Introduction to GPS/IMU Integration
by Huangqi Sun

GPS/IMU integrated systems have been widely used in many high accuracy surveying and mapping applications in airborne, land and marine environments. A GPS/IMU system generally consists of a GPS receiver, an Inertial Measurement Unit (IMU) and associated electronics and software for system control, computation and user interface. Figure 1 shows the Leica IPAS10 system with a LN-200 IMU manufactured by Northrop Grumman Corporation.

An IMU usually consists of a triad of accelerometers, a triad of gyros, the analog electronics, A/D converter and digital electronics for calibration, temperature compensation as well as data interface. Three accelerometers measure 3D accelerations in the IMU body axes, while three gyros measure 3D rotations of IMU body axes relative to the inertial frame. IMU measurements can be made at a very high data rate, from 100Hz to 1000Hz. In surveying and mapping applications, these measurements are usually output at 100Hz to 500Hz. The LN-200 shown above is a fiber-optic gyro-based IMU. It has several military usages such as missile and munition guidance; it is also used in many civilian applications.

GPS/IMU systems have been used with airborne film cameras and the latest airborne digital cameras to provide direct georeferencing or to assist in the aerotriangulation process. A GPS/IMU system is also required in an airborne lidar system to provide the georeference information for the laser scanner so that the ground three-dimensional position for each laser pulse can be calculated from the scan angle and range measured by the scanner. As new IMU technology, such as MEMS (MicroElectroMechanical System), is gradually being adapted, the price of a GPS/IMU system will...
be reduced and it will be used in more applications where it may not have been possible before.

The basic principle of IMU navigation is the application of Newton's law of motion. Gyro measurements are used to calculate the attitude of the IMU body axes relative to local geographic frame (local north, east and up axes). This attitude is then used to transform the acceleration in the IMU body axes to the local frame. The velocity change can be calculated by performing one integration on the acceleration, while position change can be calculated by performing another integration on the velocity change. Therefore the position, velocity and attitude can be computed along the time series from a known initial position and velocity.

A GPS/IMU integrated system can combine the advantages of individual GPS or IMU systems while at the same time overcoming the shortcomings of the individual systems. An IMU has the advantage of providing a very accurate short term solution at a very high data rate and it is a completely self-contained system. However, an IMU navigation solution can drift over the long term because of the sensor errors. While GPS technology can provide uniform high accuracy position and velocity usually at a rate up to 20Hz, it has several shortcomings including the dependency on the line-of-sight from receiver antenna to GPS satellites, which makes it susceptible to signal obstruction, especially in an urban environment. GPS does not provide accurate attitude information either, and usually the data rate is not high enough for the airborne applications. The integration of two technologies provides a homogenous highly accurate position, velocity and attitude solution at a high data rate. The GPS raw measurements or computed position and velocity are used to calibrate the IMU sensor error using a Kalman filter. The IMU short term solution can be used to bridge GPS outages, especially in an urban environment, under heavy canopy, underground, and underwater.

A Kalman filter is usually utilized to blend the GPS and IMU data together to produce an optimal solution from a GPS/IMU integrated system. It consists of two main steps: Kalman prediction and Kalman update. Kalman prediction predicts the system state and its covariance for the next epoch based on the information from the current epoch using a system dynamic error model, while Kalman update corrects the errors in the predicted state vector and its covariance based on the observation model using the measurements, as illustrated in Figure 2. In a GPS/IMU system, the state vector usually consists of the following elements: position error, velocity error, attitude error, accelerometer and gyro biases, scale factor error and non-orthogonality.

In the tightly coupled mode, GPS raw measurements are fed into the integration filter directly. This mode allows GPS measurements to be used when there are fewer than four satellites observed. While in the loosely coupled mode, these measurements will not be able to be fed into the integration filter.

A deeply coupled integration mode will feed the IMU derived velocity into the tracking loop of a GPS receiver to allow it to track a weaker signal and allow it to reacquire the signal much faster. This is especially useful in the urban environment when a GPS satellite is lost and reacquired frequently.

A complete GPS/IMU system typically consists of various hardware and software components. The hardware includes a controller box, an IMU, a GPS antenna and corresponding cables, while the software includes real-time firmware, controller software and post-processing.
software. Figure 5 shows a typical function and data flow, such as that of the Leica IPAS10 system.

The IPAS10 is an example of a highly refined GPS/IMU integrated system. It consists of the IPAS10 control box, IPAS Controller software and IPAS Pro, the post-processing software.

The control box included in the IPAS10 system consists of a geodetic-grade GPS receiver board, a high-speed motherboard, other boards for digital and analog input/output, power supply boards, etc. Real-time firmware controls the data acquisition from GPS and IMU and other boards, as well as performs real-time navigation calculation and interface with an external device including Leica ADS40 Airborne Digital Sensor, Leica ALS50 Airborne Laser Scanner, Leica RC30 Aerial Camera, and other sensors. The raw sensor data, real-time solution and other information can be logged either internally through a PC card or externally through Ethernet, hotlink or serial interfaces for post processing.

IPAS Controller is a Windows-based software package. It runs on a PC, which connects to an IPAS system through an Ethernet connection. It is used to configure various input/output ports, lever arm, boresight angles, etc. It can also be used to monitor the operational status for the IPAS system. Data logging can also be controlled through the software.

The post processing software included in the IPAS10 system is called IPAS Pro. It combines the GPS and IMU data through a rigorous Kalman filter to produce optimal position, velocity, and attitude with their corresponding statistics information. IPAS Pro also provides a simple Windows-based user interface and further automates the GPS/IMU data processing.

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