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The Applanix Approach to GPS/INS Integration

ERIK LITHOPOULOS, Markham

ABSTRACT

The Position and Orientation System for Direct Georeferencing (POS/DG) is an off-the-shelf integrated GPS/inertial system designed specifically for airborne applications. POS/DG measures the position and orientation of the sensor with accuracies sufficient to produce Digital Terrain Models (DTM), Orthophotos and Maps that are suitable for a wide range of applications. Over the past four years POS/DG has been installed on various airborne sensors requiring high-accuracy position and attitude measurements: aerial cameras, digital line scanners and digital cameras, laser scanners, and Synthetic Aperture Radar (SAR). For aerial and digital frame cameras, POS/DG enables the direct georeferencing of aerial photos without the need for aerial triangulation or tie points and only minimal ground control. For line and laser scanners POS/DG performs line-to-line geometric correction and direct georeferencing of the data. For SAR systems POS/DG is used for the motion compensation over the aperture length and he data geocoding of the derived DTM. The common element in all these application is a substantial reduction in the post-processing effort and rapid turnaround of data. In the case of the line and laser scanners in particular, the incorporation of POS/DG has actually enabled their use as a mapping tool an application that was previously not possible with scanning-type sensors.

1. INTRODUCTION

Differential GPS has greatly increased the productivity of survey operations in recent years. With a sufficient number of satellites in view, DGPS is now capable of delivering position fixes rapidly and reliably to accuracies of a few centimeters using carrier phase techniques. This capability enables the surveyor to move quickly from point to point - maintaining positioning accuracies to within survey standards while operating “on the fly” (OTF).
Still further gains in survey productivity can be realized by combining DGPS with precision inertial sensors. A system that combines DGPS with inertial offers the following features:

- full 6 degree-of-freedom, high-accuracy position and orientation solution (position + roll, pitch, heading)
- high rate outputs - 200 samples per second
- continuity of data through GPS outages

These features provide the user with the capability to survey reliably from remote and rapidly moving platforms. In addition, very high absolute and relative pointing accuracy can be achieved by combining carrier-phase differential GPS and precision inertial. With accurate orientation (angle) measurements available, high-resolution imaging sensors can be used to map the terrain remotely to survey-level accuracy. The ability to provide both absolute and relative measurements allows POS/DG to be effectively used with both frame and scanning-type sensors. Large gains in surveying productivity can be realized in this way. Examples of such applications include DTMs derived with three-line scanners, scanning lasers and SAR and airborne photogrammetry using traditional aerial cameras. Following a brief description of the POS/DG hardware and software applications with the various airborne sensors are described.

2. SYSTEM DESCRIPTION

Applanix manufactures a line of integrated GPS/inertial products designed for remote mapping, surveying and precision motion compensation applications. This product line is referred to collectively as POS, standing for Position and Orientation System.

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A POS model specifically designed for airborne photogrammetry applications was introduced in 1997 – referred to as POS/DG (DG = Direct Georeferencing). POS/DG is a precision integrated GPS/inertial system designed specifically for airborne applications requiring high-precision high data rate position and attitude measurements. The coordinates of ground points, height contours, etc can then be measured directly from stereo pairs (as with aerial and digital frame cameras) or direct distance measurements (as with laser scanners and SAR). This approach minimizes the need for ground control points and eliminates the need for tie points and aerotriangulation altogether.
The configuration of POS/DG installed on an aerial camera is shown in Figure 1.

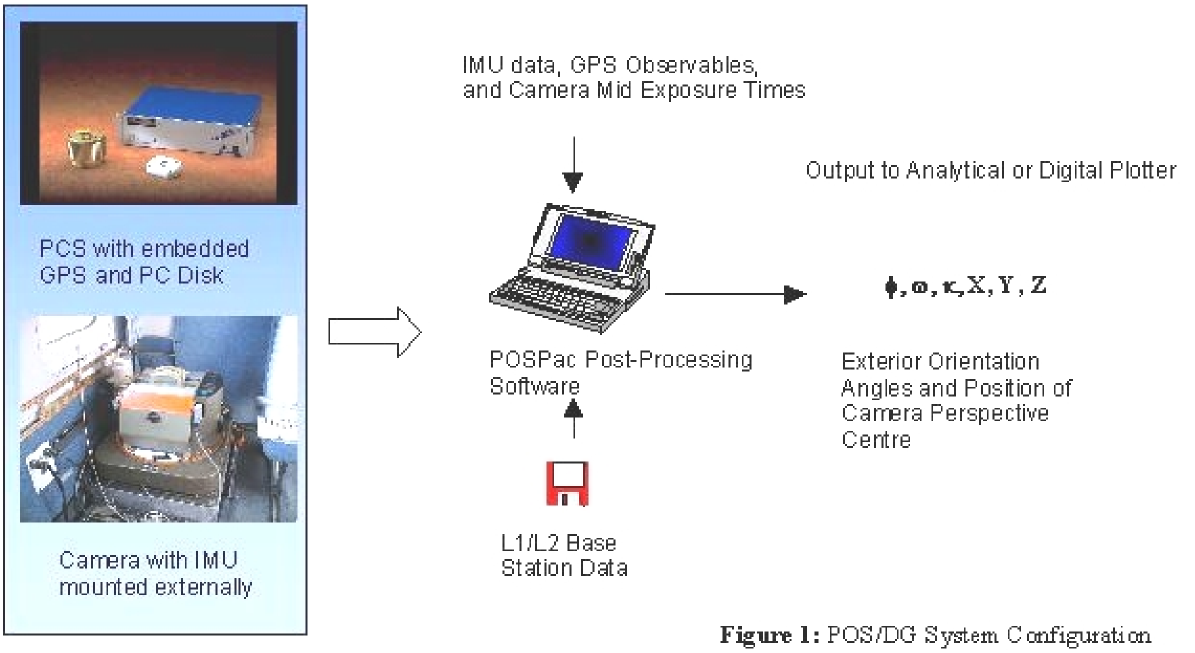

Figure 1: POS/DG System Configuration

The airborne element is made up of three main components:

- *Inertial Measurement Unit (IMU)*, comprising three accelerometers three gyros and signal conversion and processing electronics, outputs high-accuracy acceleration and angular rate measurements in digital form to the POS computer system. These measurements are processed to compute a full 6 degree-of freedom position and orientation (ω, ϕ, κ) solution referenced to the IMU location, updated at 200 Hz. The IMU is custom developed for airborne applications. It is lightweight and compact unit and it is hard-mounted directly to the aerial camera for maximum accuracy.
- *GPS:* POS/DG is typically configured with a dual-frequency differential GPS receiver embedded in the POS computer system. Alternatively, POS can be interfaced to a user-supplied stand-alone receiver.

POS Computer System (PCS) implements real-time processing, time alignment and data acquisition and storage functions. The PCS offers simple two-button operation for on-off and data recording. Several hours of data can be recorded on the PCMCIA disk for post-processing. If required, display and control is provided by a custom application running under Windows on a laptop PC. Time synchronization with the camera is achieved with the time-of-exposure pulse from the camera acquired by the PCS via its discrete port.

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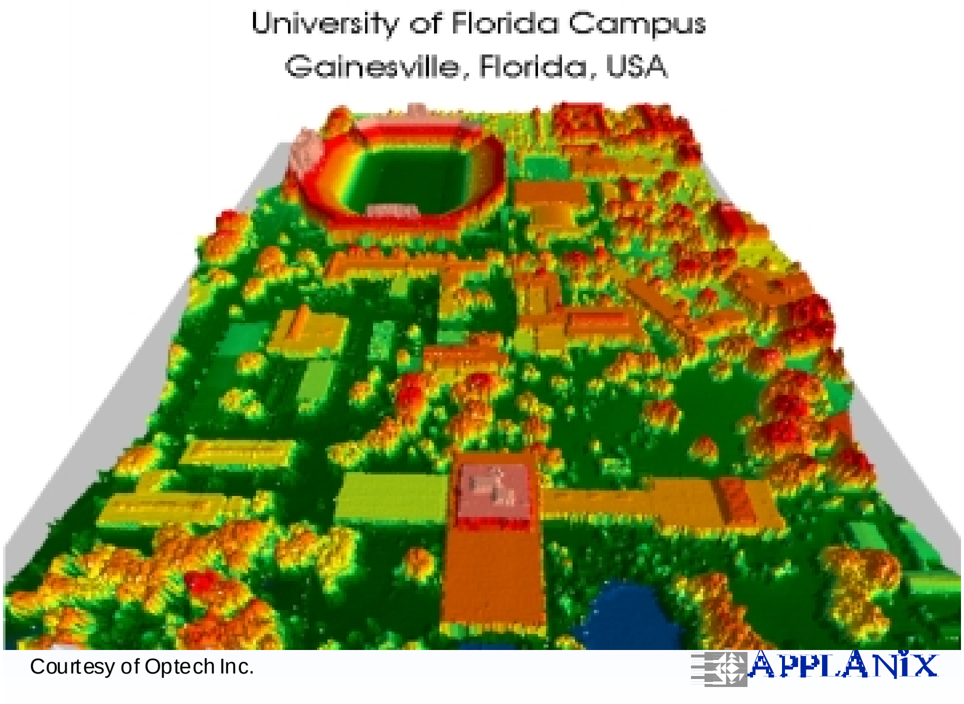

The precise camera's position and orientation parameters are determined by post-processing of the recorded POS data. Post-processing is implemented in two stages.

Forward Time: In the forward pass, the inertial sensor data are processed using a strapdown inertial navigation algorithm to compute a complete, dynamically accurate six-degree-of-freedom position and orientation solution for the camera. Update rates on the strapdown computations are at 200 Hz, with position and orientation outputs referenced to the time of film exposure by time-alignment with the camera pulse discretes. The recorded GPS data are processed using carrier phase methods to obtain position fixes to about 5 or 10 centimeter accuracy at 1 Hz. Positions logged from a dual frequency GPS base-station are used for differential corrections. The inertial and GPS data are blended using a Kalman filter configured typically with 22 to 35 states. The Kalman filter estimates the position, velocity and attitude errors of the inertial solution and the residual sensor biases, scale factor and misalignment errors. These estimates are fed back to the inertial navigation computations to remove drift in computed position and orientation and to null the effects of the residual sensor errors.

Backward Time: The estimates of camera position and orientation obtained in forward time are derived using GPS and inertial measurements that occur prior to and at the time-of-validity of each estimate. Backward-time processing incorporates GPS and inertial measurements into the computations that occur after the time-of-validity of each estimate so as to improve overall estimation accuracy. An optimal recursive smoother is used for this purpose. Accuracy improvements realized by smoothing can be very significant – with improvement factors ranging from about 2 to 10 depending on the mission profile and dynamic environment.

The WGS-84 reference ellipsoid in employed in forward and backward time processing of the data. On completion of backward processing, the computed camera position and orientation parameters are transformed from WGS-84 into the local survey coordinate system. This transformation includes conversion of the three orientation angles – roll, pitch and heading – to the three rotations employed in photogrammetry - ϕ, ω, κ. After this transformation, a file is output containing the six camera orientation parameters at the time of each exposure. This file is input to the photogrammetry process (digital or analog) to construct stereo models from the acquired imagery.

Software that implements the functions described above is bundled with POS/DG. This application – called POSPac – runs on a PC under Windows 95/98/NT. It provides the following capabilities:

- data extraction tools (to extract data from the flight disk)
- graphical user interface
- processing and display tools
- optimal aided inertial navigator processing, both forward & backward time
- differential code-phase and carrier-phase GPS processing (GRAFNAV from Waypoint)
- coordinate conversion from WGS 84 to local mapping frame
- plot file generation and graphical display

One hour of recorded data will typically take a little less than one hour to post-process with POSPac on a 266Mhz Pentium-II laptop with 64 MB RAM. A more detailed description of the POSPac software can be found in [1].

3. APPLICATIONS

The use of POS in the airborne environment is similar with all sensors. The IMU is hard-mounted to the sensor and a boresight misalignment calibration procedure is performed to measure the angle offsets between the IMU and the sensor. Although the POS and sensor data are acquired and recorded independently of each other, the two data streams are precisely time-aligned and tagged before storing. These initial steps although routine they must be carefully carried out in order to achieve the best performance possible with the system.

Three-Line scanners and Laser scanners: These are relatively new sensors, at least as far as their use as precision mapping tools is concerned. The availability of POS/DG has resulted in relatively rapid growth in the use of these sensors for aerial mapping. Although lasers and line scanners differ in their principle of operation, the geometric aspect of the collected data is quite similar. Both require continuous line-to-line correction of the sensor's orientation in order to correct for the aircraft's motion and deliver geometrically correct data. The ability of POS/DG to measure relative orientation with accuracies close to 1 arcsec allows scanners to deliver data with quality approaching that of aerial cameras. In addition, the availability of range (directly in the case of laser scanners and indirectly through fore and aft views in the case of three line scanners) permits the rapid derivation of digital terrain models (DTM) with only minimal ground control. In the case of laser scanners ground control is actually difficult to establish and typically surveys are conducted with only the use of the base GPS station as ground control. In this manner, decimeter-level DTMs are readily achievable from altitudes of a few kilometers. City-core DTMs for cellular communications companies (Figure 2), flood-plain mapping and power-line mapping are some of the applications that scanners have found increasing use over the last two or three years. In addition to fast and precise mapping, line scanners can provide multi-spectral information that can further enhance the usefulness of the collected data.

SAR: In order for radar to achieve resolutions comparable to those of light-based sensors long integration times are required over the span of the aperture. Over the period of the aperture (up to a few minutes) highly accurate motion measurements of the antenna's focal point are required. POS/DG provides the motion compensation parameters (cm-level relative position and arcsec orientation) required in order to achieve DTMs with accuracies comparable to those of, say, laser scanners. SAR advantages come from its ability to operate day or night, under most weather conditions and to rapidly cover large areas. SAR does, however, require the operation of relatively complex equipment and the processing of large amounts of data. In addition, the resulting product is somewhat more difficult to interpret than that of a visible light sensor. SAR primary use is in deriving DTMs of large areas. With the use of longer wavelengths it is possible with SAR to achieve a good degree of foliage penetration. By comparing tree crown DTM with the actual ground DTM it is possible to deduce wood volume parameters.

Aerial Cameras: A number of tests conducted by POS/DG users have consistently demonstrated the ability of POS/DG to deliver high-accuracy orthophotos and maps with minimal use of ground controls, and without the use of tie points or aerial triangulation. POS' capability can be demonstrated by viewing photo stereo pairs without any parallax just by entering the POS-derived orientation angles. The cost and time savings of this new approach can be substantial. The cost of performing aerotriangulation, including establishing ground control, is estimated as $30 to $50 per stereo model. Typically, a medium to large size airborne survey company will process from 5 000 to 10 000 stereo-models per year or more for a total cost of $150 000 to $500 000. Maps derived with POS were demonstrated to meet the National Standard for Spatial Accuracy (NSSDA) in the State of Tennessee in the USA [2]. In test conducted by ifp in Stuttgart over a well-surveyed range ω, ϕ, κ accuracies of a few mdeg were demonstrated [3]. For altitudes below about 1 km or so the dominant error source in direct georeferencing with POS becomes GPS positioning. In such cases, POS/DG data can be used in conjunction with an Automatic Aerotriangulation package to achieve the desired accuracies as well as truly automatic AT capability. Some commercially available packages already offer attitude data input capability.

4. CONCLUSIONS

The POS/DG integrated inertial/GPS system is finding increasing uses among airborne sensors. Airborne laser scanners, line scanners and more recently SAR sensors are producing high accuracy DTM and map products with significantly reduced turn-around times and operational costs. Such results were previously achievable only with aerial cameras and after extensive post-processing effort. Decimeter accuracies are routinely achievable from altitudes of a few kilometers with minimal ground control. The use of POS/DG with the traditional aerial camera also resulting is significantly reduced operational cost and turn-around times. Maps and orthophotos derived in this manner are well within photo-mapping standards defined for the majority of applications.

5. REFERENCES

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