GNSS/INS and DMI Processing of SPAN data with Inertial Explorer 7.61

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INTRODUCTION

Inertial Explorer (IE) 7.61 was released November 2006. This version of Waypoint's loosely coupled GNSS/INS post-processing software introduces support for Distance Measuring Instruments (DMI).

A DMI is a sensor that measures wheel revolutions on a vehicle. Inertial Explorer converts this measurement to either a displacement or velocity value. A DMI distance or velocity update slows inertial error growth significantly when used where GNSS position and velocity updates are unavailable,

After processing with DMI updates, the existing RTS (Rauch-Tung-Striebel) smoother is applied to produce further positioning improvements during periods of GNSS signal outage.

Novatel SPAN (Synchronized Position Attitude Navigation) Technology integrates the NovAtel PROPAK-V3 receiver with a choice of IMU's as follows:

- Honeywell HG1700 AG58 (RLG 1º/hour)
- Honeywell HG1700 AG62 (RLG 5º/hour)
- iMAR-FSAS (FOG 0.75º/hour)
- Northrop Grumman LN200 (FOG 1 º/hour)

This report shows the performance of each GNSS & IMU combination with and without DMI updates, on two vehicle surveys in downtown Calgary Alberta. See http://www.novatel.com/products/span.htm for more information on each of the above SPAN systems.

Both test runs were performed on September 23 2006. All SPAN systems, including a navigation grade IMU used for truth coordinates, were operated simultaneously using a common GNSS antenna. All solutions were output at the GNSS antenna in order to provide a common point for comparison between solutions. Any difference between the navigation grade IMU and the SPAN solutions are considered errors in the latter.

Downtown Calgary is a challenging GNSS environment with many large office buildings. The entire survey can be reconstructed for display or analysis purposes in Google Earth through Inertial Explorer's existing output functions. Alternatively, other programs such as Global Mapper can be used to plot the trajectory on a more accurate ortho-photograph. Figure 2 shows a processed trajectory from run 1 in Google Earth.

Figure 1: Downtown Calgary Alberta

PROCEDURE

Both surveys began with several minutes of static data collection at the NovAtel office in NE Calgary. This allowed a static coarse initialization to be processed in Inertial Explorer, which is necessary to accurately resolve initial roll, pitch and yaw values.

The test van was then driven down a major roadway with regular losses of GNSS signal lock (due to overpasses) towards the downtown area. Both surveys followed similar but not identical paths downtown before returning to the NovAtel office. At the end of the survey, several minutes of static data was again collected in order to process a static course alignment in the reverse processing direction. In the results to follow, only the downtown portion of the data is analyzed.

In any typical downtown environment it is good field procedure to perform regular Zero Velocity Updates (ZUPT). ZUPTS were observed at irregular intervals in the two surveys due to stops at red lights and due to traffic. When GNSS updates are not available, ZUPTS significantly limit inertial error growth.

ZUPTS are automatically detected in Inertial Explorer when DMI data is used. If DMI data is not available, a user can enter ZUPTS manually through Inertial Explorer's user interface. A planned feature for future versions of Inertial Explorer is automatic ZUPT detection using raw gyro and accelerometer measurements.

A navigation grade IMU (Honeywell CIMU) with much greater accuracy than the SPAN units was used to benchmark results for the two downtown tests. This navigation grade IMU was processed forwards and backwards in time with tight coupling of the GNSS measurements and DMI updates. The RTS smother was then applied in both processing directions. Note again that inertial Explorer is not currently tightly coupled, but a new tightly coupled engine (still in development) was used in the processing of this data. Any difference in this benchmarked solution and the SPAN results are considered error in the latter.

A benefit to tightly coupled processing of GNSS/INS data is that triple differences can be formed between epochs where as few as two satellites are observed. Phase updates are expected to be especially beneficial for post-processed SPAN results due to SPAN's tightly coupled real-time engine. This produces very fast signal reacquisition times in signal masking conditions, resulting in many more GNSS measurements than would typically be available. As a result, SPAN with IE has more GNSS raw data for post processing than that loosely coupled GNSS/INS systems.

The errors in each post-processed solution that used DMI updates are shown in figures 4 through 7 for run 1, and figures 9 through 12 for run 2. Tables 1 and 3 summarize the RMS of the errors for run 1 and 2 when a DMI is used. Similarly, tables 2 and 4 summarize the errors when no DMI sensor is used.

It is important to note that the results summarized in tables 2 and 4, which show results when no DMI sensor is used, do not include any manually entered ZUPTS. This therefore represents a pessimistic estimate of the accuracy currently possible under similar conditions with Inertial Explorer.

RESULTS

RUN 01

Figure 2: Google Earth Trajectory for Run 01

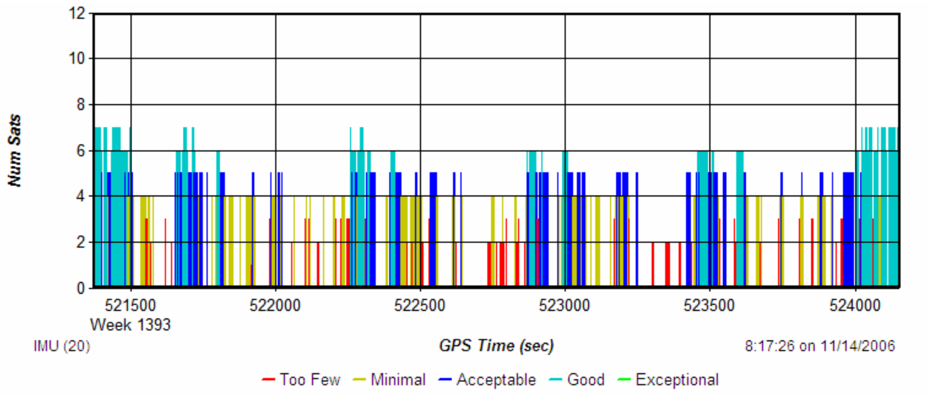

Figure 3: Number of Satellites tracked during Downtown Run 01

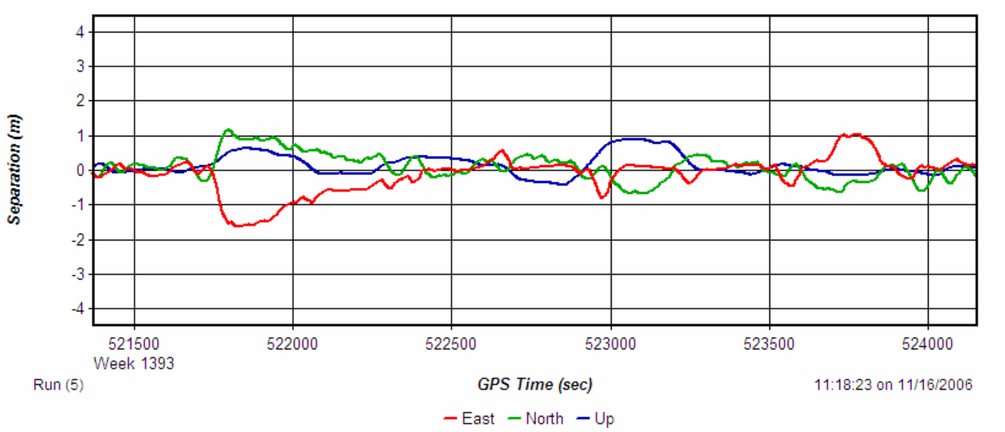

Figure 4: Error in FWD/REV Smoothed SPAN LN200 Solution using DMI updates on Run 01

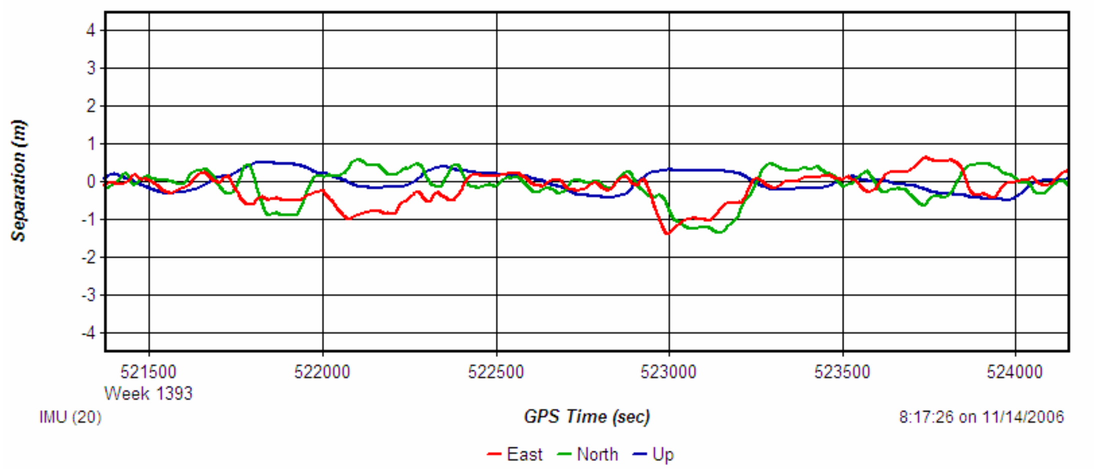

Figure 5: Error in FWD/REV Smoothed SPAN AG11 Solution using DMI for Downtown Run 01

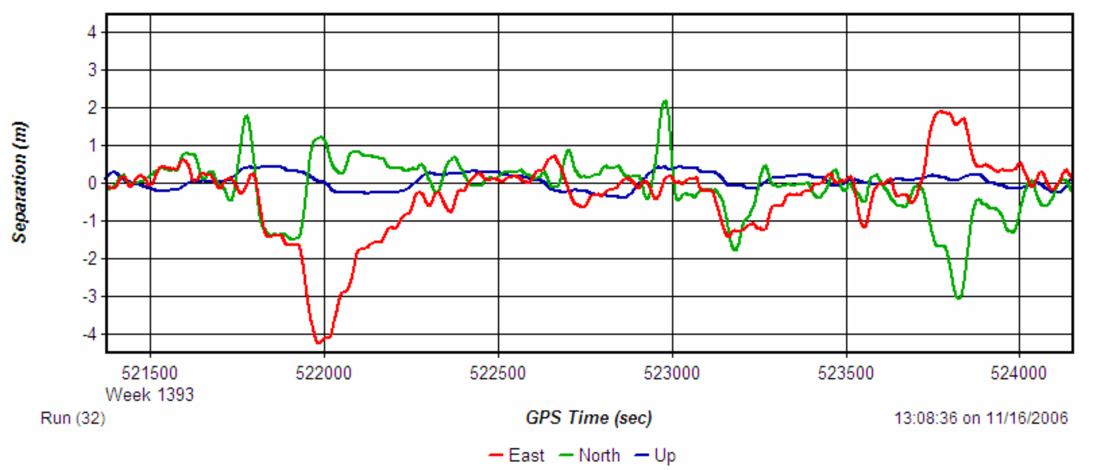

Figure 6: Error in FWD/REV Smoothed SPAN AG17 Solution using DMI for Downtown Run 01

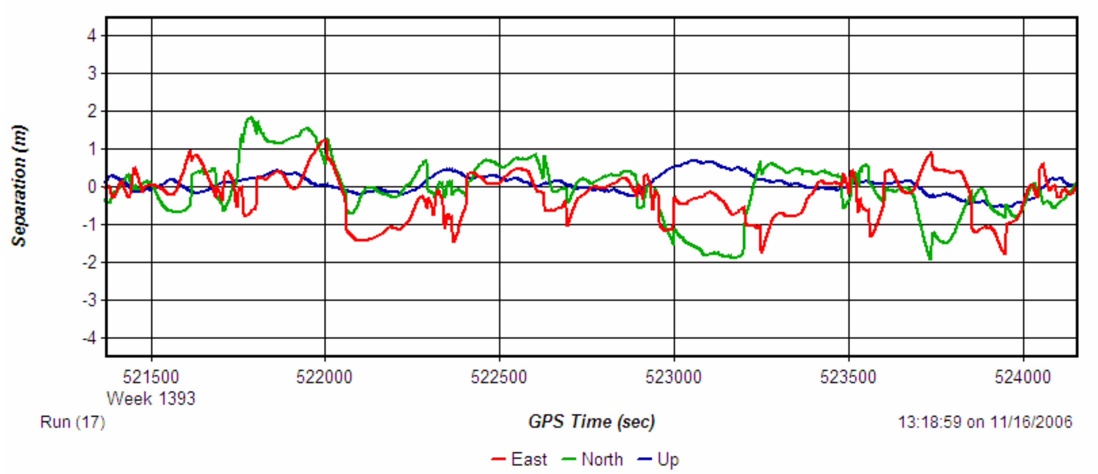

Figure 7: Error in FWD/REV Smoothed SPAN iMAR Solution using DMI for Downtown Run 01

Table 1: RMS Position Errors of Inertial Explorer Solution with DMI for Downtown Run 01

	SPAN LN200	SPAN AG11	SPAN AG17	SPAN iMAR
RMS Horizontal Error (m)	0.66	0.63	1.30	0.99
RMS Vertical Error (m)	0.33	0.26	0.22	0.26

Table 2: RMS Position Errors of Inertial Explorer Solution without DMI and without Manual Entry of Zero Velocity Updates for Downtown Run 01

	SPAN LN200	SPAN AG11	SPAN AG17	SPAN iMAR
RMS Horizontal Error (m)	3.72	5.04	9.29	5.07
RMS Vertical Error (m)	0.62	0.28	1.27	0.59

RUN 02

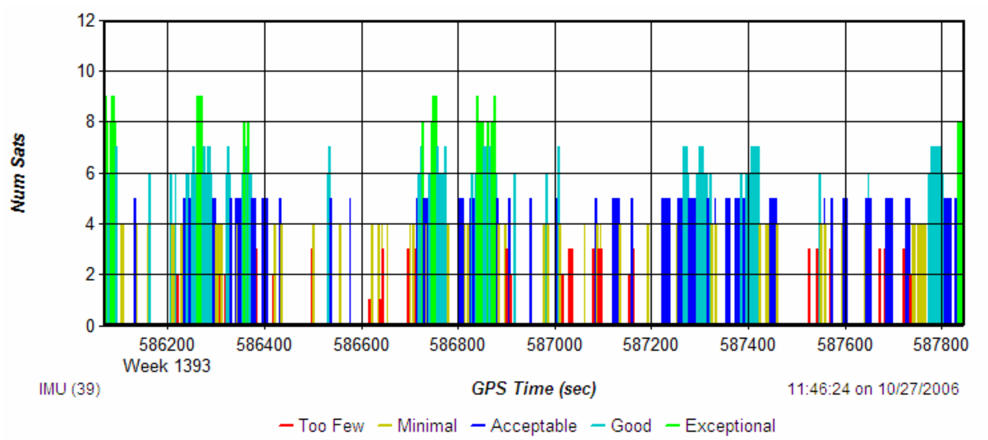

Figure 8: Number of Satellites available in GPS/INS Solution during Downtown Run 02

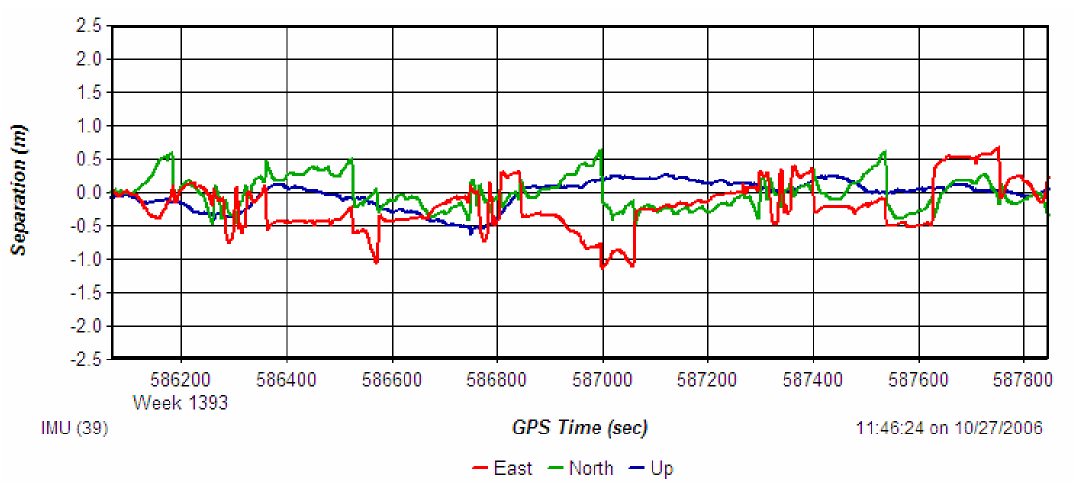

Figure 9: Error in FWD/REV Smoothed SPAN LN200 Solution using DMI updates on Run 02

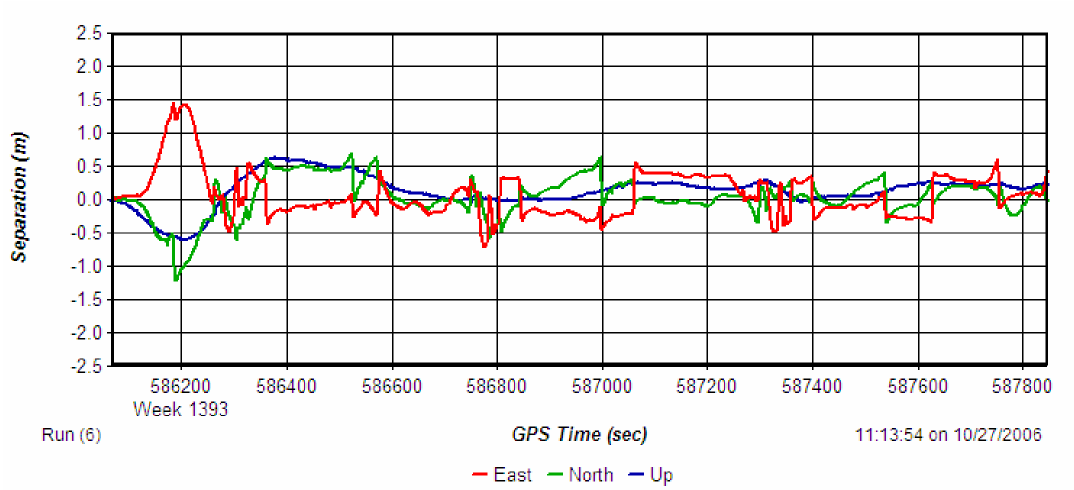

Figure 10: Error in FWD/REV Smoothed SPAN AG11 Solution using DMI updates on Run 02

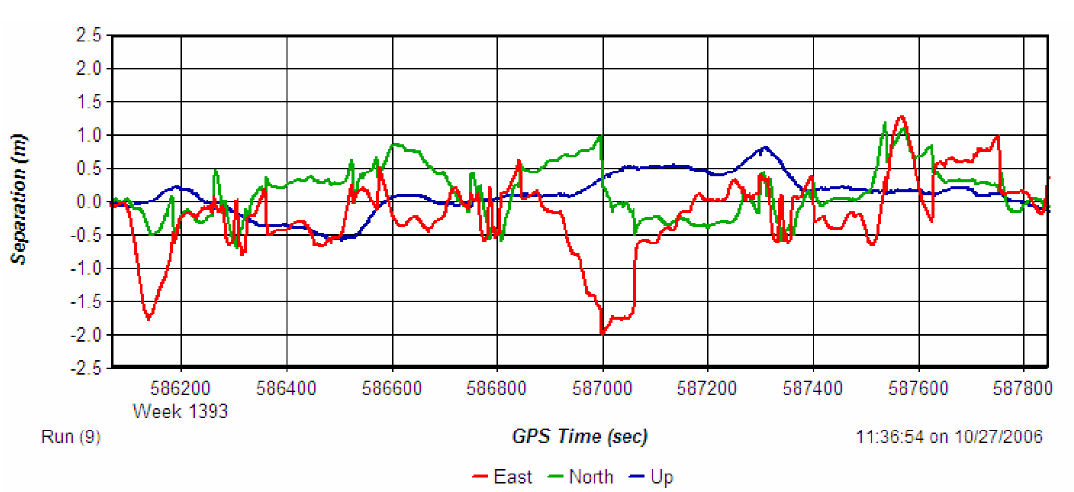

Figure 11: Error in FWD/REV Smoothed SPAN AG17 Solution using DMI updates on Run 02

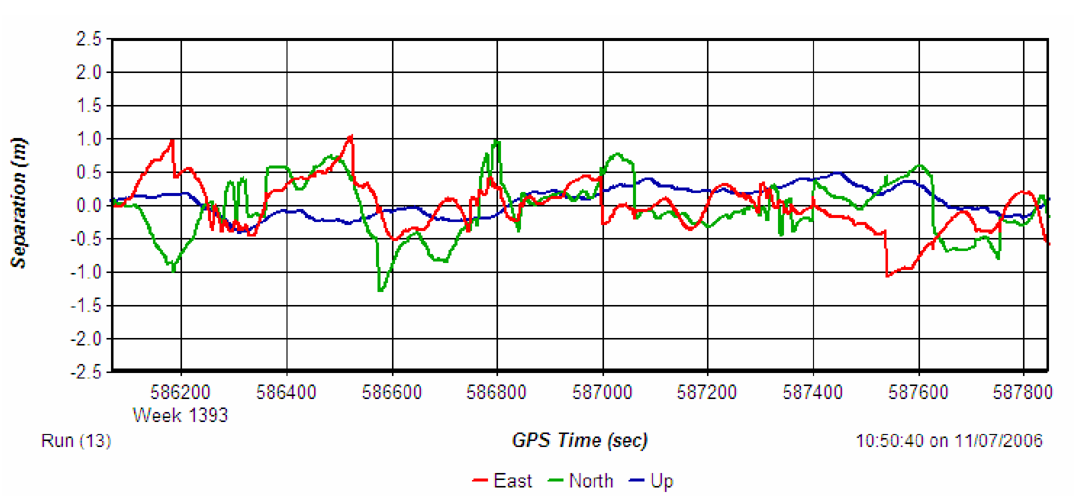

Figure 12: Error in FWD/REV Smoothed SPAN iMAR Solution using DMI updates on Run 02

Table 3: RMS Position Errors of Inertial Explorer Solution with DMI for Downtown Run 02

	SPAN LN200	SPAN AG11	SPAN AG17	SPAN iMAR
RMS Horizontal Error (m)	0.47	0.46	0.74	0.57
RMS Vertical Error (m)	0.21	0.27	0.30	0.22

Table 4: RMS Position Errors of Inertial Explorer Solution without DMI and without Manual Entry of Zero Velocity Updates for Downtown Run 02

	SPAN LN200	SPAN AG11	SPAN AG17	SPAN iMAR
RMS Horizontal Error (m)	1.64	2.59	2.13	3.25
RMS Vertical Error (m)	0.67	0.44	1.09	0.47

ANALYSIS

In a downtown environment, there are several challenges to navigation which necessitates the integration of GPS and INS. Most obvious are large buildings that cause frequent and often complete signal blockages. Secondly, due to the high multipath environment and the possibility of very poor satellite geometry when four satellites are tracked, GNSS updates can be unreliable and will only be used if the variance is within that specified in the processing options. This combination of factors can produce extended periods for which GNSS updates are unavailable to limit inertial error growth. In these circumstances, a DMI significantly improves results.

Inertial Explorer converts a DMI measurement to a distance or velocity value given the circumference of the wheel and a Kalman filter state that corrects for changes in wheel diameter (due to dynamics) throughout the survey. DMI updates are used only when GNSS updates are unavailable. Testing has shown that this update is most effective when used as a velocity update with a standard deviation of 0.2 m/s, which is the current default setting in Inertial Explorer.

Despite the challenging GNSS signal environment in downtown Calgary, sub meter (RMS) post-processed positioning results were still obtained horizontally and vertically when using the SPAN LN200, SPAN AG11 and SPAN IMAR in conjunction with a DMI sensor on both tests. All solutions were processed with Inertial Explorer version 7.61.

The GPS constellation at the time of run 2 was more favourable than run 1, resulting in more and higher quality GPS updates for run 2. The effect on the post-processed results is most obvious when a DMI is not used, because the availability of velocity updates from the DMI is effective in limiting inertial error growth where GNSS updates are unavailable.

Currently, Inertial Explorer uses DMI updates to automatically detect ZUPTS, which significantly lower inertial error growth. A user can also enter ZUPTS manually through Inertial Explorer's interface in order to improve results when not using a DMI. Tables 2 and 4 thus summarize pessimistic accuracies of those currently possible with Inertial Explorer in a downtown environment when no DMI is used.

Future versions of Inertial Explorer will not require DMI measurements in order to detect ZUPTS. Automatic ZUPT detection will be achieved through the raw gyro and accelerometer measurements which would represent a significant improvement in GPS/INS results when not using a DMI.

In addition, future versions of Inertial Explorer will also use carrier phase updates in a tightly coupled GPS/INS processing engine to further improve results in a downtown environment.