Applanix IN-Fusion™ Technology Explained

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Introduction

Mobile mapping and positioning can be defined as the creation of geospatial information from a moving platform (such as an automobile, airplane, ship or even a human). This information can be as simple as the position of the platform on the earth, or if there is an additional sensor on the platform such as a camera or laser, as complex as a 3D model of the surrounding environment.

A major trend in mapping and Geographic Information Systems (GIS) is an increased demand for the timeliness and accuracy of geospatial data, but at a lower cost. Mobile mapping and positioning systems can meet this demand by providing geospatial information at a much greater efficiency over traditional collection approaches, all without sacrificing accuracy.

The key components of a mobile mapping and positioning system are GNSS and inertial sensors (accelerometers and gyros), the data from which are integrated or "fused" together to produce a highly accurate, high-rate measurement of the platform position and orientation as it moves. These measurements are then used to directly georeference any sensors such as cameras or lasers that are mounted on the moving platform and hence create a map of the surrounding environment. In addition to providing the position and orientation used for mapping, an integrated GNSS/inertial solution has a major advantage over stand-alone GNSS positioning: if the GNSS signal is blocked, the position and orientation measurements are still computed from the inertial data alone. This capability is extended even further in land vehicle applications where additional positioning sensors such as odometers are also integrated into the solution.

The Applanix IN-Fusion technology is the powerful and unique integrated GNSS/inertial navigation technology developed by Applanix and used in its products and solutions for mobile mapping. The Applanix IN-Fusion technology provides the highest level of navigation sensor integration producing position and orientation measurements with an unequaled level of accuracy and robustness. It enables mobile mapping and positioning to be done efficiently in all types of environments where accurate differential GNSS position 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 mobile mapping and positioning.

Technology in Use Today

In order to understand the power of Applanix IN-Fusion technology, it is necessary to first understand how inertial navigation systems work.

Standard Aided Inertial Navigation

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 on the Earth. 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. Furthermore, such an INS is often too large and too expensive to be used for many mobile mapping applications.

An Aided INS is an INS that uses other sources of position and velocity information to continuously correct or "aid" the INS errors. Such an approach means that the INS errors no-longer grow unbounded, which means a less accurate and hence smaller and less expensive IMU can be used, while still obtaining sufficient position and orientation accuracy for mobile mapping applications.

Figure 1 shows the architecture of a generic aided INS. The key component in the correction process is the Kalman filter. It runs a recursive least-squares estimation algorithm that estimates the position, velocity and orientation errors in the INS using measurements from one or more aiding sensors, typically once per second. Any aiding sensor that provides some information against which one or more of the INS errors can be calibrated is useful.

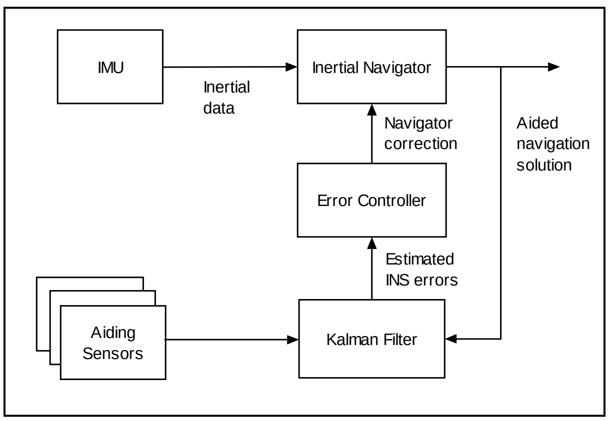

Figure 1: Generic "Loosely Coupled" Aided INS architecture

A GNSS receiver is the most widely used and generally most accurate aiding sensor. A GNSS receiver computes its own independent position and velocity navigation solution using a navigation filter that processes the so-called "observables" (pseudoranges and carrier phase measurements) from each tracked satellite. The position and velocity from the GNSS solution are then used as measurements in the aided-INS Kalman filter. Such a method is often referred to as a "loosely coupled" architecture.

Limitations:

Lack of Robustness During Loss of GNSS Signal

For highly accurate mobile mapping applications, the GNSS solution is processed using carrier phase differential techniques, either in real-time (referred to as real-time kinematic or RTK), or in post-processed (referred to as Kinematic Ambiguity Resolution or KAR). The resultant position corrections are typically at the 1 to 10 cm level accuracy, depending upon the application. This means the resultant GNSS-aided INS solution will also be at this level of position accuracy. If the GNSS solution is degraded or disrupted due to blockage of the satellite signals, the GNSS-Aided INS solution will still be generated, but the position accuracy will degrade over time until the GNSS solution re-converges.

Both RTK and KAR require the roving receiver to resolve carrier phase ambiguities in order to achieve position errors on the order of 1-10 centimeters. The ambiguity resolution process typically lasts 30 to 120 seconds, depending on the number of visible satellites and the geometric distribution of these satellites. This is acceptable provided the subsequent carrier phase measurements are continuous. GNSS signal blockages and corruptions cause phase discontinuities that require the receiver to repeat the ambiguity resolution process. Frequent signal outages due to buildings and foliage as might be experienced on a moving vehicle can be quite disruptive to RTK and KAR positioning.

The robustness of the position of a standard loosely couple GNSS-Aided INS is hence limited to the robustness of the GNSS solution. This means special restrictions must be imposed upon the operational environment when the highest level of positional accuracy is to be obtained. These include minimizing the time of signal blockage for high-accuracy land based applications, and flying shallow banked turns (i.e., 25 degrees) to avoid blocking the signals in airborne applications. Such restrictions can limit the productivity of mobile mapping.

Reduced Heading Accuracy

Another limitation of a standard GNSS-aided INS is that the heading accuracy is limited by the quality of the gyros in the IMU and by latitude. The reason is that an aided INS uses the projection of the earth rate vector into the local horizontal plane to define the North direction and uses the horizontal gyros to measure the projected earth rate vector. The horizontal projection of earth rate diminishes in magnitude with increasing North or South latitude. At the North and South poles the earth rate vector is entirely vertical, and the gyro errors interfere with this measurement. One solution is to use extremely accurate gyros, which drives up the cost of the IMU and hence the aided INS.

The Applanix IN-Fusion Technology

The Applanix IN-Fusion technology takes a completely different approach to aided inertial navigation. It employs a much deeper level of sensor integration and error modeling, significantly reducing or eliminating the limitations associated with the standard aided INS approach. The net result is a more accurate and robust solution for the highest level of productivity in mobile mapping and positioning.

Figure 2 shows the details of the Applanix IN-Fusion architecture, which is used in most of the Applanix real-time Position and Orientation Systems (POS) products, and now in all of the POSPac post-processing software products.

A key differentiator over the standard aided INS architecture presented in Figure 1 is the single centralized integration Kalman filter that processes the raw pseudorange and carrier phase observables directly from the GPS receiver, thus by-passing the receiver's navigation filter.

This has a tremendous advantage. For example, if for some reason only 3 satellites are visible to the GPS receiver (or 4 in differential mode), then the receiver cannot compute a navigation solution and the aided-INS Kalman filter receivers nothing from the GPS receiver. This is despite the fact that the receiver continues to output pseudoranges and carrier phases for these 3 satellites. The Applanix IN-Fusion technology does not have this limitation. It has continual access to all GPS aiding information even if the GPS receiver is tracking only one satellite and outputs only one set of observables. This is clearly the better method of integration.

In addition to this centralized Kalman filter, there are number of other technologies that make the Applanix IN-Fusion technology the optimal solution for mobile mapping and positioning. These are presented in the next sections.

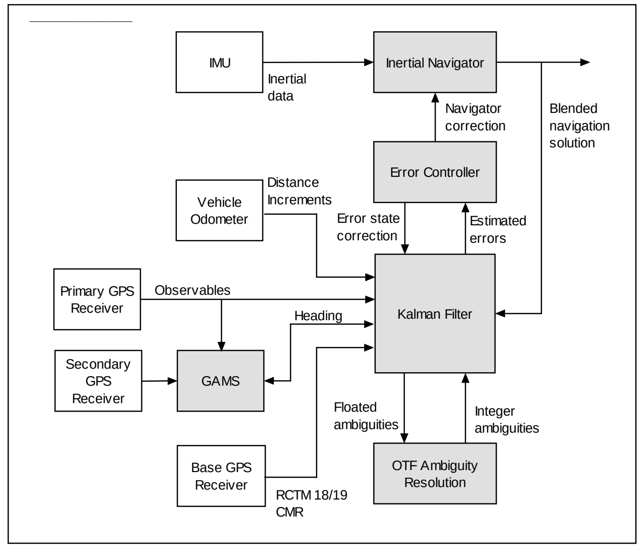

Figure 2: Applanix Error! Reference source not found. **architecture**

Inertially-Aided RTK and Inertially-Aided KAR

A major feature of the Applanix IN-Fusion technology is that it employs an ambiguity estimation and resolution technique that tied to the centralized Kalman filter, as shown in Figure 2. Here the inertial data are used to help resolve the initial ambiguities and maintain "memory" of the ambiguities during periods of GPS signal disruption. In real-time this is referred to as Inertially-aided RTK or IARTK, while in post-processing it is called Inertially-Aided KAR or IAKAR.

IARTK relies on the centimeter-level position accuracy that is preserved following a GPS outage to restart carrier phase ambiguity estimation and resolution at a much higher level of accuracy than a GPS receiver is capable of using standard RTK. IARTK is capable of re-establishing full RTK accuracy at the 1-2 centimeter-level within a few seconds of the end of a GPS outage. During the outage, the inertial position accuracy is preserved with a drift rate on the order of a centimeter per second. The result is a position solution that is continuously accurate in spite of frequent interruptions of phase continuity that would defeat a stand-alone GPS receiver.

IAKAR functions similarly to IARTK, with the exception that the data are run both forward and reverse in time, allowing for even greater robustness in re-establishing the correct ambiguities after phase disruptions.

In summary, IARTK and IAKAR have the ability to extend the duration over which good positional accuracy can obtained during signal blockage, and to immediately resolve the correct ambiguities after signal blockage, both of which are not possible with standard GPS RTK and KAR.

GPS Azimuth Measurement Subsystem (GAMS™)

In order to eliminate the problem of reduced heading accuracy at high latitudes, Applanix IN-Fusion technology incorporates a GPS Azimuth Measurement Subsystem, or GAMS. GAMS is a GPS compass comprising the primary GPS receiver plus a secondary GPS receiver in a two-antenna configuration that measures heading. It is tightly integrated into the Applanix IN-Fusion architecture so that its basic heading accuracy due phase noise is significantly attenuated due to blending with INS heading in the Kalman filter. Also, the INS heading is used to restart GAMS in a few seconds following a GPS outage due to signal blockage. GAMS provides Applanix products with the ability to compute accurate heading that is independent of latitude and vehicle dynamics. It also allows Applanix products to extract excellent heading accuracy from smaller and less expensive IMU's. Excellent heading accuracy translates to lower position drift if GPS aiding should drop out due to signal blockage. Figure 3 shows the trajectory of an Applanix POS LV through an urban canyon in which signal blockage and severe multipath reflections from buildings have severely distorted GPS positions fixes. The accurate heading due to GAMS integration ensures a continuous trajectory with no visible drift during those trajectory segments where GPS data are not available.

Distance Measurement Indicator Subsystem (DMI)

The Applanix IN-fusion technology includes the integration of a vehicle distance measurement indicator (DMI), also called an odometer, that measures incremental distance traveled from the rotations of the instrumented wheel. This is an alternative source of aiding information when the primary GPS data drops out. It provides velocity error attenuation that in turn controls the INS position error drift due to measured acceleration errors. The trajectory computed by the POS LV shown in Figure 3 benefited from DMI aiding when GPS outages occurred.

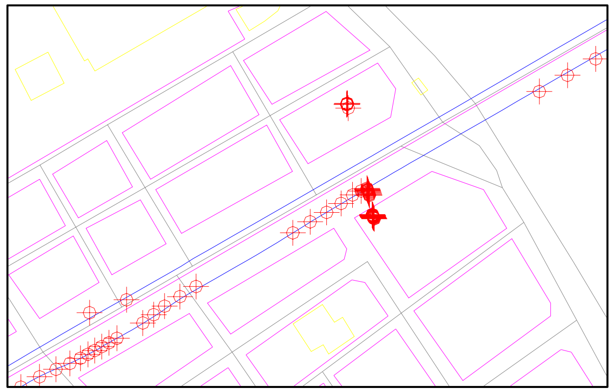

Figure 3: Continuous trajectory in an urban canyon using Applanix IN-Fusion technology (blue line)

Conclusion

The Applanix IN-Fusion technology was designed for mobile mapping and positioning applications where accuracy and robustness to environmental anomalies is paramount. It achieves this robust position and orientation by making the INS the source of position and orientation data, and by using the optimal integration of auxiliary aiding sensors. During a GPS outage, (usually caused by signal obstruction), the INS continues to deliver an accurate solution with low drift, while DMI-aiding provides additional suppression of position error drift during the outage (where applicable). As a result, the Applanix IN-Fusion technology eliminates or significantly reduces all the limitations associated with standard GNSS and GNSS-Aided Inertial technology. It enables high-accuracy mobile mapping and positioning to be performed in the most demanding of environments, including dense urban areas, under bridges, through tunnels, and during high banked turns of a survey aircraft. This translates to a dramatic increase in productivity over any other solution.

Over the last 16 years Applanix has built a legacy for performance in difficult mobile mapping and positioning applications. Emerging satellite positioning capabilities from GPS modernization, GLONASS, and Galileo, plus new positioning technologies using laser and video data are readily admitted to the Applanix IN-Fusion technology, ensuring a continual path of improvement.