Submitted to: *January 28-30, 2004*
7th Annual International Conference
Map India 2004
New Delhi, India AD92

Using Inertially-Aided Real-Time Kinematic Technology as a land-based mapping tool

by
Manfred D. M. Sever and Frank A. Artés

Applanix Corporation, a wholly owned subsidiary of Trimble
85 Leek Crescent
Richmond Hill
Ontario, Canada
L4B 3B3

Abstract

Airborne mapping techniques do not lend themselves well to mapping roads in dense urban canyons and tree canopy areas. Detailed and accurate road mapping information, especially that required for GIS databases, can often only be obtained by land-based methods. However, GPS satellite shading and multipath reception can also complicate accurate and reliable land-based GPS positioning in these types of areas.

The Applanix POS LV is an aided inertial navigation system designed for precise position and orientation measurements for survey and vehicle control applications. Utilizing IARTK (Inertially Aided Real-Time Kinematic) technology, POS LV provides continuous, robust, and reliable position and orientation data in difficult GPS environments. The fully integrated Applanix POS LV system was test driven in a mobile mapping campaign in Toronto, Canada, and the results generated were compared to those obtained using a stand-alone DGPS system.

The POS LV's IARTK configuration provided a significant improvement in overall position accuracy despite frequent GPS signal loss. In addition, the results indicated that a stand-alone GPS system cannot provide useful position data in environments that compromise GPS signal reception.

Conclusions suggest that land-based positioning systems utilizing inertial technology, such as the Applanix POS LV with GPS and DMI (distance measurement indicator) aiding, are capable of delivering position and orientation data necessary for the rapid and efficient production of maps and GIS database information.

Introduction – Mapping, a traditional methodology

Producing detailed mapping data has traditionally been an aerial survey practice using standard photogrammetric methodology. Generating accurate cartographic data from aerial photography is a well-established technology with its roots stretching back to the last century. Using conventional survey instrumentation, such as total station technology, to locate and identify map-based information has also been used with success, but can be very time consuming.

The continued drive for greater accuracy and increased productivity has always been present in the survey and mapping field, with advances in technology both hardware and software-based, making great strides in this regard. However, one fundamental remains unchanged. The ability to see the features one is trying to map often lies at the root of the accuracy issue. If the features are clearly visible on the aerial photography the chances of precisely positioning the data using today's analytical and softcopy photogrammetric technology is virtually 100% assured.

However, if feature identification is hampered by a dense vegetation canopy, or the relief displacement of tall buildings, dark shadow areas, or multi-level road and highway networks, then accurate data positioning is not possible using aerial photography alone. Land-based mapping technology is proving to be the solution to this problem.

Land-based mapping for transportation planning and GIS database feature acquisition

Transportation planners require current information on road location, surface condition, road centerline position, and details on the multitude of highway signage related to transportation routes. In addition, GIS professionals also require information on the placement of various utility infrastructure features, such as hydro poles, fire hydrants, manholes and drainage catchbasins etc., to help them plan, maintain and predict various scenarios based on asset location and condition.

The majority of these features are often associated with dense urban environments where one is likely to encounter urban canyons, tree-lined streets with overhanging foliage, underpasses and elevated roadways. Land-based GPS positioning has been used with marginal success as a mapping data acquisition tool to accurately position planimetric features in open, unobstructed areas. Commercial users of GPS systems generally find under ideal conditions a GPS system will offer excellent positional accuracy, however, this approach remains ineffective in a dense urban environment.

GPS satellite shading and dropout, the result of tall buildings blocking reception, and multipath issues generated by signals bouncing off reflective surfaces, cause stand-alone GPS systems to be completely inadequate in obtaining reliable positioning information in a downtown core area. Vehicle-mounted mobile GPS positioning is further complicated in urban or tree canopy areas as the structures that cause poor GPS reception also cause the satellites to go in and out of view, limiting a GPS receiver's ability to provide continuous, accurate positional information.

The POS LV system alternative

Following a GPS dropout or phase lock outage, a typical land-based dual frequency GPS receiver requires 30 to 120 seconds of reacquisition lock before providing RTK (real-time kinematic) level accuracy. During this time period, particularly if using a mobile land-based system, the accuracy of the data generated for position determination degrades very quickly, effectively making the system unusable.

An alternative land-based system designed to accurately position all difficult-to-locate cartographic features, such as those associated with mapping for transportation planning, or planimetric data-gathering for GIS databases, is now available. The Applanix POS LV system is an aided inertial navigation system designed specifically for precise position and orientation measurements for survey and vehicle control applications.

The system utilizes IARTK (Inertially-Aided Real-Time Kinematic) technology, providing continuous position and attitude data under the most demanding and difficult GPS conditions. A mobile mapping vehicle equipped with the POS LV system allows the operator to generate reliable and precisely positioned map data in areas where known GPS outages are routinely encountered, such as those found in a city's urban canyons.

Mapping roads and road corridors in a modern city where highrise buildings are commonplace, or generating map data for multilevel highways, or centerline road mapping under bridges and in tunnels, present the POS LV system with little problem. Likewise, heavily forested areas and mountainous terrain, locations which are particularly susceptible to GPS outages, can be successfully mapped with a degree of accuracy previously unavailable.

The technology - POS LV with IARTK

The **P**osition and **O**rientation **S**ystem for **L**and **V**ehicles (POS LV) is designed to provide a full navigation (position and orientation) solution for land vehicles engaged in road surveying and mapping, road profiling, transportation mapping and GIS database feature acquisition. These applications require continuous position and orientation information while operating in areas where problematic GPS reception would be encountered.

The system comprises four primary components, an inertial measurement unit (IMU), a two-receiver GPS azimuth measurement sub-system (GAMS), a distance measurement indicator (DMI), and a POS computer system (PCS). The vehicle-mounted POS LV system integrates inertial data from an IMU, containing accelerometers and gyros for each axis. The IMU is designed to measure the position and orientation differences and provide a true representation of motion in all axes. Velocity aiding and linear distance traveled data is derived from the DMI attached to one of the vehicle's rear wheels. The embedded GPS receivers in the PCS computer provide additional position and velocity information with further heading assistance coming from the GAMS subsystem. The RTK corrections data are received from external sources.

In its tightly coupled navigation mode (IARTK), the POS LV system does not use the position and velocity data provided by the GPS receiver, rather POS LV automatically integrates raw GPS satellite data directly into the system. This allows the POS LV to utilize position-aiding data from just one GPS satellite observable (CA code), when all others are experiencing lockout. This robust positioning solution in its simplest form is a combination of GPS data and dead reckoning navigation.

In conjunction with the combined integration of GAMS heading aiding, and DMI integrated velocity aiding, the position-error growth during a GPS outage is thus severely restricted. In this configuration, the POS LV system is able to deliver decimeter-level positioning accuracy, which gracefully degrades over time with distance traveled, together with attitude accuracies of better than 0.05 degrees.

The test project – Toronto

Figure 1. King Street

A mobile mapping campaign to evaluate the POS LV system was carried out in Toronto, a major Canadian city with all the attributes associated with a modern metropolis, tall buildings, multi-level roadways and a busy downtown area with numerous road infrastructure features. Two areas were chosen that would present the mapping vehicle with real-world conditions regarding problematic GPS reception.

Figure 1 shows the first area King Street, a typical downtown core street with both sides lined with highrise office buildings, apartment blocks and multi-storey commercial buildings. The road edge and sidewalks accommodate various utilities such as manholes, catchbasins, fire hydrants, lamp standards and hydro poles.

Figure 2. Lakeshore Boulevard beneath the Gardiner Expressway.

The second area chosen was Lakeshore Boulevard, which runs beneath the Gardiner Expressway on the south side of the city. The expressway is an elevated multi-lane highway that parallels the Toronto waterfront. Beneath the expressway is Lakeshore Boulevard. The view from the mapping vehicle (fig 2) shows it is crossed with intersections and traffic lights, various utility poles and assorted road signage, all of which would remain hidden on an aerial photograph. For the transportation planner and GIS professional this type of planimetric detail would be required information, geographically positioned and geocoded for input into their particular systems.

To successfully map areas such as these using aerial photography alone, and attain a 100% positional accuracy rate for all features, particularly those obscured by the expressway, would be extremely difficult, if not impossible to achieve. As discussed earlier in this paper, urban canyons and the area beneath elevated highways are particularly difficult environments in which to attain continuous GPS reception.

If time constraints are an issue then adopting a conventional survey approach to generate the data would take too long. A mobile land-based mapping alternative impervious to GPS dropout, such as the POS LV, would need to be considered in order to generate a complete and accurate data set in the shortest possible time to supplement or replace the information obtained from aerial photography.

The photograph in figure 3 shows an aerial view of King Street, and graphically illustrates the advantages of using the POS LV in an urban canyon environment. Figure 1 shows the same area as seen from the mapping vehicle and clearly shows why GPS reception would be difficult to maintain in this area. Equipped with the POS LV system the vehicle was driven under normal data capture conditions and at traffic speed along King Street.

The planned mission utilized the fully integrated POS LV/IARTK configuration. The blue line on the photograph was generated using the post-processed position and orientation solution, which places the vehicle in a best-estimated location. The yellow dots show the positional information derived using a single stand-alone Differential GPS solution from the same test mission.

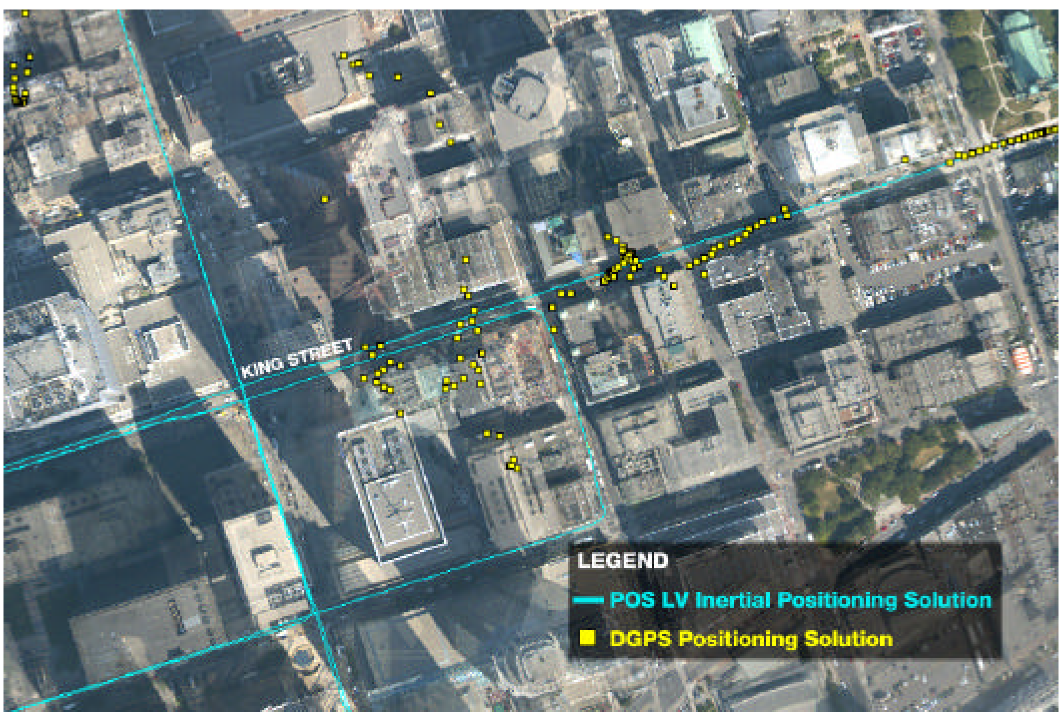

Figure 3. King Street

The 1 Hz stand-alone DGPS position solution, indicated by the yellow dots, can be seen to wander substantially off track, when compared to the blue line generated by the 200 Hz POS LV solution.

The effect of GPS satellite dropout and multipath, caused by the tall buildings, is readily apparent in the results obtained with the stand-alone DGPS solution. The solution generated using the POS LV system (blue line) shows a significant improvement in position (in addition to precise orientation data) accuracy despite the identical GPS lockout and multipath effects.

Figure 4 shows an aerial view of the Gardiner Expressway, with the POS LV blue line data correctly positioned on Lakeshore Boulevard under the expressway. GPS reception was intermittent and often non-existent along Lakeshore Boulevard, with the result that a corresponding DGPS solution was unavailable in places.

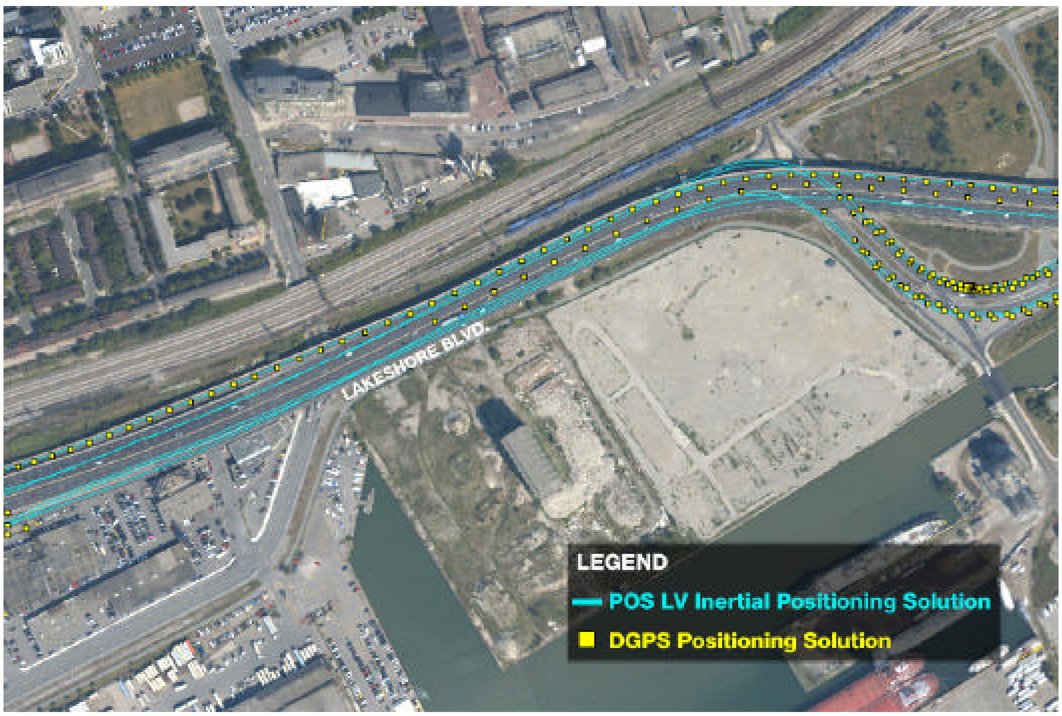

Figure 4. Lakeshore Boulevard

The mapping vehicle was driven along the road beneath the expressway with the POS LV/IARTK configuration in operation. The data was post-processed using the Applanix POSPac software. An accurate position and orientation solution was obtained by processing the aided inertial data in both forward and reverse directions, placing the vehicle in its true estimated position, despite a complete absence of GPS reception in most locations. The stand-alone DGPS solution generated substantial position errors, and a total lack of DGPS data can be seen at the south west edge of Lakeshore Boulevard. In contrast, the DGPS data on the north side of the expressway was generated by the mapping vehicle traveling on the Gardiner Expressway at the end of the demonstration and virtually mirrors the POS LV data, illustrating that full GPS reception was available. From the results obtained during the Toronto mobile mapping demonstration, it is apparent that a stand-alone DGPS system cannot provide reliable or in fact useful position data in environments that compromise GPS reception.

The following table compares the vertical error of both solutions, the post-processed POS LV and the DGPS, presented in meters. The values are relative to the Toronto published survey elevations, which were derived from a Digital Terrain Model with a 25cm allowable error. Vertical accuracies are generally 50% worse than the horizontal accuracies obtained. The horizontal accuracy is evident by the positioning of the colored marks on the aerial photography, the blue lines are POS LV, and yellow dots are DGPS (fig 3 and fig 4).

Intersection	POS LV Vertical Error (post-processed) (m)	DGPS Vertical Error (Coast Guard Beacon) (m)
King & John Streets	1.665	5.712
King Street & University Ave	1.680	20.850
King & York Streets	1.873	No GPS Position
King & Bay Streets	1.109	316.079
King & Young Streets	0.859	9.338
Lakeshore Blvd W & York Street	0.562	No GPS Position
Lakeshore Blvd W & Bay Street	0.274	No GPS Position
Lakeshore Blvd W & Young Street	0.379	No GPS Position
Lakeshore Blvd W & Cherry Street North	0.917	3.126
Lakeshore Blvd W & Carlaw Ave	0.133	1.645

Conclusions

Conclusions drawn from the test mapping demonstration indicate that positioning systems utilizing inertial technology, such as the Applanix POS LV with its IARTK configuration, are capable of delivering precise position and orientation data, in dense urban environments that deny effective GPS reception. As an enabling technology for mobile mapping vehicles tasked with capturing planimetric data for topographic maps and GIS databases, the POS LV system can confidently be engaged in data capture applications in environments where GPS reception is questionable and non-existent.

With a high-bandwidth of 200Hz and a low-latency of <3 msec, the POS LV system was able to successfully maintain decimeter-level positional accuracy horizontally, and meter-level accuracy vertically. With the IARTK configuration, raw satellite data rather than receiver-computed positional information enabled the POS LV system to reacquire RTK lock within seconds after GPS signal loss. This enabled positional accuracy to be maintained in areas of frequent GPS interruption and limited reception, utilizing data from as few as one visible satellite to aid the inertial solution. For organizations involved with terrestrial photogrammetry for road mapping, GIS data generation or vehicle tracking, POS LV provides the positioning heartbeat for data acquisition vehicles, as a fully integrated and self-contained solution ready to integrate with additional onboard sensors, cameras and laser scanners.

REFERENCES

[1] B. Scherzinger, *Precise Robust Positioning with Inertially Aided RTK*, Proceedings of CASI, Montreal, 2003

[2] N. Bingham, A. Parsons, *Evaluating the Use of Inertial GPS While Collecting PMS Data*, Research report by the Alaska Department of Transportation, 2002

[3] W. Caspary, G. Graefe, H. Heister, J. Klemm, M. Sever, *The Road Data Acquisition System MoSES – determination and accuracy of trajectory data gained with the Applanix POS LV*, Proceedings of 3rd International Symposium on Mobile Mapping Technology, Cairo, Egypt, January 3-5, 2001

[4] R. McCuaig, B. Scherzinger, M. Sever, M. Zywiel, *Navigation Through GPS Data Gaps*, Proceedings of IRF2001, Paris, France, June 12-15, 2001

[5] B. Scherzinger, *Robust Inertially-Aided RTK Position Measurement*, Proceedings of KIS2001, Banff Canada, June 5-8, 2001

[6] B. Scherzinger, *Precise Robust Positioning with Inertial /GPS RTK*, Proceedings of ION-GPS _2000, Salt Lake City, UH, September 20-23, 2000

[7] B. Scherzinger, *A Position and Orientation Post-processing Software Package for Inertial/GPS Integration (POSProc)*, Proceedings of KIS97, Banff, Canada, June 3-6, 1997

Acknowledgements
The authors would like to thank the following people for their assistance in the preparation of this paper:

Carson Allen	-	*Survey and Mapping Division, City of Toronto*
Kevin Tierney	-	*Survey and Mapping Division, City of Toronto*
Francesco Martinelli	-	*Engineering Department, Applanix*
Murray Tustin	-	*Engineering Department, Applanix*

Manfred D. M. Sever is a Principal Engineer at Applanix Corporation, where he is a Product Manager in the Land Vehicle Applications group, and leads the development of the POSLV and POSLR product lines. He obtained his license to practice Professional Engineering in Ontario Canada in 1998. He received his Ph.D. and M.A.Sc. in the control of structurally flexible manipulator system from the University of Toronto Institute for Aerospace Studies in 1998 and 1991, and his B.A.Sc. in engineering science (aerospace) from the University of Toronto in 1989.

Frank A. Artés is a Technical Writer at Applanix Corporation where he is responsible for technical marketing / communications documentation. He has an extensive background in the Geomatics field, with particular expertise in aerial and terrestrial photogrammetric applications. He received an Honours Diploma in Photogrammetry from Algonquin College, Ottawa and certification in Technical Communication from Humber College, Toronto.

Applanix Corporation
85 Leek Crescent
Richmond Hill, Ontario
Canada. L4B 3B3
Tel: 905-709-4600
Fax: 905-709-6027
Email: msever@applanix.com artesf@applanix.com