

Inertially Aided RTK Performance Evaluation

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BIOGRAPHY

Dr. Bruno M. Scherzinger obtained the B.Eng. degree from McGill University in 1977 and the M.A.Sc. and Ph.D. degrees in system control engineering from the University of Toronto respectively in 1979 and 1983. He is a founding partner and Chief Technology Officer at Applanix Corporation. He has recently been appointed an Adjunct Professor at the University of Calgary's Geomatics Engineering Department.

ABSTRACT

This paper describes the results of a series of performance tests of an inertially aided RTK (IARTK) positioning system using dual frequency GPS receivers. The system being evaluated is the Position and Orientation System for Land Vehicles (POS LV) developed by Applanix Corporation, whose design objectives are to achieve robust positioning with decimeter-level accuracy during various levels of satellite coverage ranging from total outage to complete coverage. The performance tests described here comprise a series of urban navigation tests in downtown Toronto and Tokyo. These test environments can be described as urban canyons, which severely limit GPS coverage during most of the tests.

This paper first gives an overview of the POS LV and the IARTK architecture that it implements. The paper then describes the performance tests and the results that the tests generated. The performance tests comprise a series of trajectories through Toronto and Tokyo that were performed as part of demonstrations to potential POS LV customers. This paper reports one of the Tokyo tests. Consequently there was no preplanning of the trajectories. The performance is assessed from a comparison of the computed trajectories with the cities' curb maps. The performance tests demonstrate that the POS LV with IARTK is able to navigate with sub-meter accuracy through urban canyons that deny GPS coverage for tens of minutes and allows one or two satellites for most of the remainder of the trajectory, and is able to recover integer RTK within seconds of full GPS coverage.

INTRODUCTION

This paper presents the performance that an inertially aided real-time kinematic (IARTK) system with dual frequency GPS aiding can achieve in an urban canyon environment. The basic algorithm, architecture and experimental performance of a Position and Orientation System for Land Vehicles (POS LV) with IARTK were first presented in [1] and [2]. [3] describes the performance of IARTK with a single frequency receiver during brief (10-30 second) GPS outages in order to highlight the key advantage of inertial aiding. The work reported here is a continuation this previous work, and is focused on realistic experience with GPS-aided INS and IARTK in urban canyon environments.

Robust positioning describes a positioning system's ability to maintain position data continuity and accuracy through most or all anticipated operational conditions. The operational condition of interest here is the loss of good GPS satellite visibility due to partial or total obstruction of the sky. The key performance attribute investigated here is the overall positioning accuracy that the POS LV with IARTK can achieve in an urban canyon environment.

This paper is organized as follows. The paper first gives a brief overview of the POS LV that was used to conduct the tests. This is a summary of the more elaborate descriptions given in [1]-[3]. The paper then describes one of several urban canyon tests conducted with the POS LV. The test reported here was conducted in downtown Tokyo, and was in fact one of several demonstrations of the POS LV to potential customers. The Tokyo test had no preplanned route. The trajectory includes substantial sections in an underground tunnel with no GPS coverage. The paper then ends with a summary of assessed performance in these tests.

SYSTEM DESCRIPTION

The POS LV shown in Figure 1 and described here is a tightly coupled inertial/GPS integrated system with IARTK shown in Figure 2. *Tightly coupled inertial/GPS*

integration implies the Kalman filter processes the GPS pseudorange, phase and Doppler observables. *Inertially-aided RTK* implies the Kalman filter that estimates the inertial navigator errors also estimates the floated phase ambiguities, and an on-the-fly (OTF) ambiguity resolution algorithm operates on these to fix the integer ambiguities. In this case, the GPS receiver is strictly a sensor of the GPS observables. Any GPS receiver that outputs the observables and satellite ephemerides can be used. The navigation functions in the GPS receiver, namely position and clock offset fixing and the receiver's RTK function, are not used.



Figure 1: POS LV 320

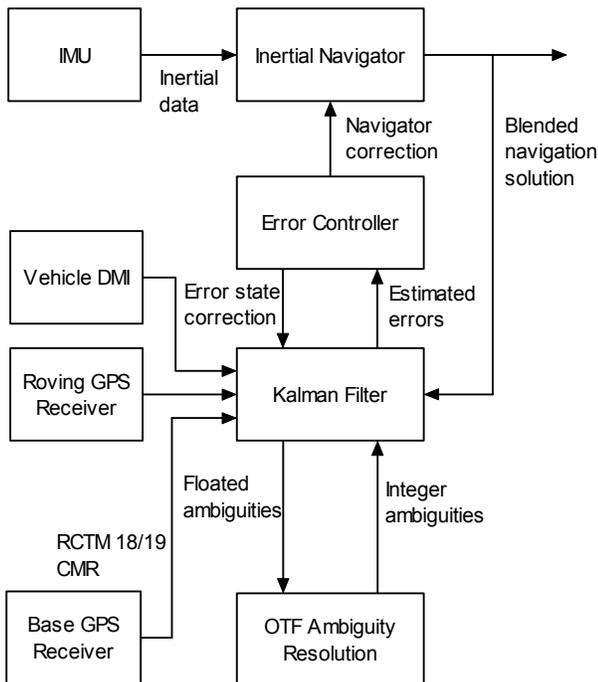


Figure 2: IARTK system architecture

Figure 2 shows the architecture of an IARTK system, comprising a standard closed-loop aided INS configuration with a few non-standard components. The sensor components comprise the inertial measurement unit (IMU), roving GPS receiver and base receiver, and a precise odometer here called a distance measurement indicator (DMI). The IMU provides measurements of incremental velocities and angles resolved in the IMU sensor coordinate frame. The roving receiver provides dual frequency observables and ephemerides for the visible satellites. The base receiver provides standard RTK messages in RTCM or CMR format that contain the base receiver observables and clock error. The DMI measures the rotations of an instrumented wheel and from this reports the distance of the wheel ground track.

The processing components comprise the inertial navigator, Kalman filter, error controller and OTF ambiguity resolution module. The inertial navigator computes the position, velocity and orientation of the IMU sensor frame from the IMU data. The Kalman filter estimates the errors in the inertial navigator, IMU, DMI and GPS receivers. These estimated errors include the floated ambiguities in the phase double differences. Additional components not shown can include a GPS azimuth measurement system (GAMS), which is part of the Applanix POS/LV. The GAMS provides direct heading observations, which provide for latitude-independent regulation of the inertial navigator heading error.

TEST AND RESULTS

The method of performance assessment used here is a combination of the following.

1. We evaluate the POS LV trajectory against the precise GPS positions where these are available. This must be handled carefully because the precise GPS solution may itself be incorrect because of massive multipath interference and poor geometry caused by buildings.
2. We evaluate the continuity of the POS LV solution against the city map where no other reference is available. Discontinuities occurring from areas of no GPS coverage to full GPS coverage indicate the position drift during the GPS outage.

This is clearly not as rigorous as was done in [1]-[3], where GPS outages were synthesized and hence a reference for position error was available. It is however the best that can be done in an uncontrolled yet realistic operational scenario.

Figure 3 shows an AutoCAD™ map of downtown Tokyo with the real-time POS LV and post-processed precise GPS solutions. The vehicle navigated the circuit twice in

order to generate an approximate repeatability test. Each circuit had a length of approximately 30 kilometers and required approximately 45 minutes to complete. The base receiver was located at the starting point in the upper right-hand corner of Figure 1. The maximum baseline was 6.5 kilometers. The base receiver generated CMR-Plus corrections records, which were transmitted to the POS LV via a GSM cell telephone modem, which the POS LV used to compute an IARTK solution. The trajectory passed through sections where no GPS positioning was possible. This included an underground tunnel and several multi-level overpasses, each generating 10-15 minute GPS outages. Figure 3 indicates a continuous and 100% available position solution from the POS LV against a post-processed GPS position solution that is available for approximately 50% of the complete trajectory.

Figure 4 shows another detailed section of the trajectory in which the post-processed GPS position solution contains erratic points that are clearly wrong, falling into areas occupied by buildings. The POS LV solution on the other hand is continuous and remains on the road.

Figure 5 is another detailed section of the test that shows a noticeable position reset in the POS LV solution on one of the two circuits following a 15-minute GPS outage. Each octagon in Figure 5 surrounding a GPS position fix has a center-to-vertex distance of 2.5 meters. The magnitude of the reset is approximately one meter, and indicates the position drift during the outage.

This test demonstrates the following performance attributes of the POS LV in this urban canyon environment:

1. The POS LV was able to maintain better than 25 centimeters position error throughout 90% of the trajectory.
2. The POS LV was able achieve RTK positioning within 5-10 seconds of adequate GPS coverage (4 or more satellites) and thereby maintain better than 10 centimeters during areas of full GPS coverage. The

dominant error source is multipath reflections off of the buildings. The POS LV is able to reject GPS positions that are clearly wrong and maintain decimeter position accuracy through bad multipath environments.

3. The position drift during complete or partial GPS outages was better than one meter. The worst position error occurred following one of several long GPS outages lasting upwards of 10 minutes.

CONCLUSIONS

This paper has examined the performance of the POS LV with inertially aided RTK in a real and rather difficult urban canyon environment that denied adequate GPS coverage 50% of the time. The POS LV was able to maintain decimeter position accuracy throughout most of the trajectory, and limit position drift to one meter during long GPS outages. The POS LV IARTK was able to rapidly re-acquire fixed integer RTK positioning whenever GPS coverage permitted it to do so. The POS LV has therefore met its design goal of providing *robust positioning at the decimeter level* in an urban canyon environment. A stand-alone GPS solution either real-time or post-processed was not able to do so.

REFERENCES

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- [3] B.Scherzinger, *Robust Positioning with Single Frequency Inertially Aided RTK*, Proceedings of ION-GPS-2001, Salt Lake City, UH, September 12-15, 2001.
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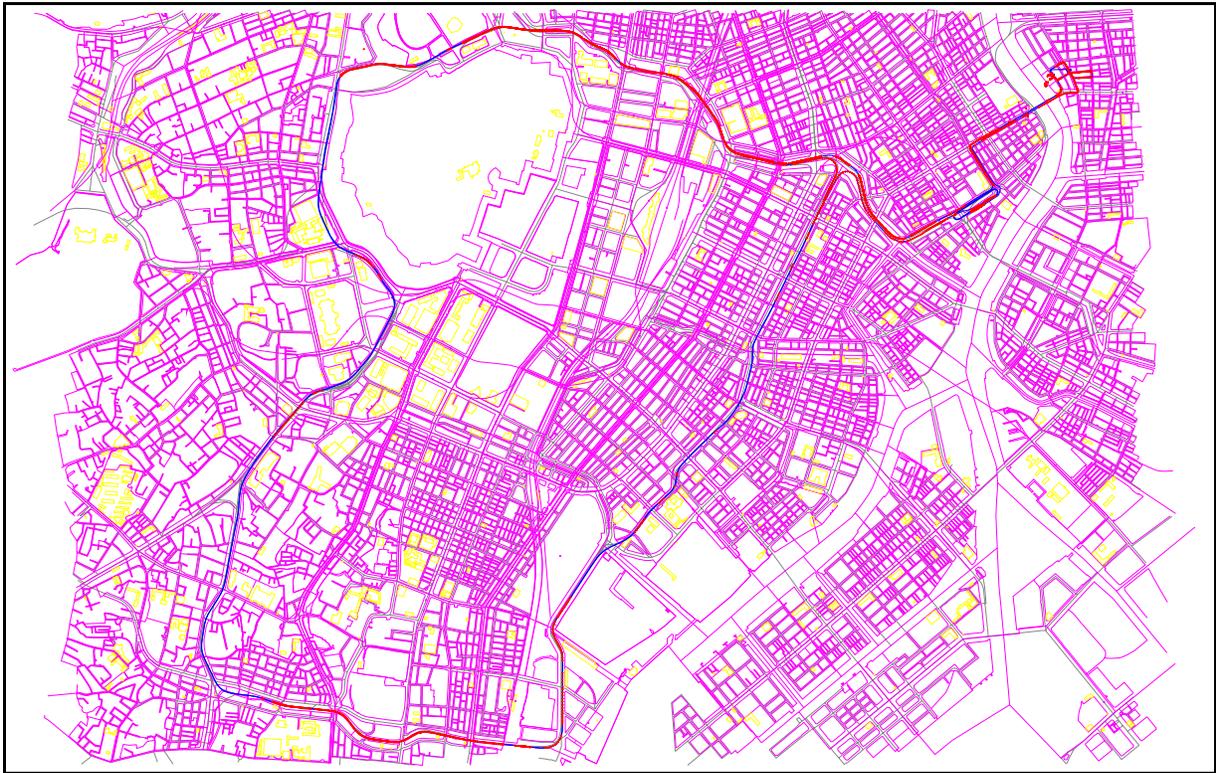


Figure 3: Downtown Tokyo map with POS LV (dark blue) and GPS (red) solutions

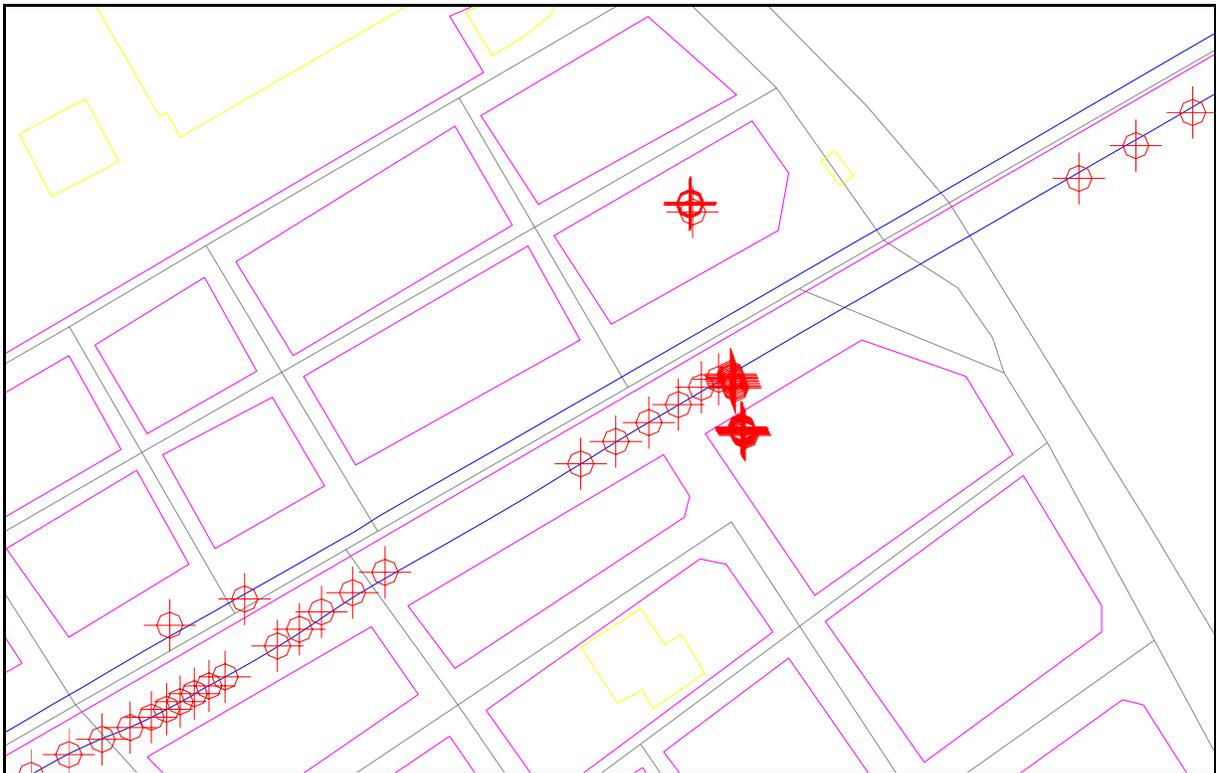


Figure 4: Downtown Tokyo test detail

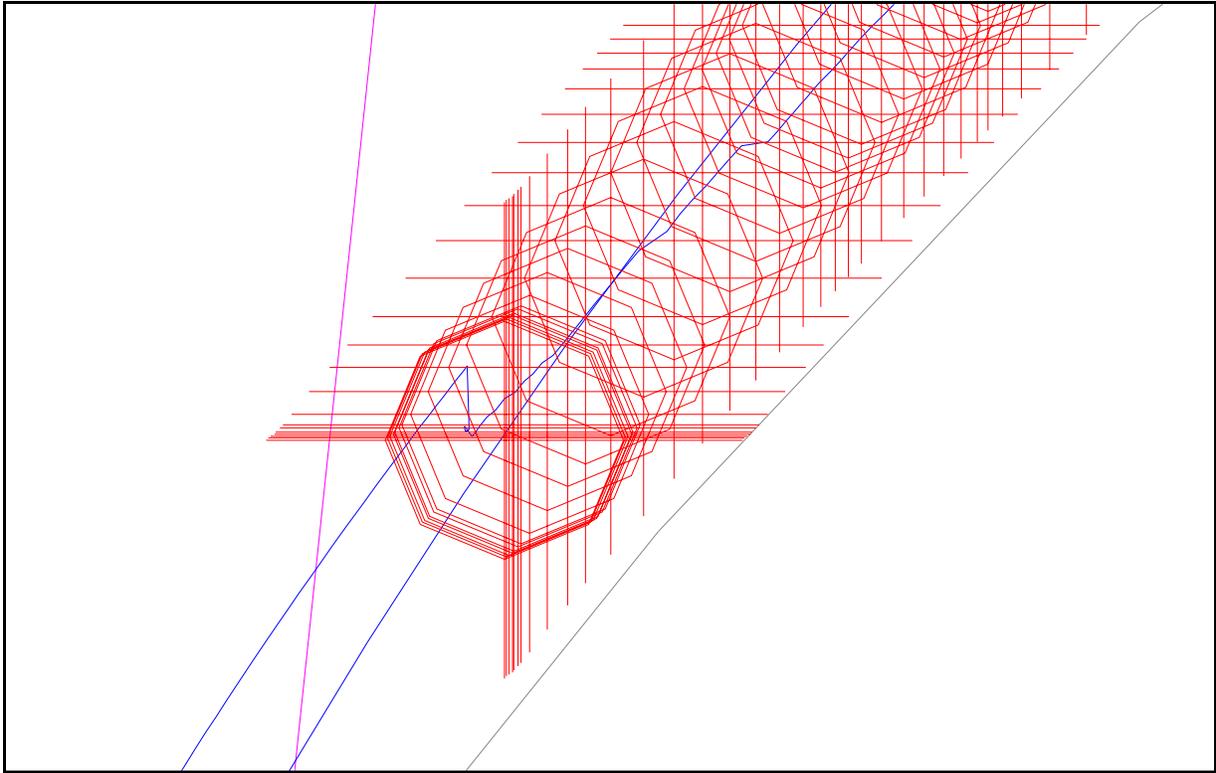


Figure 5: Downtown Tokyo test detail following an extensive GPS outage