C-Nav Positional Reliability in a High Blockage and Multipath Environment

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Abstract

This paper describes an experiment to test a technique referred to as L1Phase Navigation, or "L1PNav", which has been developed and integrated into the C-Nav GPS receiver engine algorithm to enhance positional estimation integrity. This technique, which is also designated "SureNav" by NavCom Technology, Inc., adjusts the weighting of carrier phase and code based navigation in order to maximize the robustness of the output position. A general introduction of the L1PNav technique is followed by an experiment in which C-Nav is concurrently tested in High Blockage/Multi-Path and Clear View Environments. The results and conclusions are presented.

Introduction

The C-Nav GPS system employs the Real-Time Gypsy (RTG) Precise Point Positioning solution to provide a global decimeter-level navigation solution. Earlier C-Nav firmware versions relied upon the receiver's ability to continually maintain a dual-frequency solution. Interruption of continuous dual-frequency lock could result in the loss of decimeter-level accuracy due to several interrelated factors:

1. Navigation is often forced to transition out of a dual frequency mode and into a single frequency mode where:
    a. The residual errors associated with each satellite are greater.
    b. Refraction correction cannot be performed to remove ionosphere errors.
    c. Extended dual frequency smoothing cannot be performed to reduce code multipath errors.
2. Both carrier phase smoothing and multipath rejection are adversely affected by intermittent tracking.
3. The geometry (horizontal and vertical Dilution of Precision or DOP) is typically worse with fewer satellites, which magnifies the effect of the residual errors.

To address these universal GPS limitations, the L1PNav technique has been developed to sustain C-Nav's decimeter-level navigation during periods of blockage and shading. This results in decimeter-level accuracy being maintained even when the number of satellites continuously tracked would normally be insufficient. As with C-Nav's earlier RTG technique, L1PNav level of performance is not relative to distances from reference stations and can be relied upon anywhere within INMARSAT satellite visibility (75° N to 75° S Latitude).

C-Nav navigation firmware is structured in two tiers that coordinate with one another to provide 10Hz (or greater) updates to both position and velocity. At one-second intervals, the first layer performs a total re-computation of satellite geometry and code-carrier smoothing of refraction-corrected measurements augmented with RTG corrections. The second layer, which we refer to as L1PNav, uses the integrated carrier phase for each satellite for each proceeding 0.1-second interval to yield a very accurate estimate of the *change* in position over that interval. The values developed by this technique are combined in a weighted solution to generate the user position.

The success of L1PNav is a function of several factors:

1) Only carrier phase measurement differences are utilized in the L1PNav technique. Code measurements, which can be noisy and biased in the single frequency mode, are not used.
2) Delta phase measurements are not as susceptible to un-modeled atmosphere errors as are code measurements; therefore a lower elevation mask may be employed.
3) A lower elevation mask increases the likelihood of having additional satellites in view, which:
    a. Reduces transitions between the 3D and 2D modes of operation within the GPS receiver.
    b. Provides better geometry, resulting in a lower Dilution of Precision.

As exhibited in the following experiment, incorporating the C-Nav L1PNav technique produces a highly robust and accurate position estimation - even when encountering shading and partial blockage from structures and foliage.

The Experiment

The primary purpose of this experiment was to test C-Nav system under a high blockage and multi-path environment. On November 15th, 2004, four C-Nav2000 GPS units were used to collect raw GPS measurement solutions.

To exemplify a high blockage / multipath environment, two of the four C-Nav units were mounted on a stairway handrail next to a metal clad building where they were shadowed by a blockage angle of approximately 55 degrees from horizontal in the northerly direction (Figure 1). Progressing upward towards the east, the stairway additionally created an eastward blockage angle of 37 degrees from horizontal (Figure 2). Stands of trees situated to the south and to the west produced blockage angles of 36 degrees and 17 degrees respectively (Figures 3 & 4). Each of these two C-Nav GPS units incorporated a different version of firmware, one with the older (pre-L1PNav) firmware and the other with the newer L1PNav firmware.

Figure 1 – Northeast view of two C-Nav2000 units (to the left) in a high blockage and multipath environment.

Figure 2 - West view of two C-Nav units in a high blockage and multipath environment.

Figure 3 - South view of two C-Nav units in a high blockage and multipath environment.

Two additional C-Nav units, again one using the older firmware and one using the newer L1PNav firmware, were mounted on the rooftop an adjacent building. These units were used to monitor GPS system performance under clear and open sky conditions (Figure 5).

Results from a Clear View Environment

Table 1 and Chart 1 reveal the results obtained from unfiltered data (which in this case means all data with a valid format) collected in the clear view environment as photographed in Figure 5. No significant difference exists between the horizontal positions derived from the older pre-L1PNav firmware and the newer L1PNav firmware.

Receiver ID	**264894**	**264159**
Firmware	**Old version**	**L1PNav**
Total epochs:	315966	315690
Mean:	0.09	0.10
Std dev:	0.04	0.05
Maximum	0.22	0.37
Confidence Level (absolute value of error)		
Median:	0.09	0.09
68 %:	0.12	0.12
95 %:	0.16	0.18
99.7%:	0.19	0.29

Table 1 - Horizontal error (meters) in a clear view environment.

Figure 4 - West view of two C-Nav units in a high blockage and multipath environment.

Figure 5 – Two C-Nav units (front row) on the roof of an adjacent building.

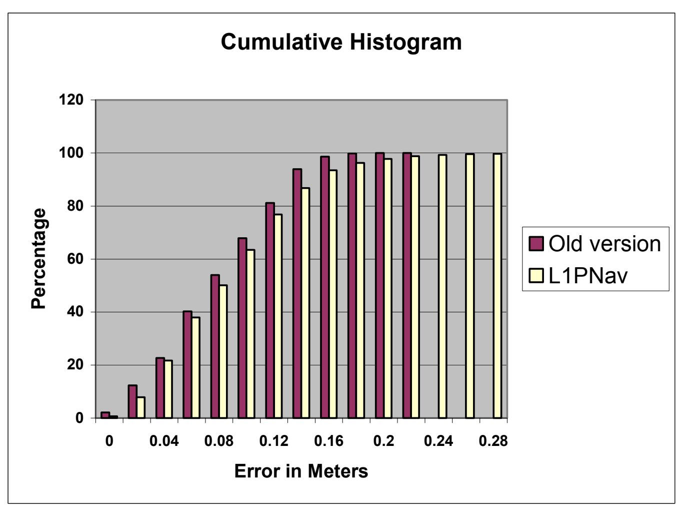


Chart 1 – Cumulative histogram reveals no significant difference between the firmware versions' horizontal positions in a clear view environment.

Vertical position data obtained in the clear view environment with the L1PNav firmware and its predecessor firmware are displayed in Table 2 and Chart 2. Again, the differences are minimal.

Receiver ID	**264894**	**264159**
Firmware	**Old version**	**L1PNav**
Total epochs:	315966	315690
Mean:	0.13	0.11
Std dev:	0.12	0.13
Maximum	0.72	1.01
Confidence Level (absolute value of error)		
Median:	0.10	0.07
68 %:	0.15	0.12
95 %:	0.39	0.35
99.7%:	0.61	0.81

Table 2 - Vertical error (meters) in a clear view environment.

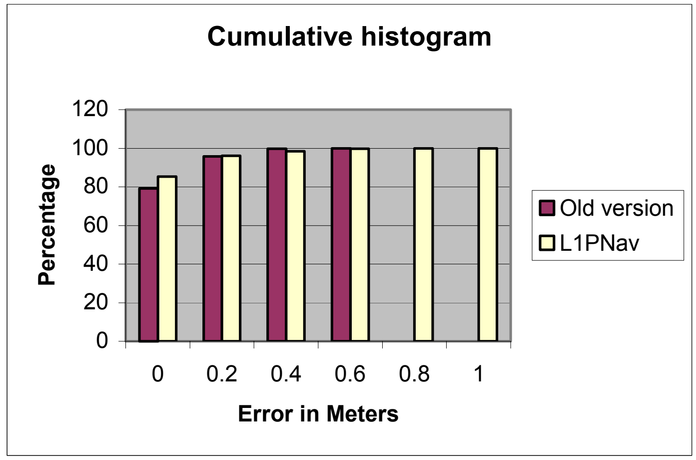


Chart 2 – Cumulative histogram reveals no significant difference between the firmware versions' vertical positions in a clear view environment.

No significant positioning difference was noted between the differing firmware versions in the clear view environment. The older (pre-L1PNav) firmware version resolves slightly closer to the reference position in horizontal (Table 1), while the L1PNav firmware version resolves slightly closer to reference position in the vertical axis (Table 2).

Results from a High Blockage and Multipath Environment

Table 3 and Chart 3 were developed from the unfiltered horizontal position data collected in the high blockage and multipath environment. The standard deviation of the horizontal positions shows that L1PNav firmware provides a significant improvement over pre-L1PNav firmware version. No large position jumps or instability were observed utilizing the L1PNav firmware during the experiment. This is characterized by the maximum observed horizontal error of 1.34 meters.

Receiver ID	**264543**	**265013**
Firmware	**Old version**	**L1PNav**
Total epochs:	331644	333294
Mean:	0.50	0.24
Std dev:	0.89	0.12
Maximum	13.96	1.34
Confidence Level (absolute value of error)		
Median:	0.31	0.23
68 %:	0.45	0.28
95 %:	1.32	0.46
99.7%:	7.93	0.77

Table 3 - Horizontal error (meters) in a high blockage and multipath environment.

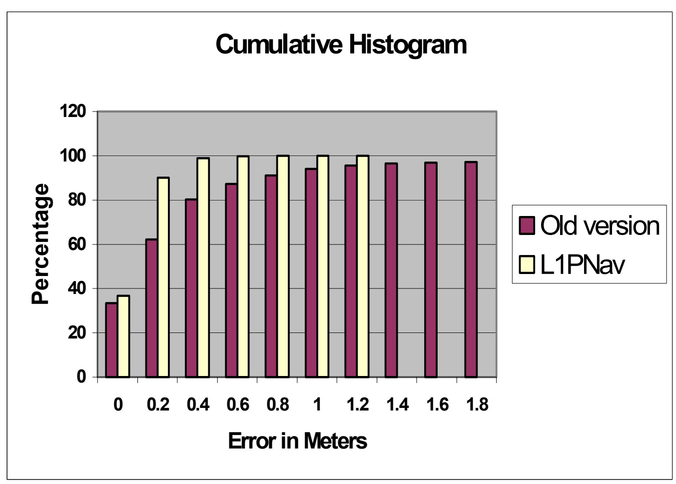


Chart 3 – Cumulative histogram of the L1PNav horizontal positions in a high blockage and multipath environment.

Table 4 and Chart 4 were developed from C-Nav vertical position data adjusted for solid earth tides in a high blockage and multipath environment. Better than a four-fold improvement in the standard deviation of the vertical positions was observed utilizing the L1PNav dataset (0.80 meters down to 0.18 meters). Vertical excursions were reduced by more than one order of magnitude with 99.7% of the vertical positions within 1.01 meters.

Receiver ID	**264543**	**265013**
Firmware	**Old version**	**L1PNav**
Total epochs:	331644	333294
Mean:	0.45	0.25
Std dev:	0.80	0.18
Maximum	51.37	1.57
Confidence Level (absolute value of error)		
Median:	0.22	0.21
68 %:	0.34	0.31
95 %:	1.75	0.58
99.7%:	6.72	1.01

Table 4 - Vertical error (meters) in a high blockage and multipath environment.

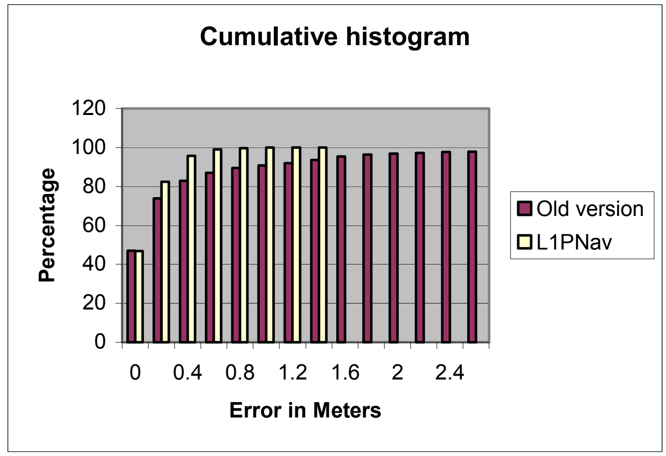
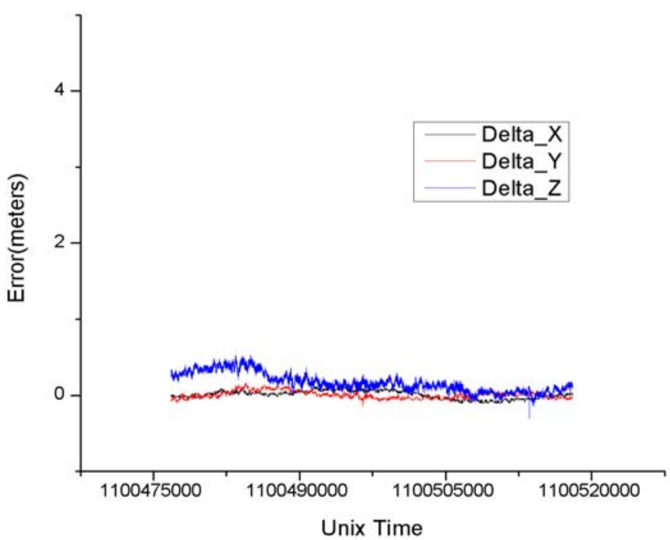


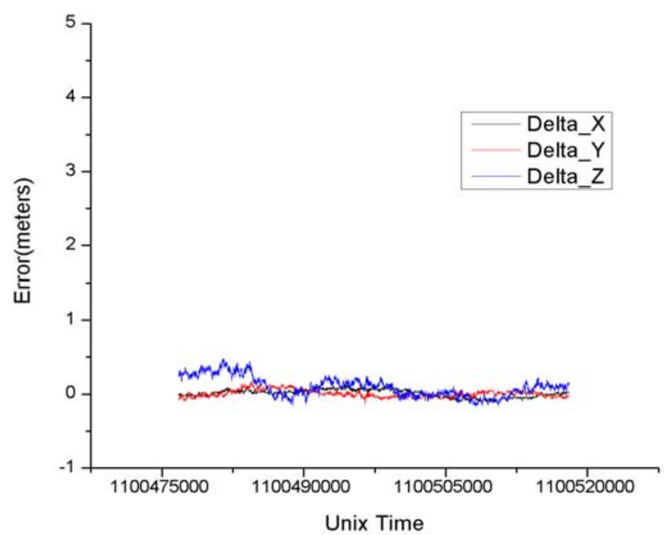
Chart 4 – Cumulative histogram shows 99.7% of the L1PNav vertical positions within 1.01 meters in a high blockage and multipath environment.

Time Series Perspective

Graphs 1, 2, 3, and 4 are plots of time series data acquired from the four C-Nav GPS units during this experiment. Graphs 1 and 2 are from the clear view environment. Here, the horizontal position perfectly matched the ITRF reference position.

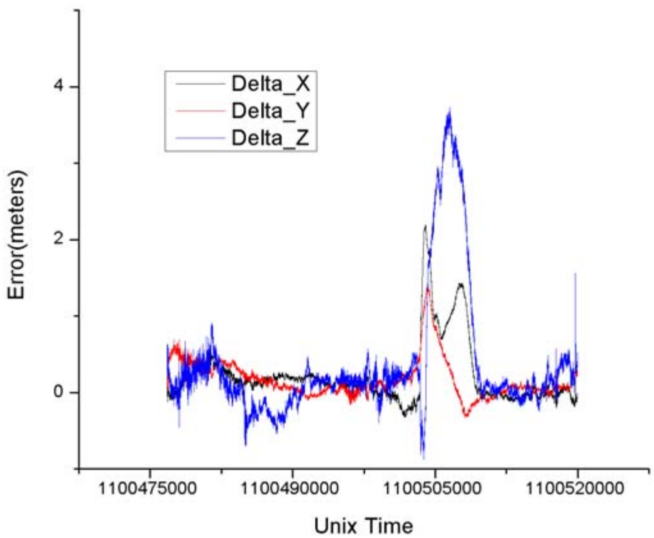


Graph 1 - Older firmware (pre-L1PNav) in the clear view environment reveals stable positioning.

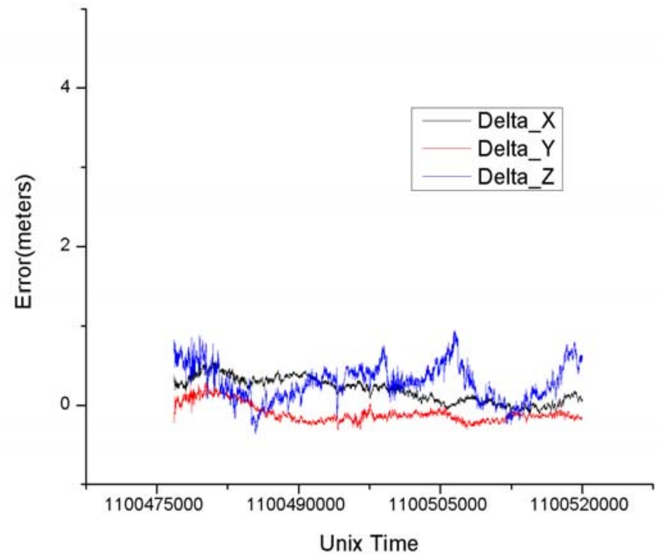


Graph 2 - L1PNav firmware in the clear view environment reveals stable positioning.

Graphs 3 and 4 were developed from the high blockage and multi-path environment datasets and also adjusted for solid earth tides. Position jumps are evident in Graph 3 (the pre-L1PNav firmware dataset) during restrictive conditions when only 3-4 satellites were in view. Concurrently collected L1PNav positioning data remained stable as evidenced in Graph 4.



Graph 3 - Older firmware (pre-L1PNav) in the high blockage and multipath environment reveals effects of an insufficient number of satellites in view.



Graph 4 –L1PNav firmware provided stable positioning in the high blockage and multipath environment with a normally insufficient number of satellites in view.

Conclusions

This experiment exhibits that the new L1PNav algorithm provides a substantial improvement in position stability and reliability over the previous C-Nav firmware version in a high blockage and multipath environment. A simultaneous comparison in a clear view environment disclosed no significant differences in either horizontal or vertical positioning. Quantitative testing in a high blockage and multipath environment revealed C-Nav's horizontal position solutions to vary by less than 0.5 meters and vertical solutions by less than 0.6 meters at the 95% confidence level. In the clear view environment, C-Nav's horizontal position solutions varied by 0.18 meters and vertical solutions by 0.35 meters at the 95% confidence level.

References

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