THE POSITION AND ORIENTATION SYSTEM (POS) FOR SURVEY APPLICATIONS

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ABSTRACT

The Position and Orientation System (POS) is an integrated inertial/GPS system that generates accurate position (latitude, longitude, altitude) and orientation (roll, pitch, heading) for airborne survey/mapping applications as well as various other land and marine applications. POS is a GPS-aided strapdown inertial navigator that uses a Kalman filter and a closed-loop error controller to provide an optimally blended position and orientation solution from inertial data from an IMU and aiding data from a GPS receiver. This paper gives a brief description of POS and compares it to other available technologies. It then describes the various application areas of POS for airborne vehicles (POS/AV). Some applications from other POS variants, POS/LV for Land Vehicles, POS/MV for Marine Vessels, are also described.

1. INTRODUCTION

The Position and Orientation System (POS) developed by Applied Analytics Corporation is a Kalman filter-based integrated navigation system designed for airborne surveys and mapping. POS performs an automatic leveling and heading *in air-alignment* and computes a *real-time* position (latitude, longitude, altitude) and orientation (roll, pitch, heading) solution using Kalman filter based aided inertial navigation algorithms. The primary aiding sensor for most applications is GPS or differential GPS. POS technology is an example of conversion of military integrated navigation technology to meet commercial applications.

POS consists of two components the Inertial Measurement Unit (IMU), and the POS Computer System (PCS). The IMU is self contained and consists of three gyros and three accelerometers in orthogonal triads. It is small, lightweight and can be mounted directly onto most sensors. The PCS is a 19" rack mountable chassis that contains the data acquisition electronics, data recording equipment, GPS receiver and various ports for easy interfacing to other sensors. POS/AV is used in conjunction with various airborne sensors to provide accurate attitude measurements (roll, pitch, true heading and crab angle) as well as uninterrupted position. These measurements can be provided in real-time or in post-processing for enhanced accuracy by using the recorded raw data and the post-processing software 'POSPROC'. The type of sensors that POS/AV is typically used with include multispectral scanners, scanning lasers, cameras (both film and digital) and Synthetic Aperture Radar (SAR). Although the use of POS/AV varies somewhat between applications, its main purpose is to provide accurate pitch/roll/heading measurements for motion compensation and geocoding without or with only minimal use of ground control points.

2. PHYSICAL DESCRIPTION

The major components of POS are the POS computer system (PCS) and the IMU. Unlike an inertial navigation system (INS) or attitude and heading reference system (AHRS), POS uses an IMU that is self-contained and separate from the PCS, connected to the PCS by a data interface and power cable. The IMU is selected from among several different candidates to be small, light and commensurate in cost and performance with the targeted application. POS "navigates" the IMU, i.e. computes the IMU position and orientation. The IMU is separated from the PCS to allow it to be mounted directly to or close beside the survey instrument or reference point

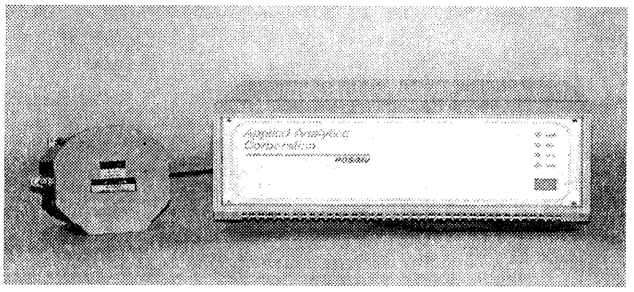

Figure 1 . Core POS Showing the IMU and PCS.

whose position and orientation are sought. IMUs that are currently used with POS are the Litton LR-86 dry tuned gyro IMU, the LN-200 IFOG-based IMU also from Litton, and the BAT IMU from Allied Signal. All these IMUs are small and lightweight, and therefore can be mounted directly to instruments or platforms on which larger and heavier inertial reference systems could not fit. The LR-86 has dimensions of 3.3x5x5.6 inches and weighs 4.2 lbs. The LN-200 is even smaller at 3.5x3.35 inches (diameter x height) and 1.5 lbs. Figure 1 shows the core POS configuration comprising the LR-86 IMU and the PCS.

The PCS contains all the data acquisition and processing hardware, GPS receiver, data recorder and power supplies for the PCS and the IMU. The PCS interfaces to a notebook PC for control and monitoring functions. POS is nominally configured with the Novatel Performance Series embedded GPS card to provide a complete and self-contained position and orientation solution. In many POS applications, however, the target vehicle carries an existing GPS receiver for navigation. POS can be configured to interface with a number of external GPS receivers such as the Trimble 4000 and the Ashtec Z12. The position and attitude data from POS is available in real-time over RS232, RS422, and ethernet ports. An event marker port is also available for easy and precise time-alignment with the sensor data. The real-time data as well as raw data is also recorded for post-processing on a built-in 8mm exabyte tape recorder. Using this data the companion post-processing software 'POSPROC' generates a more accurate position and orientation solution. POSPROC runs on the Windows NT platform and is also available for the Sun workstation environment.

3. AIDED INERTIAL NAVIGATION

Figure 2 shows the aided inertial navigation algorithm implemented by POS. The term *aided inertial navigation* defines a method of blending inertial data from accelerometers and gyros with position and velocity data from an aiding navigation sensor, in this case GPS or differential GPS receiver. The algorithm combines inertial navigation with GPS navigation and any other available aiding sensor in an optimal manner to generate a blended navigation solution that retains the best characteristics of inertial and GPS navigation. The key components are an *inertial navigation component* and an *navigation error regulation component.*

initialization, leveling and heading alignment under almost all normal dynamic conditions. Static initialization, as would normally be required by an INS, is not required by the POS. The POS error controller includes a coarse leveling

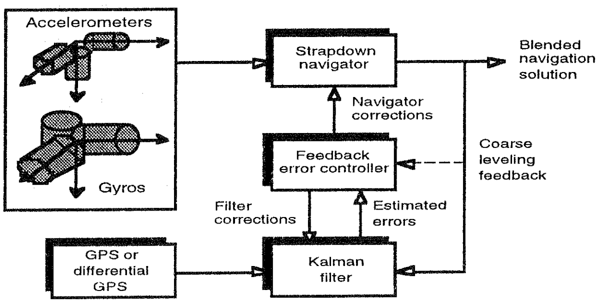

Figure 2 : POS Aided Inertial Navigation Algorithm

loop that provides rapid coarse leveling of the strapdown navigator mathematical platform. The POS Kalman filter implements a modified ψ-angle error model for coarse azimuth alignment, subsequent fine roll, pitch and heading alignment and continuous error control.

4. PERFORMANCE

POS attitude performance is dependent on the quality of the IMU, the quality of the GPS data, and whether real-time data or post-processing is used. Typically, with a LN-200 IMU and real-time differential GPS, pitch/roll of $< 0.05^0$ is achieved. With a LR-86 IMU, carrier phase GPS, and data post-processing, accuracies down to the 20arcsec level are possible. Heading performance is further dependant on maneuvering as well as latitude.

TABLE I. POS/AV Performance

Quantity	*Single GPS*	*Real-Time Differential*	*Post-Processed Carrier -Phase*
Position	75 m	2-5 m	10-30cm
Roll, Pitch	3 arcmin	1 arcmin	0.5 arcmin
Heading	20 arcmin[1]	<10 arcmin[1]	5 arcmin[1]

1. Following heading calibration maneuver.

The inertial navigation component comprises the IMU and a full strapdown navigator that computes the IMU position, velocity and 3-axis attitude. The error regulation component comprises the Kalman filter and closed-loop error controller. The Kalman filter estimates the strapdown navigator errors and selected inertial sensor and GPS errors. The error controller computes and applies resets to the strapdown navigator integration process to achieve initial alignment and subsequent continuous error regulation. When good quality position and velocity aiding data are available, such as from the GPS or differential GPS, the POS aided inertial navigation algorithm provides

Typically, for latitudes below 70^0 and maneuvers every 10 to 15min heading accuracies of 10 to 20 arcmin can be achieved in real-time. With more frequent maneuvering, and/or post-processing heading accuracies of 4-5 arcmin are achievable. If frequent maneuvering is not possible or operation at high latitudes is required, a two-GPS antenna version of POS/AV is available that eliminates the need for maneuvering and brings heading performance at par with roll/pitch. Table I summarizes POS performance for the LR-200 IMU and two different GPS configurations.

5. INTEGRATED INERTIAL/GPS vs. OTHER ATTITUDE SENSORS

Compared with other approaches for attitude measurements, the inertial/GPS integration approach used in POS/AV has distinct advantages that combine to offer excellent performance/price ratio from the medium-low to the highest performance range:

Multiple-antenna GPS: Commercial systems are available that provide attitude information by using four GPS antennas. Although they can be fairly inexpensive, they provide only limited accuracy. This accuracy can be improved by increasing the spacing between the antennas. Flexing of the hull the antennas are mounted on, however, quickly degrades performance and spacing the antennas can be impractical on an airborne platform. Further, the rms (1-σ) level of accuracy achieved with this approach does not fully reflect the performance of the system. Unlike a well-behaved gaussian error distribution where the maximum errors are at about 3-5σ, the error statistics in a multiple antenna system are not well behaved. As a result, maximum attitude errors in a multi-antenna system can be many times the rms level. The error statistics of an inertial/GPS system on the other hand are relatively well approximated by a gaussian distribution and predictable from the rms level.

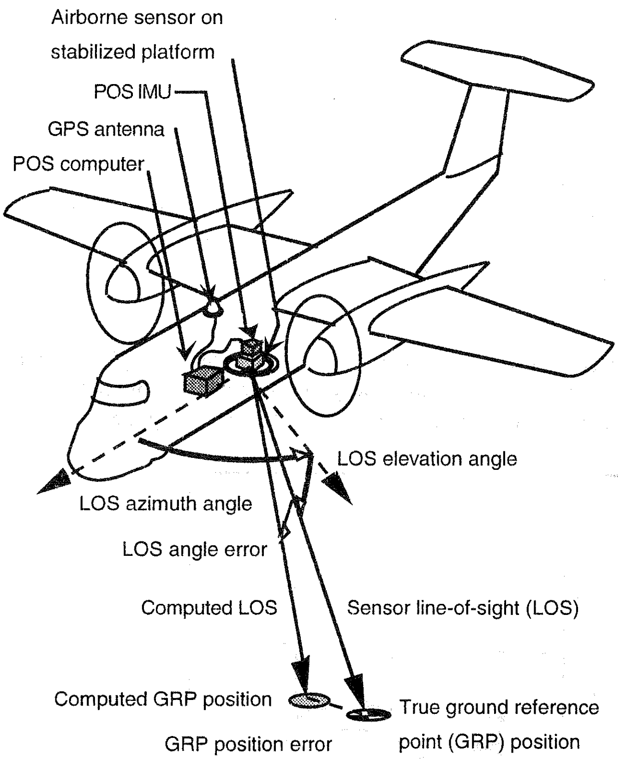

Figure 3. Airborne Geocoding of Survey Data

Inertial Navigation Systems (INS): These are usually based on high-quality ring-laser gyros (RLG) with low drift rates and high-quality accelerometers to provide the highest level of performance. INSs can be operated unaided, but do require a fairly extensive period of ground alignment. Although INSs have come down in price, they are still quite expensive. Because they are mostly developed for military applications their interface is usually based on the 1553-bus and the NRE costs associated with the development of a data acquisition and control unit for it can be non-trivial. The size and weight of an inertial unit, significantly higher than an IMU, can also be a limitation and can restrict its ability to be mounted on a small sensor. In some high-end applications, however, only the accuracy of a ring laser gyro will meet the requirements. For these applications, and since there are currently no high-quality RLG-based IMUs, an INS must be used. POS is currently being upgraded to provide an interface to an INS and further enhance the INS' performance by allowing integration with differential GPS.

Attitude Heading Reference Systems (AHRS): An AHRS consists of gyros, accelerometers, and a magnetic sensor unit. The heading provided by an AHRS is magnetic heading derived from measurements on the earth's magnetic field. To measure the platform's heading the magnetic sensor must be mounted on the platform and calibrated for the soft and hard magnetic errors caused by the platform. Such a calibration requires 360^0 turns of the helicopter and it is not very accurate. In order to provide true heading from magnetic heading, a local magnetic field map is required to transform magnetic to true heading. Besides the need for obtaining such a map, local magnetic fields vary continuously and further corrections based on time of year and day must be applied. In general, an AHRS cannot be expected to provide attitude accuracies better than about 1.0^0 rms.

Vertical and Directional Gyros: These provide only limited capability and are suitable for applications where only limited attitude information and accuracy is required.

Integrated Inertial/GPS: Inertial and GPS sensors have complementary strengths and shortcomings. GPS provides very good long term accuracy but in the short term suffers from outages, multipath and noise. Inertial sensors have excellent short-term characteristics but suffer from long-term drift. By combining the two sensors, levels of performance can be achieved that match or exceed those of much more expensive INS systems. Integrated systems provide excellent short-term dynamics greatly reducing GPS's multipath and outage problems, and have none of the long-term drift problems associated with inertial sensors. Further, they can automatically perform in-air heading alignment to true North without the need for the ground alignment of INSs or the turning of the aircraft required for AHRS.

Fully integrated inertial/GPS sensors such as POS/AV provide the best performance of all position and attitude sensors at a reasonable cost. Being small, modular and lightweight they are suitable for virtually all applications requiring accurate and reliable position and attitude measurements.

6. AIRBORNE SURVEY APPLICATIONS

Airborne POS applications include film and digital frame cameras, pushbroom-type multi-spectral scanners, scanning lasers, shallow water bathymetry, SAR, airborne gravimetry and gradiometry and stable platforms. All these applications have a requirement for precise attitude measurements.

Figure 3 shows a typical POS/AV application for an airborne survey instrument. The position of the ground point is determined from the position of the aircraft, the pointing angle or line-of-sight (LOS) angle of the survey instrument and a digital terrain model (DTM) with respect to local level. Accurate determination of individual points requires accurate measurements of both position and orientation. The integrated approach of POS generates both quantities.

Imaging Scanners: These include digital multi-spectral scanners such as the casi and the Daedalus and other types of scanners such as thermal infrared. In this application the image formed by the forward motion of the aircraft is distorted by pitch, roll, and platform crab angle. These parameters are measured by POS/AV and recorded on tape. In post-processing POS' attitude and position measurements are combined to correct for sensor motion artifacts. Following correction, and by using a DTM, image pixels can be accurately geocoded and finally the individual strips mosaiced. To perform these operations geocorrection software such as GEOCOR from CCRS must be used. Up until recently airborne scanners have been used primarily for remote sensing applications. By incorporating attitude data from POS/AV a scanner can now be used as mapping instrument as well.

recording attitude in real-time POS not only provides the required precision pitch/roll measurements but also provides ready to use data. Further, and by being able to perform in-air alignment POS eliminates the need for time-consuming ground alignment procedures prior to take-off.

Film Cameras: This is an area where POS/AV has the potential to offer a breakthrough in airborne survey and mapping. By providing precise arcsec-level pitch/roll/heading measurements, POS/AV can reduce and potentially even eliminate the need for ground control points and aerotriangulation. Tests conducted using Leica RC10 and RC30 cameras indicate that such accuracies are possible. For this level of accuracy solid mounting of the IMU on the sensor is very important.

The small size of the IMUs used in POS permits mounting of the IMU right on the sensor. Precise time alignment of the POS data with the shutter exposure pulse is also key in obtaining good quality results. POS' event marker input is used to time stamp the shutter pulse down to sub-μsec accuracy. This is particularly important for this level of accuracy since time can differ between GPS receivers by up to a few msec.

Digital Frame Cameras: The resolution of digital frame cameras is still a long way from that of film, but these cameras are finding an increasing number of applications.

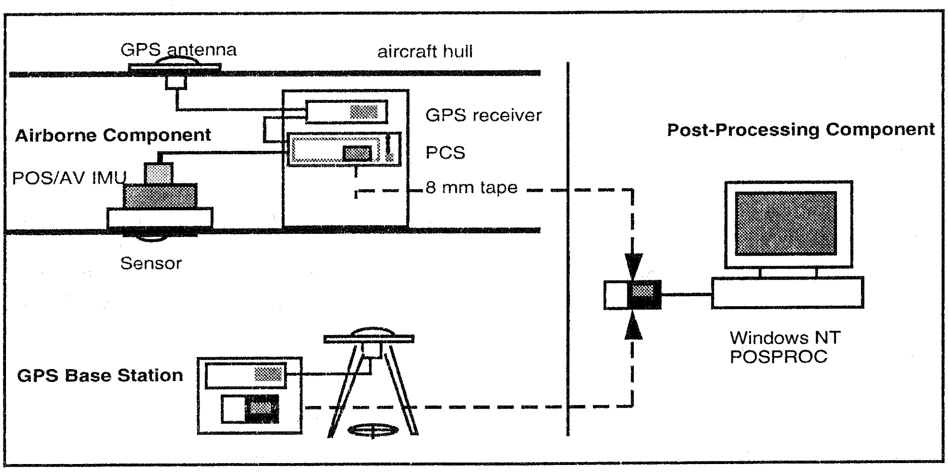

Figure 4. POS/AV with External GPS Receiver

Scanning Lasers: This is a new generation of airborne sensors opening a new class of applications and making old survey and mapping applications easier and faster. An airborne scanning laser flies at altitudes of up to 1km and scan swaths typically 40^0 wide. With footprints smaller than a foot and scanning rates of a several KHz a fairly dense grid of ranges can be collected within the scanned swath. One fly-over can provide DTMs of the area with unprecedented density and accuracy. In order to take full advantage of the capabilities offered by this type of instrument, however, precise measurements of the sensor's attitude must be performed. Because of the difficulty in providing ground control points for this type of sensor, an attitude measuring system is an integral part of the sensor. By measuring and

POS is being used to provide attitude measurements for such cameras that permit the rapid mosaicing of individual frames to cover large areas. With POS flying over relatively flat terrain, it is possible to mosaic hundreds of image frames within a few hours and form large area maps for fast delivery to the end customer.

Synthetic Aperture Radar: POS can provide high precision position and attitude measurements over the span of the synthetic aperture (typically of the order of 10-20sec). Sub-millimeter position and sub-arcsec relative attitude measurements are required for SAR and have been achieved with POS.

Other airborne POS applications include gravimetry and gradiometry, laser bathymetry and stabilized sensor platforms.

7. OTHER POS APPLICATIONS

Road Survey Vans: POS/LV, (POS for Land Vehicles), was developed to measure vehicle motion dynamics for the purpose of computing road inspection parameters such as the transverse slope of the road (crossfall), and the longitudinal profile of the road. Measurements of crossfall provide useful information such as the bank of the road during curves, as well as whether the road is properly sloped for drainage purposes. Longitudinal profile is the vertical variation of the road with respect to the local level, for wavelengths of up to 200 m. Such information is useful for evaluating road roughness which effects ride quality. In addition to GPS, POS/LV integrates measurements from a Distance Measurement Indicator (DMI) subsystem. The DMI provides accurate distance travelled and velocity measurements, which complement the aiding information from the GPS. This additional information increases the accuracy of the blended attitude solution to better than 2 arc-min RMS for roll and pitch.

Track Geometry Cars: POS/TG (POS for Track Geometry) is quite similar to the /LV application. The IMU is mounted on the axle of a car to measure various types of deformation of the railway tracks. A DMI and GPS are used as the aiding sensors.

Hydrographic Survey Applications: POS for Marine Vehicles (POS/MV). Motion compensation of multibeam sonars for quantitative hydrographic survey can take one of two forms. The returned echoes from the sea floor received on multiple acoustic beams fixed in the ship's reference frame are dynamically corrected for ship orientation relative to the geographic reference frame at the instant the bottom echo from each beam is detected. Alternatively, the multibeam sonar continuously "steers" its beam array so as to decouple the beam array orientation from the roll and pitch of the ship. In both cases, ship roll, pitch and heave data are required from a motion sensor that ideally monitors the motion of the sonar transducer directly. Typically the motion sensor is located near the sonar transducer on the assumption that the relative motion between the transducer and motion sensor is negligible.

8.0 ACKNOWLEDGEMENTS

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9.0 REFERENCES

[1] C.D.Anger, S. Mah, S.K.Babaey, Technological Enhancements to the Compact Airborne Spectrographic Imager (casi) 1st International Airborne Remote Sensing Conference and Exhibition, Strasbourg, France, September 1994.

[2] W. Gesing and D.B. Reid, *An integrated multisensor aircraft track recovery system for remote sensing*, IEEE Transactions on Automatic Control, Vol AC-28, March 1983.

[3] J.R.Gibson, *Photogrammetric Calibration of a Digital Electro-Optical Stereo Imaging System*, GEOMATICA, Vol. 48, No. 2, Spring 1994, pp. 95-109.

[4] Mary Jo Wagner, *Seeing in 3-D Without the Glasses, Earth Observation Magazine*, July 1995, pp. 51-53.