being produced (horizontal or vertical) and the type of camera being used.

The POS AV 510 system was designed to meet the requirements for large format film and digital cameras for map scales as large as 1:1000, after which point the error of the GNSS computed photo centers usually becomes too large and Assisted-AT needs to be employed.

The POS AV 410 system was designed to meet the requirements for Direct Georeferencing of medium format sensors. However it can still be used with Large format sensors for smaller scales, and with Assisted-AT for larger scales.

**27) How often do I need to boresight the IMU?**

Over ten years of Direct Georeferencing experience using POS AV on cameras and LIDAR have proven that as long as the IMU is rigidly attached to the sensor device and is not disturbed, the boresight does not need to be recomputed on a regular basis. Studies conducted by Applanix and their customers have shown stability over periods well over 6 months to a year. In some cases however, where the IMU is mounted externally to a sensing device, or if the device with the IMU is shipped or re-installed quite frequently, or the mounting is not as rigid as one would like, the boresight can change slightly over time and it will need to be recomputed. However, any changes in the boresight can be instantly detected by CALQC during the standard mission specific QA procedure, and the users can simply re-boresight at that time if necessary.

**28) What is Applanix' support structure?**

Applanix currently offers worldwide support through offices in Toronto Canada, Huston USA, Newcastle UK, Berlin Germany, Beijing China and Tokyo Japan.