Slope Deformation Monitoring with RTKNav / RtStatic

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Introduction

Waypoint has added a major new feature called **RtStatic** to its RTKNav real-time kinematic processing package. This option is aimed at near real-time deformation monitoring applications. RtStatic uses Waypoint's GrafNav processing engine to provide Fixed Static solutions in near real-time. Simultaneously, the standard kinematic engine processes the same data in real-time to monitor fast moving events. Filtering of the time history of the Fixed Static solutions produces millimetre level coordinate changes on slow moving features such as slopes or dams. This process is demonstrated below:

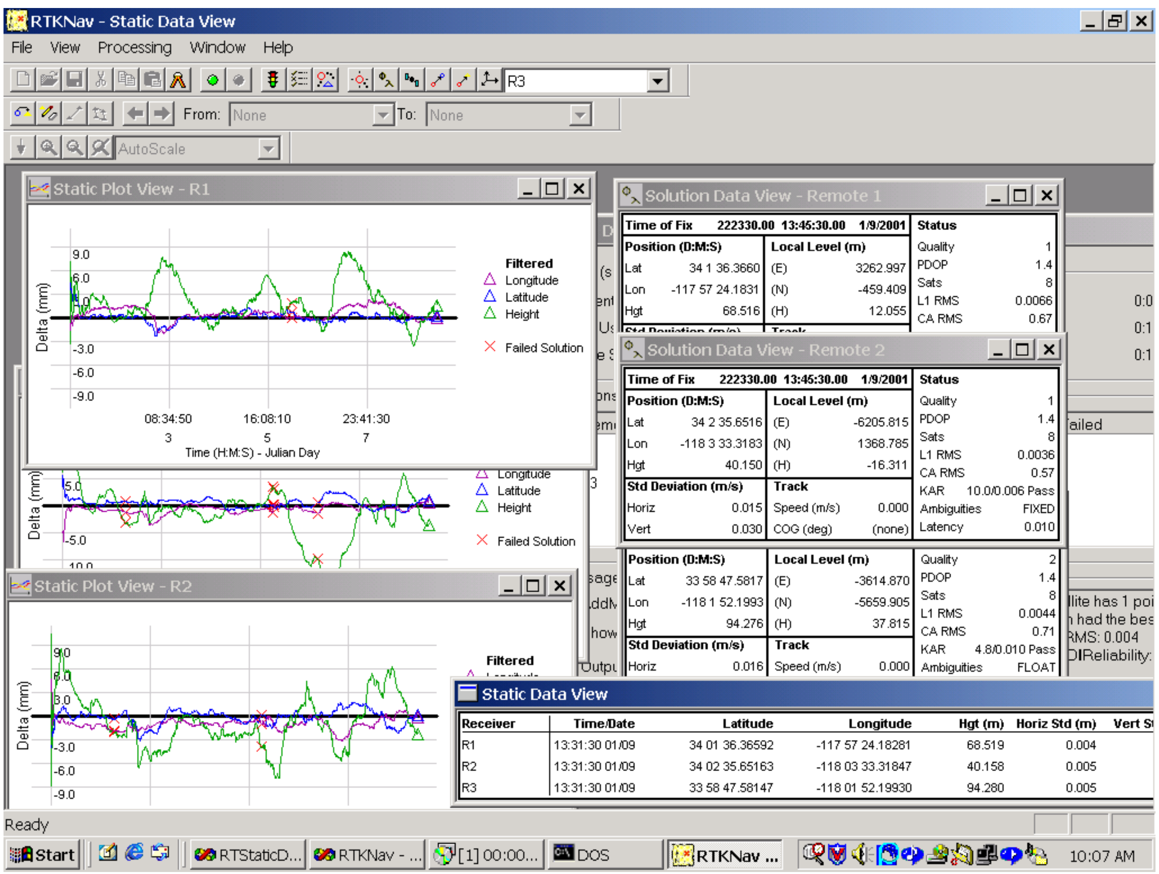

Figure 1: Simultaneous near-real time Fixed Static and real time KAR solutions

In this example, RTKNav processed three baselines over almost nine days. The baselines are designated R1, R2, and R3. For each baseline, a real-time kinematic solution is computed in the foreground (shown on the right), while RtStatic utilizes the last 'n' minutes of data (by default 15) to obtain fixed static solutions in near real-time mode (plotted on left). The continuous 15-minute static coordinate "snapshots" are also low-pass filtered with a 24-hour time constant to remove noise in the solutions.

When RTKNav computes a real-time kinematic solution, either a standard float solution can be computed or kinematic ambiguity resolution (KAR) techniques can be used. If KAR is engaged, the fixed static solutions obtained from RtStatic can be compared with the KAR solution. When KAR is turned on, as in this example, it engages upon loss of lock or when noisy data is encountered. Optionally, the user can specify to reengage KAR every 'n' minutes.

On short baselines (<3 km), single or dual frequency receivers can be used with similar precision. Up to 20 base/remote combinations can be processed on the same computer platform. Raw input or processed output data can be transferred in real-time over serial or network connections.

The following tests demonstrate the use of RtStatic in conjunction with RTKNav.

Test 1: 3 baselines of various lengths tested over a 30 day period

Introduction

As a test of RTKNav's RtStatic component, three fixed baselines were processed over a 30-day period. Two instances of RTKNav/RtStatic were created, which allowed both a dual and a single frequency test of each baseline. The baselines used were obtained by downloading GPS RINEX data from a network of four SCIGN stations in close proximity. The data was obtained from the SOPAC site and we gratefully acknowledge the Southern California Integrated GPS Network and its sponsors, the W.M. Keck Foundation, NASA, NSF, USGS, SCEC, for providing data used in this study.

To simulate real-time processing, the RINEX data was read from disk by a special utility program and converted to NovAtel GPS binary data format. This binary GPS measurement data was piped with appropriate time delays through MULTICAST network ports over a local computer network. RTKNav reads data in real-time either through serial or network ports. In this case, RTKNav simply believed that it was reading and decoding data from 4 NovAtel dual frequency GPS receivers in a real-time process. From a processing point of view, the simulation network was no different in any way from a true real-time scenario.

The baselines processed by RTKNav can be viewed in the GrafNet screen shot seen in figure 2.

Baseline distances were as follows:
- VYAS to LPHS (R1): 3.30 km
- VYAS to WHC1 (R2): 6.72 km

• VYAS to WNRA (R3): 6.35 km

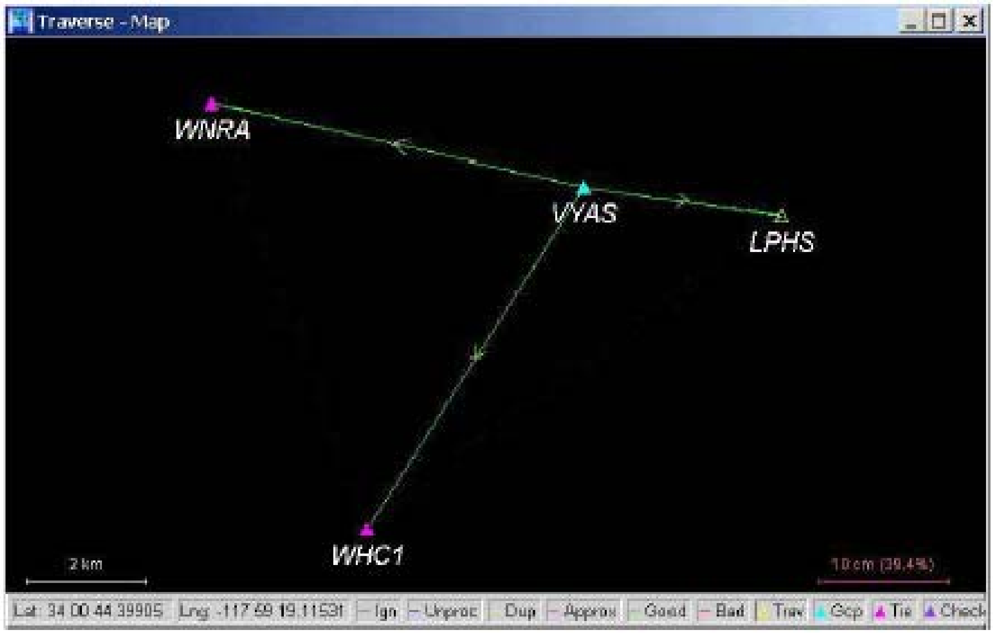

Figure 2: Baselines Used in RTKNav/RtStatic 30-Day Deformation Monitoring Test

Results

Trial 1 - Dual Frequency Test

In the first test, 30 days of data was processed from the three baselines simultaneously using dual frequency measurements. The figure below shows the filtered fixed static solutions obtained every 15 minutes for each baseline:

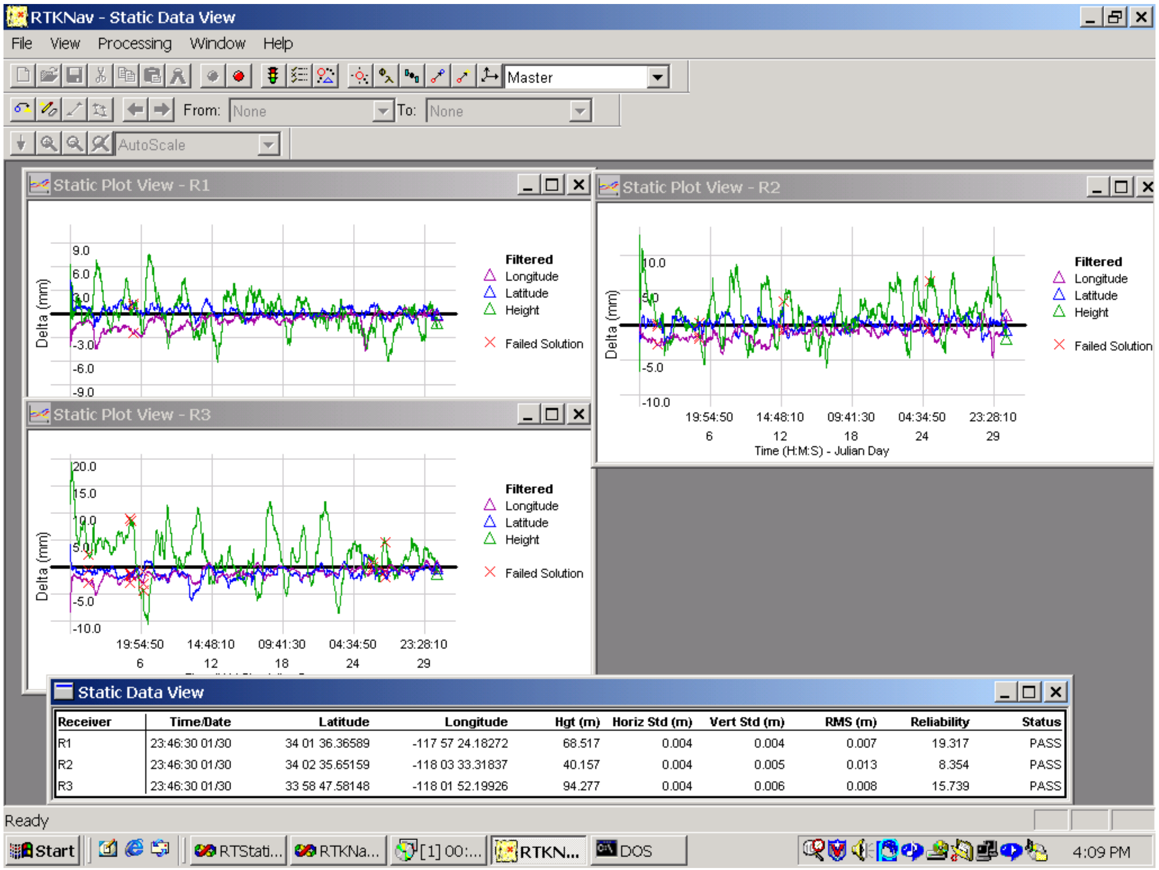

Figure 3: Dual Frequency results (30 Days of Data)

It should be noted that these results, shown on the computer screen, can also be exported into .CSV format and read into plotting programs such as Microsoft Excel for further analysis. As seen from the above graphs, horizontal accuracies are generally consistently within 2–3 millimeters for all the baselines. As seen in the plot of R3 (the longest baseline at 6.72 km) the plotted height values vary by a significant amount – approximately 1 cm. However, due to the apparent random fluctuations in these coordinate changes it is apparent no movement is being observed.

Trial 2 - Single Frequency Test

In this test, the above data was reprocessed using single frequency measurements only. The filtered fixed static solutions obtained every 15 minutes for each baseline are shown below:

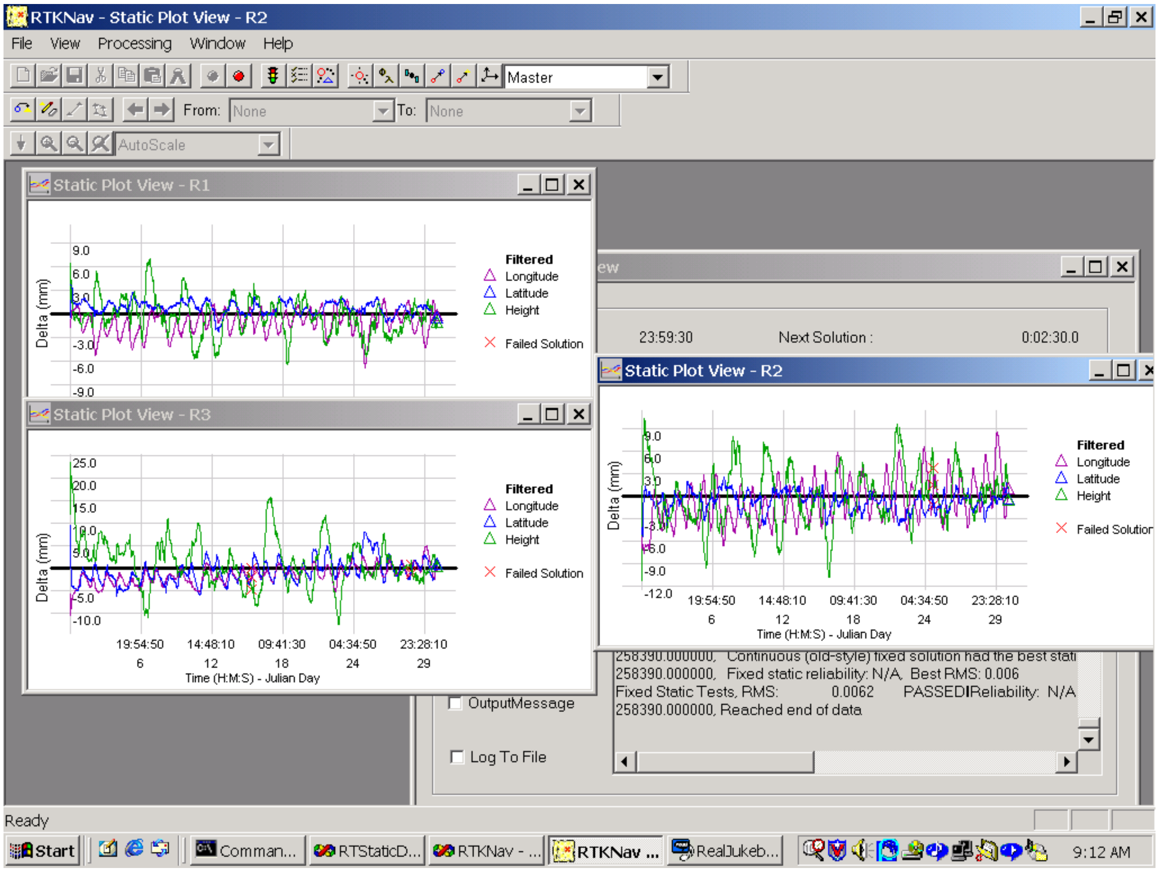

Figure 4: Single Frequency Results (30 Days of Data)

Single frequency accuracies for the baseline R1 was very similar to the dual frequency results. This was expected, as the baseline length is only 3.3 km and the effects of the ionosphere are minimal. The other two baseline accuracies degraded somewhat due to their larger master-remote separation (greater than 6 km). Despite this decrease in accuracy, slow movement would still be detected as a gradual ramp in the plots above.

The graph of R1 (3.3 km baseline) was exported into .CSV format and plotted in Microsoft Excel. This allows users to better catalog and examine some plots. The following is the plot of the filtered horizontal and height coordinates computed by RtStatic at 15-minute intervals:

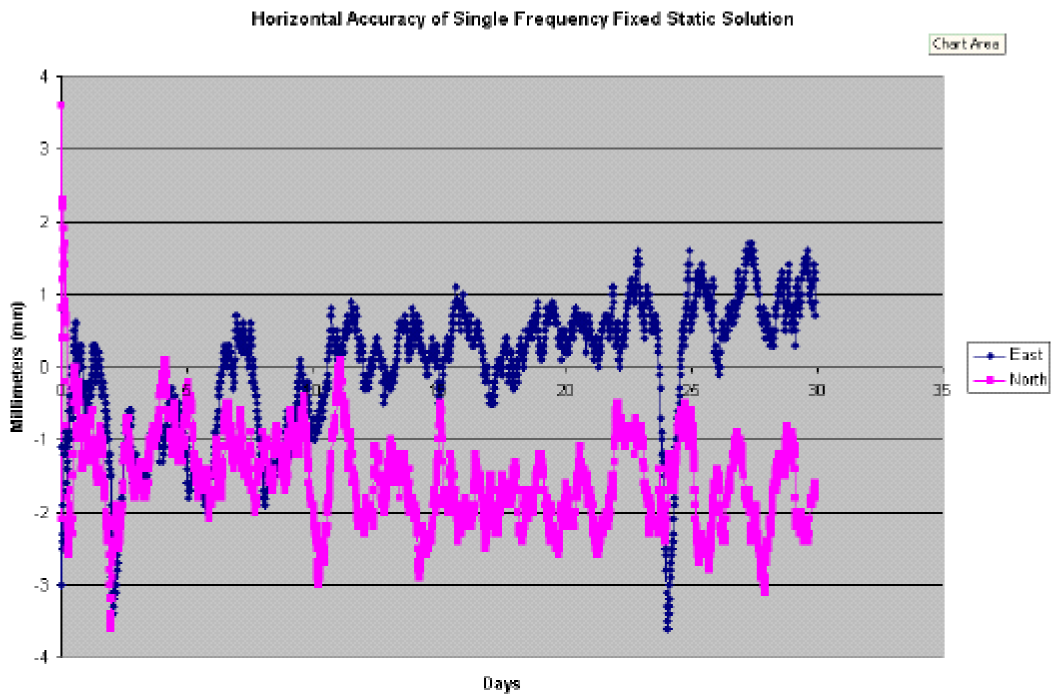

Figure 5:Horizontal Low Pass Filtered Results (30 Days of Data, 3.3 km baseline)

The 1 mm ramp in easting and 2 mm ramp in northing is not sufficient to reliably conclude that gradual movement exists.

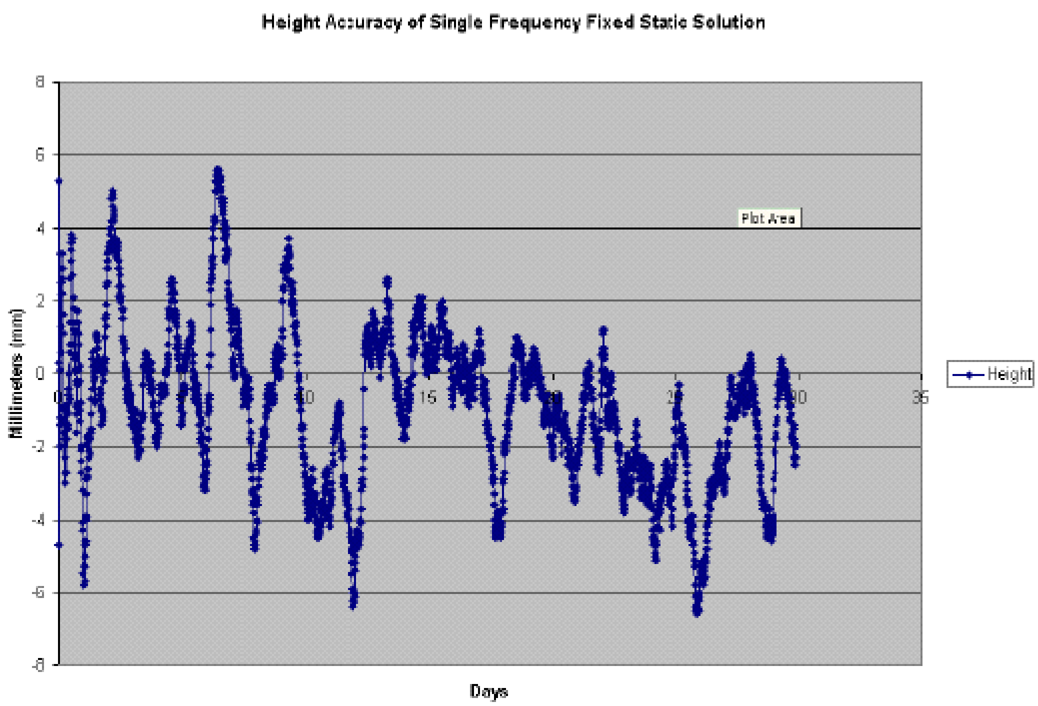

Figure 6: Vertical Low Pass Filtered Results (30 Days of Data, 3.3 km baseline)

Accuracies in height are typically 2-3 times worse than horizontal accuracies.

Test 2

Intro

This test was done to measure RtStatic's ability to detect a known amount of movement. Conducted in rural conditions just outside of Calgary AB, Canada, two single frequency Ashtech GPS receivers were used. The baseline length was approximately 1.3 km. Approximately two hours of data was collected, and then the receiver acting as the remote was moved two centimetres north. Nearly two hours later, the batteries powering the GPS receivers died, halting data collection.

In principle, any amount of receiver movement is reliably detected by viewing the plot of the filtered 15-minute fixed static solutions. This procedure works best when there is a substantial amount of data collected after the movement occurs. While the standard kinematic solutions or the unfiltered fixed static solutions will warn of immediate possible receiver movement, these solutions are subject to cm variations due to noise and are thus inherently unreliable.

As shown in the previous tests, 30 days of data was needed to show apparent millimeter movement. However due to the nature of the system, we are not claiming we actually detected such a minute change in coordinates. Therefore the remote receiver was moved a rather large amount (2 cm) as we suspected that only hours worth of data would be collected after the movement. It should be noted that much smaller receiver movement should also be reliably detected if days (or weeks) of data is collected.

Results

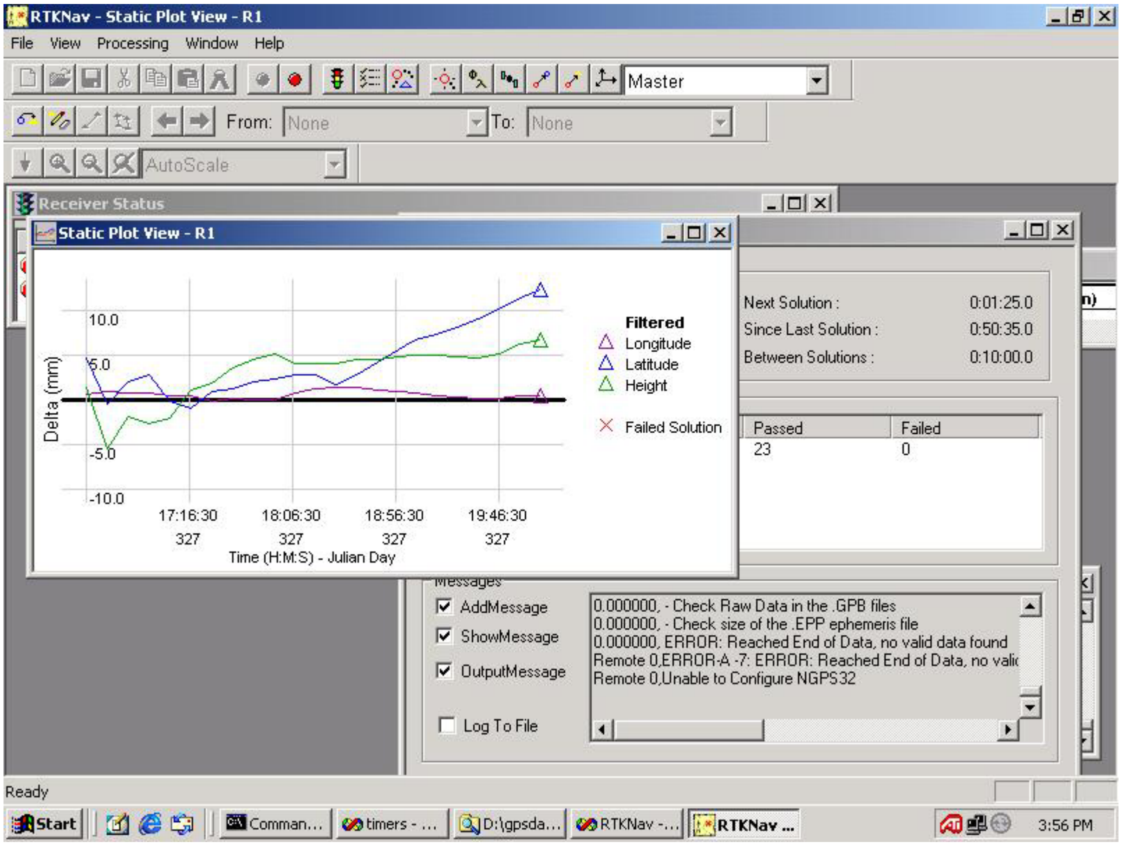

Figure 7: 4 Hour 2 cm movement test – 1.3 km baseline

As expected, no significant ramps (indicating movement) were detected in either the height or the longitude. The latitude, however, began showing a steady ramp in its solution at precisely the same time as the actual receiver movement (2 hours into the survey). As the receiver was actually moved north, this apparent change in latitude was a reality. Overall, approximately 1.2 cm of movement were reliably detected out of the 2.0 cm it was moved. Had more data been collected after the receiver was moved (less than two hours were collected) the plot would have continued to rise and should have leveled off at the 2 cm mark.

Given that this level of movement was detected with less than two hours of data after it occurred, we consider the results very promising. More tests are planned in the near future.

Conclusions

Waypoint Consulting has added a new background Fixed Static processing engine to its real-time kinematic package, RTKNav. The optional RtStatic library uses the last "n" minutes of data to obtain a fixed static integer ambiguity solution for slope and dam deformation monitoring applications. These solutions are low-pass filtered to produce millimetre level results for such tasks. Simultaneously, the standard RTKNav processor outputs data processed in conventional RTK fashion, in the case that high rate coordinate data is required for the application.