Fast Kinematic Ambiguity Resolution in GrafNav Version 6.03

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Purpose

The intention of this report is to examine fast on the fly ambiguity resolution on baselines less than 10 km in length under various observation conditions.

Introduction

Although not required in many GPS surveying applications, conditions exist in which fast kinematic ambiguity determination is necessary for precise positioning. Some examples include race car or rocket trajectory determination, some types of road surveys, and other surveys under generally open conditions with scattered obstructions of the sky.

Five tests were performed to determine GrafNav's ability to quickly resolve integer ambiguities on the fly. A moving baseline, a marine survey, two road surveys, and a series of static baselines processed in kinematic mode were all tested. Care was taken to ensure good observation conditions for some of the tests, however care was also taken to ensure less than ideal conditions for others. This was done not to answer "how good" GrafNav can perform fast kinematic ambiguity resolution under the best of conditions, but rather under what conditions can it be reliably resolved, and when does it fail?

It is important to note here that the receiver types used throughout the experiments included the NovAtel OEM-4, the Ashtech Z-12, as well as Trimble and Javad receivers. All of these receivers have dual frequency capabilities and are of high quality. High quality phase measurements are essential to reliable fast ambiguity determination. All data was collected (or interpolated) and processed at 1 Hz, unless otherwise noted.

By default, GrafNav will not attempt fast ambiguity resolution. However, the following figures show the changes necessary to enable this:

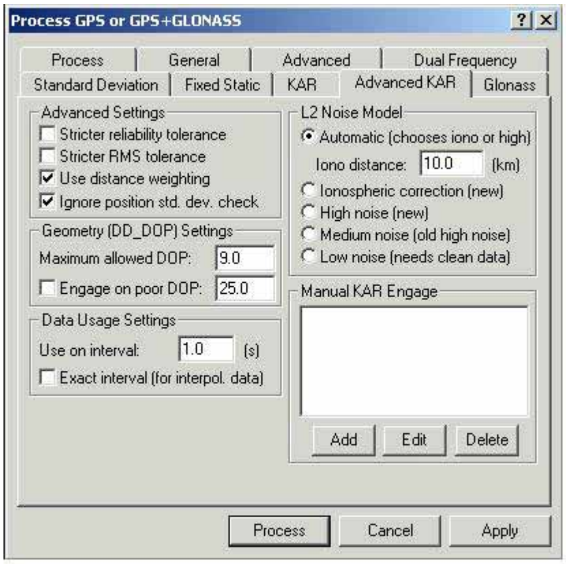

Figure 1: Advanced KAR Options

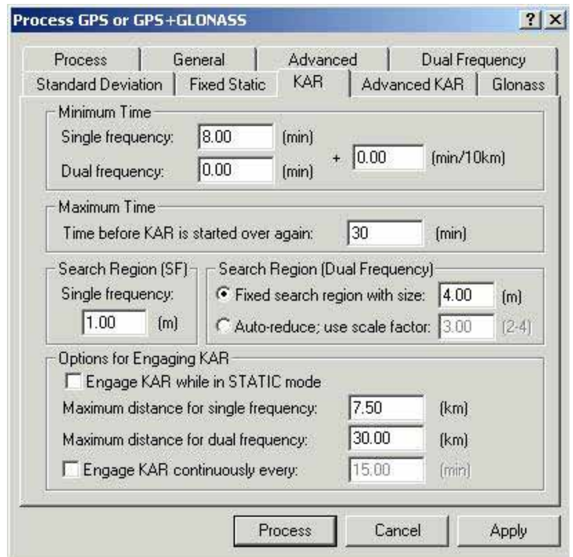

Figure 2: KAR Options

The important changes to note in the Advance KAR options (figure 1) are to check the box labeled "ignore position std. dev. check", and the "Data Usage Settings" should be changed to the interval the data was collected at. The one necessary change in the KAR options (figure 2) is the minimum time for KAR to engage must be reduced to 0.00 min + 0 min/km.

Background

Kinematic Ambiguity Resolution (KAR) is a technique that allows the user to compute integer fixed solutions (centimeter accuracies) while the remote antenna is in motion. KAR is necessary in kinematic environments or after a serious loss of lock, if centimeter-level accuracies are to be maintained. This technique needs 5 or more satellites in view. Dual frequency measurements help considerably as the wide-lane technique can be used.

There are two types of measurements available in GPS positioning: code and phase measurements. Some receivers also output Doppler. High quality receivers can resolve satellite-receiver ranges derived from code measurements to about 2-3 meters, which is not good enough for centimeter-level positioning. Precise positioning requires measurements with far greater accuracy than this, which is why phase measurements must also be observed. Phase measurements are very accurate in part because they are simply carrier waves with precisely known wavelengths.

There are two ways to process using phase measurements. The first involves solving the ambiguities without the constraint that they must be integers, which is known as the float solution. A fixed solution employs techniques that force the ambiguities to be integers. This initial integer ambiguity for a given satellite is a constant value as long as lock is maintained on that satellite.

The mathematical model underlying the search for a fixed solution assumes statistically normally distributions. This is why systematic effects such as multipath and ionospheric interference can cause the wrong solution to be found, or no solution at all.

Test #1: Kinematic Road Survey #1

Introduction

This experiment was performed to test GrafNav's very fast ambiguity determination under five and six satellite conditions. A kinematic road survey, originally processed with GrafNav's default options, was reprocessed with a complete loss of lock induced at two-minute intervals. This solution was then graphically compared to the original solution.

GrafNav's processed representation of the survey's trajectory is shown below.

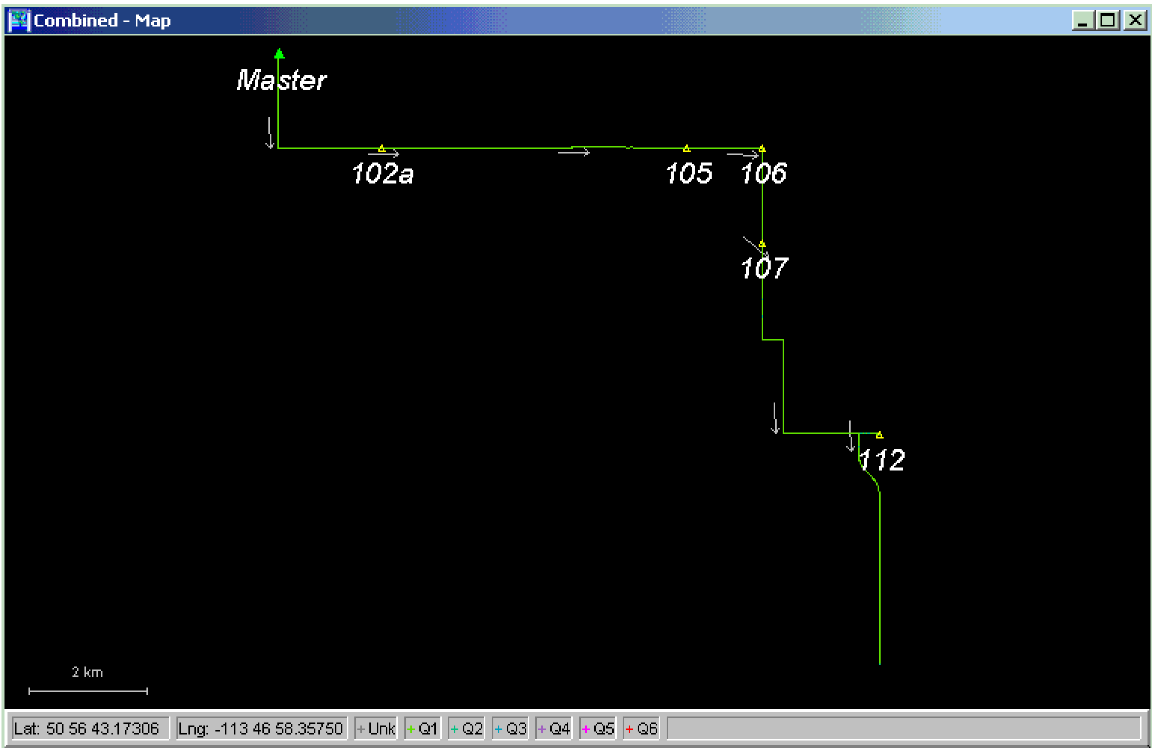

Figure 3: Road Survey Trajectory

Results

Restored	Engaged	TimeUsed	AvgSats	Dist	Status
	(sec)	(sec)		(km)	
315422	315421	3	6	0.004	PASSED
315432	315431	3	6	0.004	PASSED
315552	315551	3	6	0.004	PASSED
315672	315671	3	6	0.935	PASSED
315792	315791	3	6	1.8	PASSED
315912	315911	3	6	2.37	PASSED
316032	316031	3	6	2.6	PASSED
316152	316151	3	6	3.5	PASSED
316272	316271	3	6	5.2	PASSED
316392	316391	3	6	7	PASSED
316512	316511	3	6	7.3	PASSED
316632	316631	3	6	8.3	PASSED
316992	316751	3	6	8.8	FAILED
317112	317111	3	6	8.8	PASSED
317233	317232	3	5.4	9.4	PASSED
317352	317351	3	6	10	PASSED
317472	317471	6	6	11.5	PASSED
317592	317591	30	5.1	12	PASSED
317713	317712	9	6	11.7	PASSED
317952	317831	3	6	13.9	FAILED

The following graph shows how well these solutions compared to the original solution, obtained from processing with GrafNav's default options:

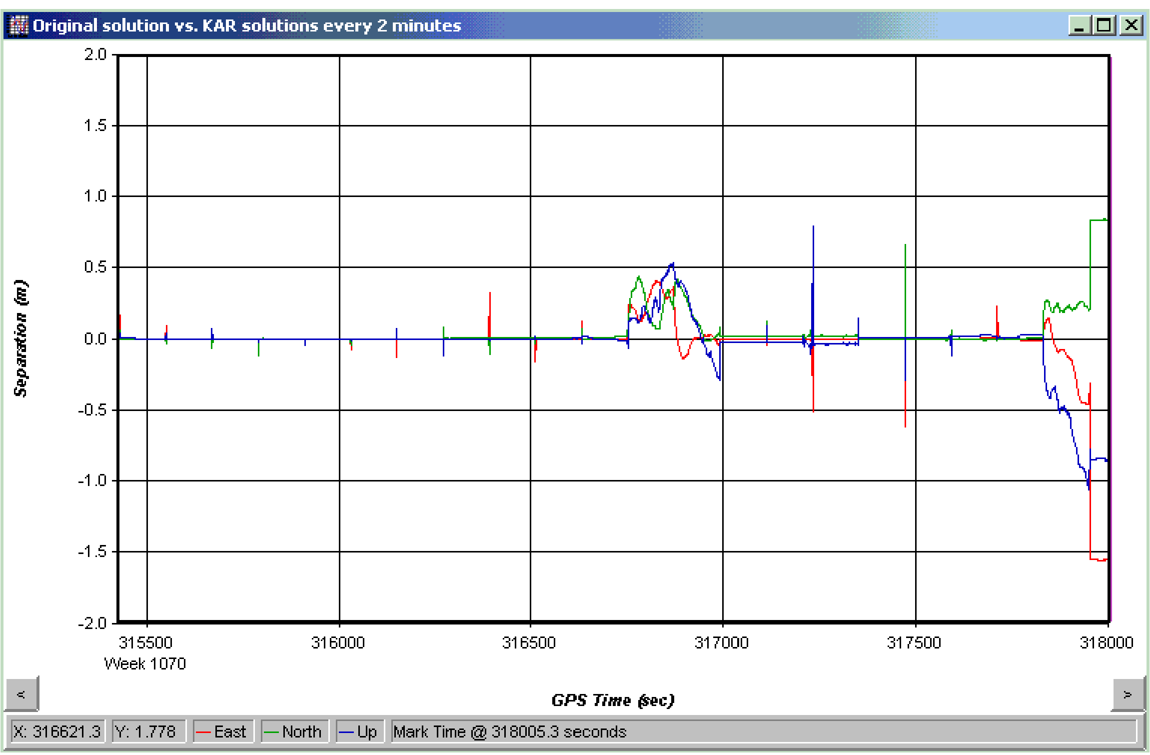

Figure 4: Original GrafNav Solution vs. KAR solution at two minute intervals

The small spikes at two-minute intervals show where KAR engaged. Eighty-five percent of the above trials took only three seconds for KAR to resolve, and only twice did KAR pick a solution that differed by more than 5 cm from the benchmark solution.

It is interesting to note that the first time KAR failed the master-remote separation was approaching the nine-kilometer mark. At these distances, very fast ambiguity resolution will not always produce a result, and can fail for many reasons including satellite count, satellite geometry, multipath, ionospheric effects and a variety of other reasons. Despite the large master-remote separation, KAR was reestablished soon afterwards and did not fail again until the master-remote separation approached the 14-kilometer mark. These results are quite good considering that only six satellites (one more than the minimum required for KAR) were observed for the majority of the survey.

Test #2: Kinematic Road Survey #2

Introduction

General observation conditions for test #2 were much improved over test #1, as at minimum eight satellites were observed during the survey. Similarly to test #1, a solution obtained using GrafNav's default processing options was compared against a solution in which a complete loss of lock was induced at two-minute intervals, forcing KAR to engage. The following figure shows a processed representation of the survey, which actually took place on an unused airstrip.

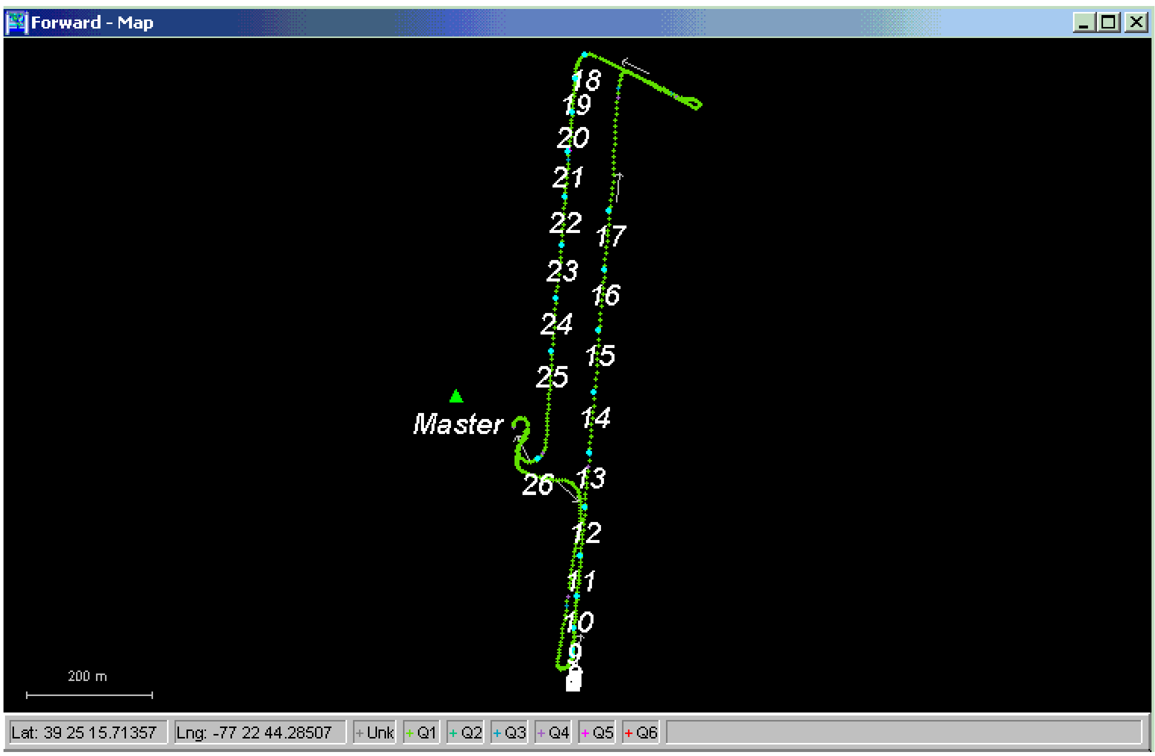

Figure 5: Trajectory of Road Survey #2

Results

Restored	Engaged (sec)	TimeUsed (sec)	AvgSats	Dist (m)	Status
483484	483483	3	8	102.24	PASSED
483549	483542	3	8	101.5	PASSED
483604	483603	3	9	101.72	PASSED
483664	483663	3	9	101.72	PASSED
483724	483723	3	9	101.72	PASSED
483784	483783	3	9	101.72	PASSED
483844	483843	3	9	101.72	PASSED
483904	483903	3	9	101.68	PASSED
483964	483963	3	9	101.69	PASSED
484024	484023	3	9	101.68	PASSED
484084	484083	3	9	101.68	PASSED
484144	484143	3	9	100.97	PASSED
484204	484203	3	9	139.42	PASSED
484264	484263	3	9	143.75	PASSED
484324	484323	3	9	378.53	PASSED
484384	484383	3	9	448.09	PASSED
484444	484443	3	9	448.1	PASSED
484504	484503	3	9	448.1	PASSED
484563	484562	3	8	447.72	PASSED
484623	484622	3	8	225.86	PASSED
484683	484682	3	8	552.34	PASSED
484743	484742	3	8	583.41	PASSED
484803	484802	3	8	405.23	PASSED
484863	484862	3	8	161.14	PASSED
484923	484922	3	8	124.14	PASSED

As summarized above, every time KAR engaged it was successfully resolved in three seconds. The following figure graphically shows the difference between the solution in which KAR was forced to engage at two-minute intervals and the benchmark solution:

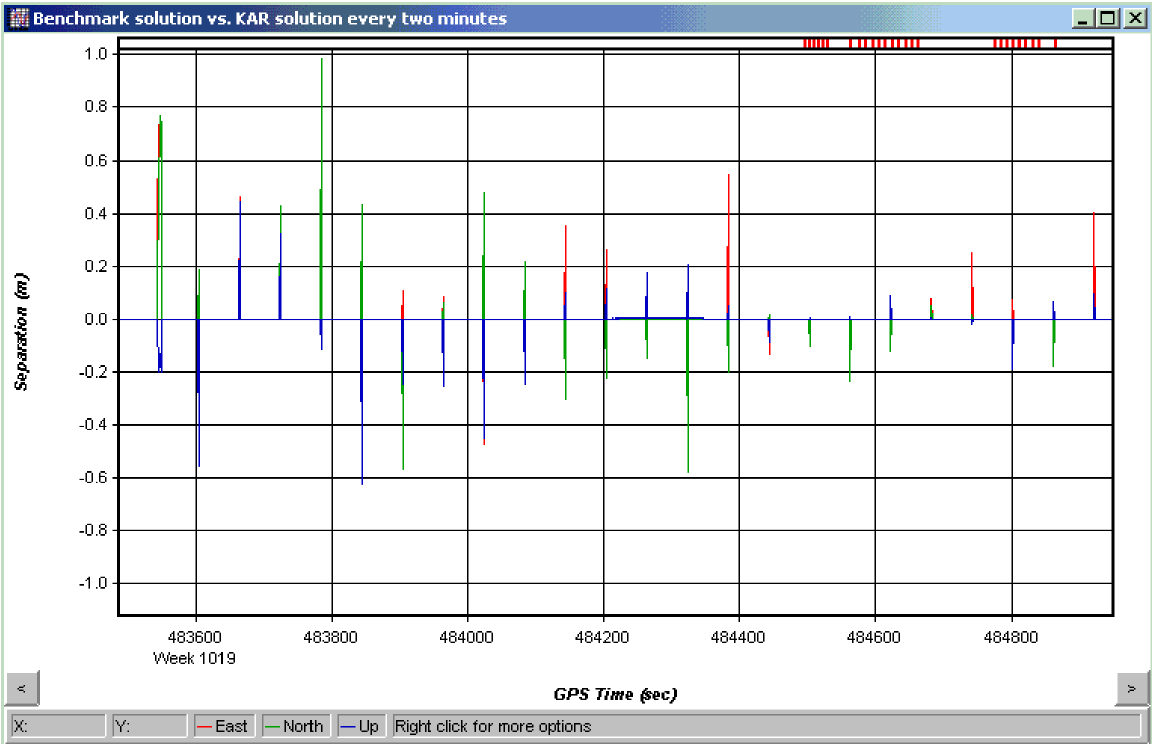

Figure 6: Difference in Benchmark Solution vs. KAR solution Every Two Minutes

As seen above, KAR picked the correct solution every time it engaged, as only small spikes are shown. If the above graph showed large areas enclosed by the two solutions (such as boxes or rectangles instead of vertical lines) it would have indicated a disagreement between the default processing solution and the solution in which fast kinematic ambiguity determination was used.

Test #3: Airborne Kinematic Survey

Introduction

General observation conditions for this test were generally good, as seven satellites were observed for the majority of the survey. Similarly to the previous tests, a solution obtained using GrafNav's default processing options was compared against a solution in which KAR was forced to engage at two-minute intervals. This was done by inducing a complete loss of lock at regular two-minute intervals in the remote observation file.

The following figure displays the airborne trajectory:

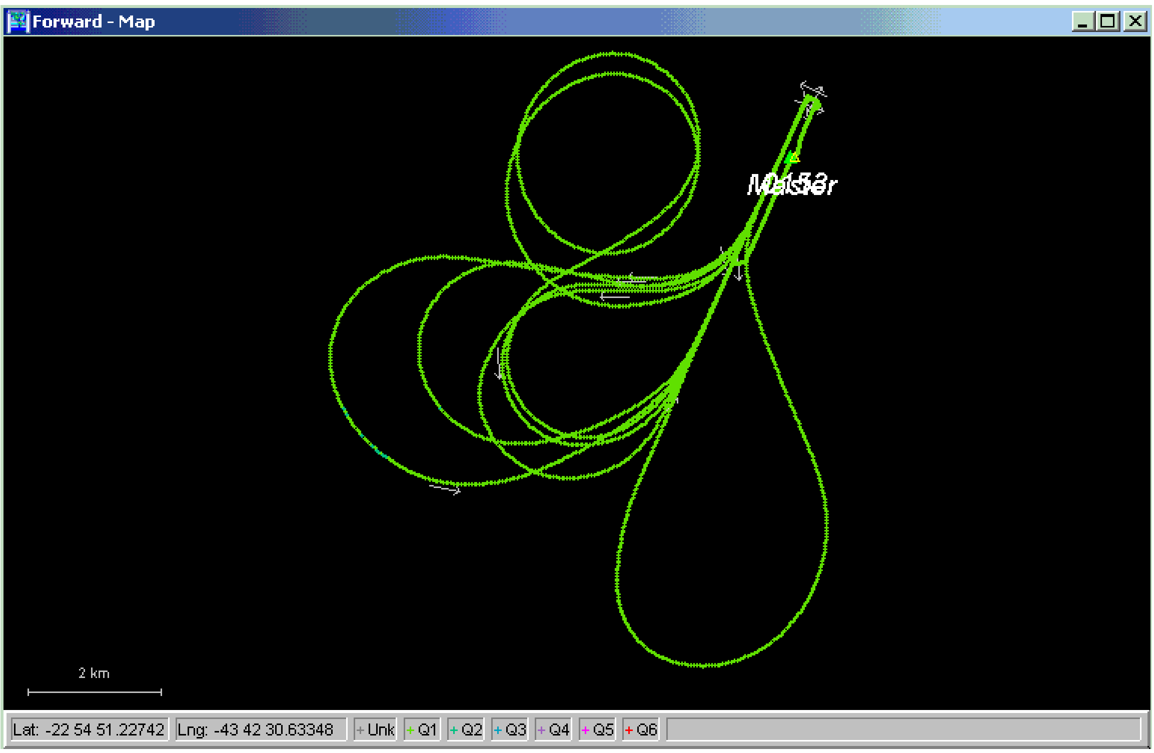

Figure 7: Airborne Trajectory

Results

Restored	Engaged (sec)	Time Used (sec)	AvgSats	Dist (km)	Status
383559	383559.5	3	7	0.06	PASSED
383538.5	383539	3	7	0.061	PASSED
383418.5	383419	3	7	1.36	PASSED
383298.5	383299	3	7	1.8	PASSED
383178.5	383179	3	7	1.44	PASSED
383058.5	383059	3	7	0.91	PASSED
382938.5	382939	3	7	2.38	PASSED
382818.5	382819	6	7	2.14	PASSED
382698.5	382699	3	7	3.76	PASSED
382578.5	382579	3	7	0.9	PASSED
382458.5	382459	3	7	0.91	PASSED
382338.5	382339	3	7	0.26	PASSED
382218.5	382219	60	6.1	1.38	PASSED
382098.5	382099	3	7	0.89	PASSED
381978.5	381979	3	7	2.55	PASSED
381858.5	381859	6	7	5.85	PASSED
381738.5	381739	3	7	0.91	PASSED
381618.5	381619	3	7	1.22	PASSED
381498.5	381499	51	7	3.13	PASSED
381378.5	381379	3	7	0.9	FAILED
381258.5	381259	3	7	0.91	PASSED
381138	381138.5	3	7	0.82	PASSED
380898	381018.5	3	7	0.23	PASSED
380778	380778.5	3	7	0.61	PASSED
380658	380658.5	102	6.4	0.73	PASSED
380418	380538.5	3	7	0.76	PASSED
380228	380298.5	2	6	0.06	PASSED
380178	380178.5	3	6	0.06	PASSED

In the above trials, KAR resolved 82% of the time in 3 seconds or less, and only once did KAR pick a solution greater than 5 centimeters different from the benchmark solution. It is interesting to note that in this test, no seven-satellite solutions took longer than three seconds to resolve. To see if the results found by KAR are in fact correct, they are graphically compared against the solution obtained from the default processing:

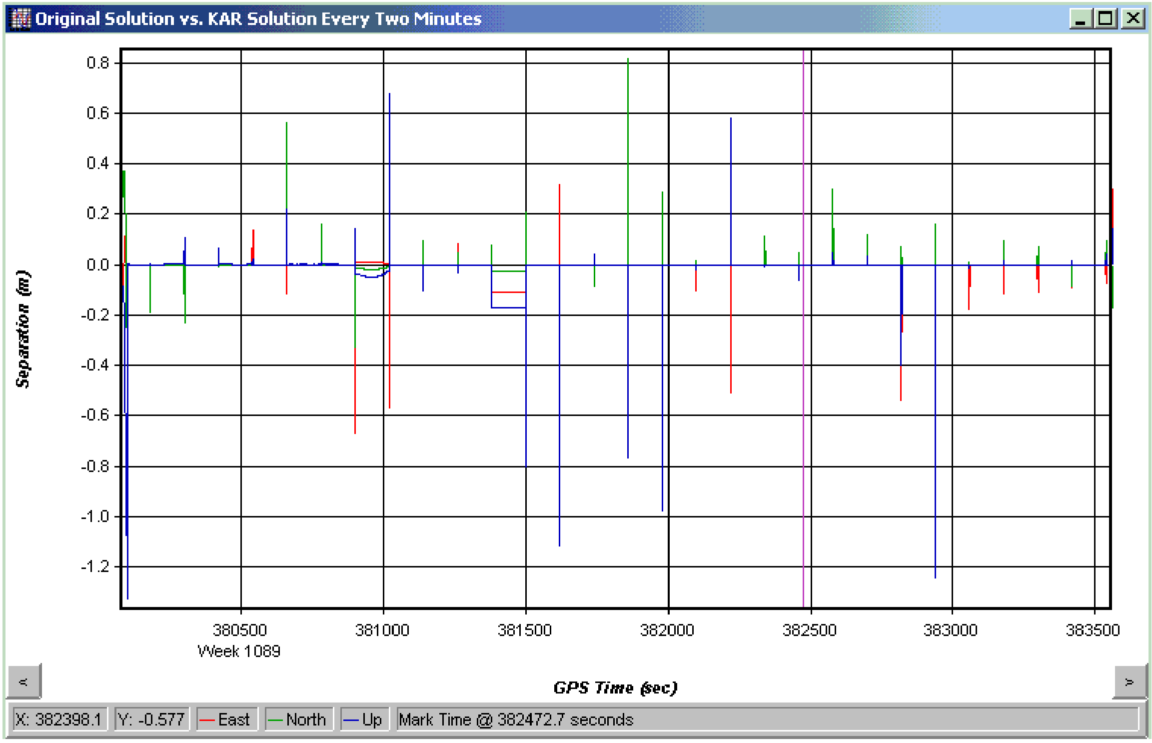

Figure 8: Original Solution vs. KAR solution every two minutes

As previously mentioned, the numerous spikes in the graph indicate induced losses of lock, which causes a brief spike, or disagreement between the two solutions. A single spike shows the successful resolution of KAR, as the solution quickly converges back to the benchmark solution.

Test # 4: Marine Moving Baseline Survey and Azimuth Determination on a Towed Array

Introduction

GrafMov was used in this test to determine the distance between two moving receivers. Both receivers were fixed to an array in tow, therefore fixing the distance between the receivers. Using this procedure, errors are easily identified from the computed distance between the receivers.

Measurement Quality

No losses of lock were induced during processing, as the remote antenna suffered from frequent losses of lock during data collection, as illustrated in the following plot:

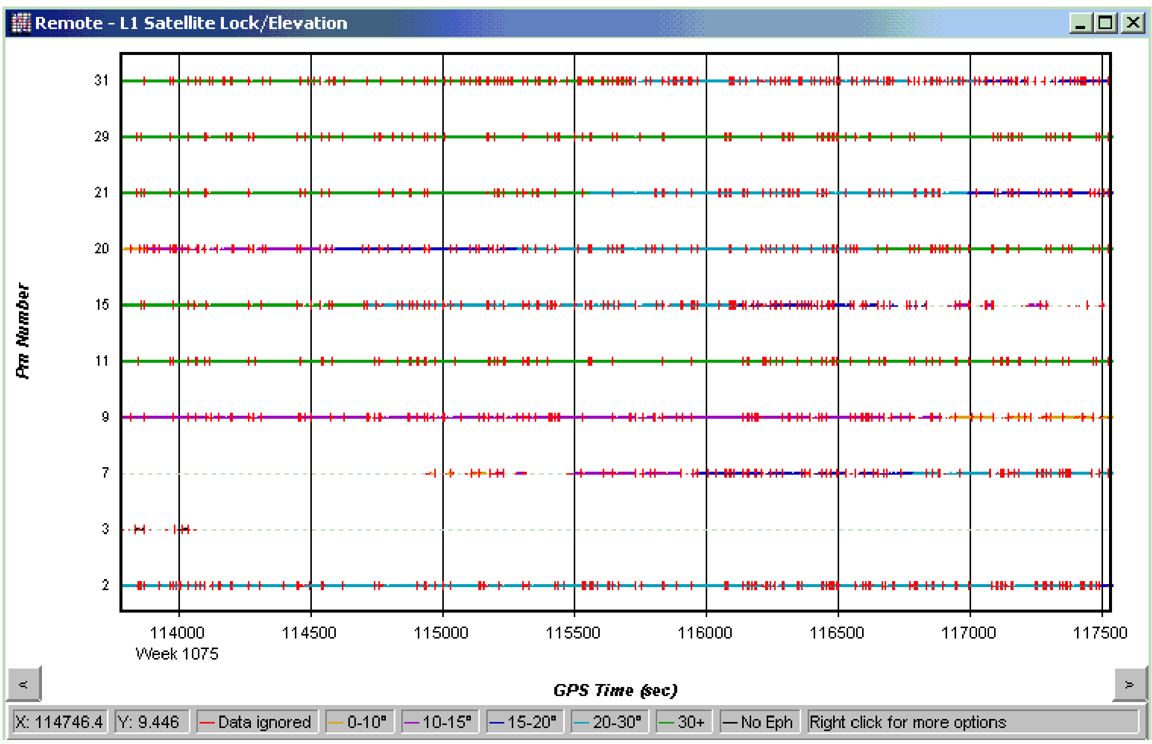

Figure 9: Remote Satellite Lock Plot

The red lines in the above graph indicate unusable data where a loss of lock occurred. Additionally, a plot of the L1 phase RMS shows how noisy the measurements were:

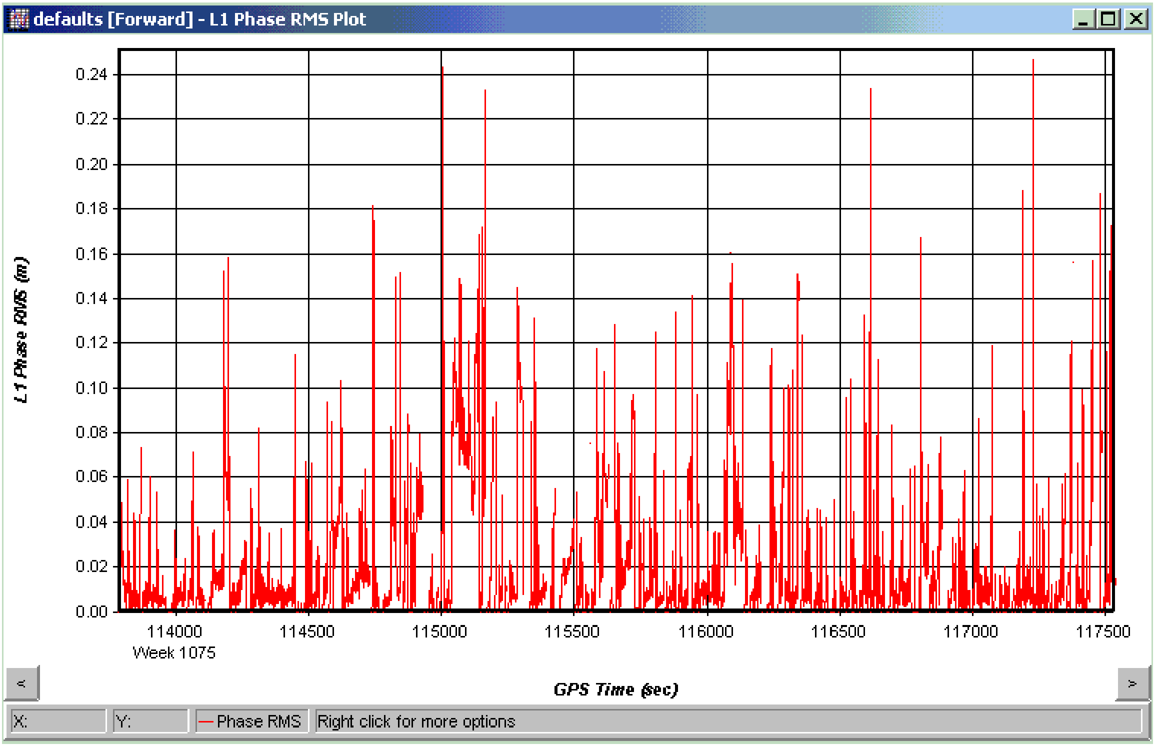

Figure 10: L1 Phase Residuals

Ideally, the phase RMS should plot as white noise with 90-95% of the values below 0.02 m. Quality phase measurements help KAR resolve faster and more reliably.

Results

Restored	Engaged (sec)	TimeUsed (sec)	AvgSats	Dist (m)	Status
113786	113780	43	5.9	4.31	PASSED
113876	113867	9	7	4.35	PASSED
113985	113970	5	5.7	4.38	PASSED
114044	114043	6	6.4	4.36	PASSED
114091	114073	1	6	4.38	PASSED
114206	114104	6	6.7	4.36	PASSED
114227	114226	3	8	4.36	PASSED
114296	114281	13	5.8	4.39	PASSED
114411	114410	3	8	4.35	PASSED
114458	114447	5	5.2	4.37	PASSED
114500	114469	7	6	4.38	PASSED
114578	114553	1	6	8.3	PASSED
114628	114587	2	6	14.28	PASSED
114796	114708	6	5.4	4.36	PASSED
114854	114826	3	5.2	4.36	PASSED
114896	114883	6	5.4	4.35	PASSED
114951	114919	15	5.4	4.35	PASSED
114997	114970	1	8	4.35	PASSED
115016	115015	6	5.6	4.35	PASSED
115034	115033	3	6.5	4.36	PASSED
115047	115046	3	7	4.35	PASSED
115148	115138	3	6	4.35	PASSED
115184	115157	3	5.2	4.35	PASSED
115220	115201	1	6	4.36	PASSED
115254	115243	3	5.5	4.36	PASSED
115550	115338	4	5.6	4.35	PASSED
115573	115560	6	7.6	4.34	PASSED
115585	115584	3	7	3.99	PASSED
115671	115630	29	6.9	4.37	PASSED
115768	115760	5	5.2	4.35	PASSED
115818	115806	4	5.2	4.34	PASSED
115863	115862	6	5.1	4.35	PASSED
115892	115882	3	8.5	4.36	PASSED
115976	115944	1	7.5	4.36	PASSED
116079	116078	3	7.8	4.32	PASSED
116144	116083	3	7.5	4.36	PASSED
116188	116147	5	6.5	4.29	PASSED
116238	116208	1	5.5	4.36	PASSED
116254	116241	6	6	4.35	PASSED
116270	116269	6	6.2	4.35	PASSED
116295	116294	3	6	4.33	PASSED
116318	116310	2	8	4.36	PASSED
116336	116325	2	7.7	4.36	PASSED
116366	116344	3	7.2	4.36	PASSED
116448	116394	2	6	4.38	PASSED
116710	116474	6	5.6	4.37	PASSED

116721	116720	6	6.9	4.36	PASSED
116840	116805	3	7	4.35	PASSED
116864	116863	3	7	4.35	PASSED
116929	116917	7	5.2	4.35	PASSED
116954	116940	2	6	4.35	PASSED
116980	116977	4	5.2	4.37	PASSED
117004	116993	4	6	4.36	PASSED
117164	117075	3	5	6.09	PASSED
117200	117183	9	5.6	4.35	PASSED
117325	117233	1	5.5	4.35	PASSED
117507	117355	6	5.6	4.35	PASSED

Eighty-six percent of the losses of lock were resolved in 6 seconds or less, and 91% of all trials found a solution within 4 cm of the true value. We consider this good given the quality of the measurements.

It should be noted that the table above only reflects the number of epochs used in each independent ambiguity determination. From the phase residual plot in Figure 9, it is clear that some sections of data are not used in the ambiguity resolution process. It is not practical to expect that phase measurements with residuals at the decimetre level can be used for a typical high precision GPS survey. These sections of data are generally rejected by internal GrafNav subroutines and a float ambiguity solution output instead.

Test #5: Static Baselines

This test saw four static baselines of various lengths processed in kinematic mode. KAR was forced to engage by inducing complete losses of lock at regular intervals in the remote observation files.

The advantage of performing such a test is the ability to examine actual errors in the KAR solution (given the coordinates of the remote receiver), as opposed to simply comparing the data to a benchmark solution.

160 m Static Baseline

This test saw the base and the remote separated by approximately 160 meters, and data was processed in three-minute intervals. Three separate trials were collected at different times of the day. Many urban land surveys begin with a close master-remote separation, and thus this experiment has some practical implications.

Results

Trial #1

Engage Time (GPS Seconds)	Seconds Used	Average # of SV's	Latitude Error (cm)	Longitude Error (cm)	Height Error (cm)
495361	3	9	0.87	0.1	0.33
495541	3	11	0.12	0.73	1.45
495721	3	11	0.3	0.05	1.02
495901	3	10	0.63	0.05	0.58
496081	3	10	0	0.45	1.57

Trial #2

Engage Time (GPS Seconds)	Seconds Used	Average # of SV's	Latitude Error (cm)	Longitude Error (cm)	Height Error (cm)
492936	3	9	0.63	0.53	0.61
493111	3	9	0.12	0.6	1.16
493291	3	10	0.18	0.2	0.4
493471	3	10	0.27	0.03	0.13
493651	3	10	0.09	0.25	0.72
493831	3	10	0.3	0.08	1.19
494011	3	10	0.09	0.78	0.48

Trial #3

Engage Time (GPS Seconds)	Seconds Used	Average # of SV's	Latitude Error (cm)	Longitude Error (cm)	Height Error (cm)
496416	3	10	0.33	0.475	1.16
496591	3	9	0.03	0.2	0.37
496771	3	9	0.42	0.225	0.25
496951	3	9	0.36	0.43	0.96
497131	3	9	0.39	0.075	0.96
497311	3	9	0.69	0.18	0.2

This test shows how consistently GrafNav resolves KAR solutions given agreeable observation conditions and a short baseline. These conditions would resemble actual conditions if mission planning were used to conduct the survey at an optimal time. As seen in the above tables, all solutions were resolved in three seconds, and were correct to the centimeter level.

1 km Static Baseline

While observation conditions were similar in this experiment to the 160-meter test, the baseline length was increased to a kilometer in length and losses of lock were induced at two-minute intervals.

Results

Restored	Engaged	Time Used	AvgSats	Dist	Error in	Error in	Error in	Status
	(sec)	(sec)		(m)	Lat. (cm)	Long. (cm)	Height (cm)	
224742	224741	27	6.8	1069.64	0.6	0.175	0.68	PASSED
224857	224856	3	7	1070.26	0.84	0.125	1.12	PASSED
224977	224976	3	8	1070.61	0.03	0.275	0.13	PASSED
225097	225096	3	8	1070.34	0.12	0.075	0.52	PASSED
225218	225217	3	8	1070.15	0.18	0	0.24	PASSED
225338	225337	3	8	1070.16	0.6	0.125	0.01	PASSED
225458	225457	3	8	1070.15	0.3	0.05	0.32	PASSED
225578	225577	3	8	1070.16	0.27	0.075	0.22	PASSED
225698	225697	3	8	1070.16	0.09	0.025	1.15	PASSED
225818	225817	3	8	1070.15	0.81	0.175	0.59	PASSED
225938	225937	3	8	1070.15	0.33	0.25	0.45	PASSED
226058	226057	3	8	1070.15	0.06	0.2	0.34	PASSED
226178	226177	3	8	1070.15	0.09	0.125	0.36	PASSED

All trials were resolved in three seconds with the exception of the first. Upon examination of the raw data, it was found that the receiver was not tracking L2 measurements cleanly at the beginning of the survey, which was the cause of the delayed KAR resolution.

5 km Static Baseline

Like the 1 km baseline, losses of lock were induced in this experiment at two-minute intervals and processing was performed in kinematic mode.

Results

Restored	Engaged	Time Used	AvgSats	Dist	Error in	Error in	Error in	Status
	(sec)	(sec)		(m)	Lat. (cm)	Long. (cm)	Height (cm)	
226375	226374	3	8	4957.02	0.93	0.1	0.06	PASSED
226495	226494	3	8	4956.65	0.96	0.225	0.49	PASSED
226615	226614	3	7	4956.66	1.29	0	0.08	PASSED
226735	226734	3	7	4956.66	1.47	0.275	0.91	PASSED
226855	226854	3	7	4956.66	1.17	0.1	0.5	PASSED
226975	226974	3	7	4956.65	0.72	0.1	0.35	PASSED
227095	227094	3	7	4956.65	0.27	0.275	0.4	PASSED
227214	227213	3	7	4956.67	0.03	0.05	0.41	PASSED
227575	227333	3	8	4956.71	1.83	1.125	1.82	PASSED
227694	227693	3	7	4957.08	0.69	0.575	0.25	PASSED
227814	227813	3	6	4956.61	0.63	0.125	0.96	PASSED
227934	227933	3	6	4956.55	0.51	0.35	0.33	PASSED
228054	228053	3	6	4956.49	1.32	0.25	1.36	PASSED
228174	228173	3	6	4957	0.63	0.1	0.62	PASSED

The excellent results of the above 5 km test show that fast ambiguity resolution can be performed reliably on baselines of this length given good observation conditions.

10.8 km Static Baseline

Like the previous two tests, a complete loss of lock was induced in this data set at two-minute intervals. Unlike previous tests, this data was collected at a 10-second data rate.

Results

Restored	Engaged	Epochs Used	AvgSats	Dist	Error in	Error in	Error in	Status
	(sec)	(sec)		(m)	Lat. (cm)	Long. (cm)	Height (cm)	
427980	427940	1	7	10886.24	1.29	2	2.97	PASSED
428020	428000	1	7	10885.6	0	0.8	3.36	PASSED
428080	428060	1	7	10886.96	0.72	0.875	6.4	PASSED
428200	428120	1	7	10886.83	1.86	0.7	0.36	PASSED
428280	428240	1	7	10885.96	1.89	1.225	0.51	PASSED
428320	428300	2	7	10887.53	3.18	0.175	4.23	PASSED
428500	428360	1	7	10885.04	0.39	0.2	1.13	PASSED
428680	428540	1	7	10885.69	3.51	0.6	5.64	PASSED
428740	428720	1	7	10884.78	3.03	3.075	4.34	PASSED
429100	428760	1	7	10886.47	1.47	2.325	2.67	PASSED
429180	429140	1	7	10884.31	1.2	0.95	0.73	PASSED
429220	429200	1	7	10885.92	0.69	0.725	2.52	PASSED

429280	429260	2	7	10887.02	0.21	0.025	2.3	PASSED
429340	429320	1	7	10887.14	0.51	1.275	0.59	PASSED
429400	429360	2	7	10885.65	1.53	2	1.93	PASSED
429520	429440	1	7	10885.73	1.83	0.5	0.16	PASSED
429580	429560	1	7	10887.46	2.25	0.625	0.48	PASSED
429640	429620	1	7	10886.26	2.52	0.2	0.56	PASSED
429700	429660	2	7	10886.27	1.02	1.525	0.14	PASSED
429880	429740	1	7	10886.39	1.29	1.7	0.38	PASSED
429940	429920	1	8	10886.48	0.54	2.05	0.14	PASSED
430000	429960	2	8	10886.85	1.05	0.525	2.71	PASSED
430080	430040	1	8	10886.23	0.15	1.1	0.66	PASSED
430180	430100	1	8	10887.49	0.99	1.775	2.28	PASSED
430240	430220	1	8	10886.16	0.12	1.5	0.92	PASSED
430300	430260	1	8	10887.54	1.26	2.65	0.31	PASSED
430420	430340	2	8	10886.78	2.01	0.25	1.75	PASSED
430480	430460	1	9	10886.77	1.14	1.575	0.83	PASSED
430540	430520	1	9	10887.14	1.86	0.675	1.31	PASSED
430680	430560	1	9	10885.77	1.71	0.1	1.97	PASSED
430720	430700	1	9	10884.44	2.13	0.425	2.6	PASSED
430780	430760	1	9	10885.87	0.57	0.125	1.1	PASSED
430840	430820	1	9	10886.31	0.33	0.425	0.41	PASSED
430900	430860	2	9	10885.31	0.87	0.1	1.74	PASSED
430980	430940	1	9	10886.78	0.66	0.775	1.97	PASSED
431020	431000	1	9	10886.94	0.99	0.975	0.69	PASSED
431080	431060	1	9	10885.95	3.36	0.825	0.56	PASSED
431140	431120	1	9	10886.3	0.42	0.675	0.66	PASSED
431440	431160	1	9	10887.34	14.16	0.75	2.47	PASSED
431500	431460	1	9	10886.37	0.45	1.7	0.09	PASSED
431620	431540	1	9	10885.71	0.33	2.9	5.61	PASSED
431680	431660	1	9	10886.64	1.29	1.7	1.07	PASSED
431740	431720	1	9	10885.12	0.75	0.05	2.8	PASSED
431800	431760	2	9	10885.24	0.24	1.325	0.6	PASSED
431980	431840	1	9	10886.59	0.15	0.75	1.84	PASSED
432040	432020	1	9	10886.02	0.6	1.525	3.65	PASSED
432100	432060	1	9	10887.3	3.09	1.05	0.1	PASSED
432220	432140	1	9	10886.93	0.57	0.475	4.03	PASSED
432780	432260	1	10	10885.29	0.15	0.925	0.2	PASSED
432820	432800	1	10	10887.04	1.02	0.325	2.96	PASSED
432940	432860	1	10	10885.49	1.59	0.125	1.68	PASSED
433000	432960	2	10	10885.44	1.38	0.4	1.71	PASSED
433140	433080	1	11	10887.14	0.48	0.75	0.3	PASSED
433180	433160	1	11	10885.76	0.48	0.75	0.3	PASSED
433240	433220	1	11	10886.23	0.33	0.65	0.61	PASSED
433300	433260	1	11	10884.55	0.18	2.95	4.27	PASSED
433380	433340	1	11	10884.62	0.6	0.55	0.2	PASSED
433420	433400	1	11	10885.98	0.42	0.075	0.29	PASSED
433780	433460	1	11	10886.77	1.23	0.45	0.63	PASSED
433840	433820	1	11	10886.61	1.11	0.375	1.99	PASSED

433900	433860	1	11	10886.78	1.68	0.05	3.71	PASSED
434020	433940	2	10	10887.75	1.59	0.375	1.19	PASSED
434320	434060	1	10	10886.84	2.67	2.1	3.74	PASSED
434380	434360	2	10	10885.23	0.54	0.275	0.37	PASSED
434440	434420	1	10	10886.06	1.47	0.825	0.74	PASSED
434580	434460	1	10	10886.26	0.45	0.275	1.23	PASSED
434620	434600	1	9	10885.36	0.15	0.375	4.61	PASSED
434680	434660	2	10	10885.67	1.56	0.175	0.06	PASSED
434740	434720	1	9	10886.91	2.43	1	0.79	PASSED
434880	434760	1	9	10885.18	0.87	0.925	1.19	PASSED
434920	434900	1	9	10885.85	0.39	0.45	2.95	PASSED
434980	434960	1	9	10886.48	0.93	0.175	0.73	PASSED
435040	435020	1	9	10887.11	1.02	0.825	0.54	PASSED
435100	435060	1	9	10886.94	0.48	1.425	2.86	PASSED
435280	435140	2	9	10885.43	1.8	0.575	0.61	PASSED
435340	435320	1	9	10885.61	1.62	0.8	0.13	PASSED
435400	435360	1	9	10887.43	1.26	0.175	0.99	PASSED
435480	435440	1	9	10886.95	0.72	0.675	4.67	PASSED
435520	435500	1	9	10884.85	0.54	1.75	0.07	PASSED
435640	435560	1	9	10885.24	0.6	0.975	2.22	PASSED
435700	435660	1	9	10886.33	1.02	0.325	1.06	PASSED
435780	435740	1	9	10885.27	0.15	0.65	1.11	PASSED
435940	435800	1	9	10886.34	1.47	0.2	2.79	PASSED
436080	435960	1	9	10885.18	2.43	0.35	0.81	PASSED
436120	436100	2	9	10885.84	0.03	0.375	3.21	PASSED
436180	436160	2	9	10887.06	0.69	1.9	4.33	PASSED
436300	436220	1	9	10885.19	1.35	1.05	2.42	PASSED
436380	436340	1	9	10885.68	1.38	1.15	3.29	PASSED

These results are encouraging when the length of the baseline distance is considered.

Conclusion

The purpose of these experiments was to test GrafNav's ability to perform fast ambiguity determination (1-5 epochs) under various observation conditions. Effort was taken to examine KAR performance under non-ideal conditions.

Seventeen out of twenty trials in the first experiment succeeded, despite only six satellites being used for the majority of the survey. The first failure occurred when the master and the remote were separated by about 9 km, however KAR did not consistently fail until the master and remote were separated by roughly 14 km. Given six satellites, KAR resolved in three seconds 89% of the time. These results are encouraging, as these observation conditions are not considered optimal for fast kinematic ambiguity resolution and can be easily avoided using mission-planning software.

The second experiment succeeded in resolving kinematic ambiguities in three seconds at every induced loss of lock. This was not surprising, as eight or nine satellites were visible and the master-remote separation never exceeded 600 meters.

The third experiment saw 23 out of 28 trials succeed in three seconds or less. These results were obtained over a maximum master-remote separation of about six kilometers, and seven satellites were observed for the majority of the survey.

The fourth experiment saw only 5 failures out of 57 trials, and eighty-six percent of all trials resolved in 6 seconds or less. These results were obtained despite exceptionally noisy data, which shows the robustness of GrafNav's fast ambiguity resolution under less than ideal conditions.

Four baseline lengths were examined in the fifth experiment. A 100% success rate was observed in the 160 m, the 5 km and the 10 km tests in successfully resolving KAR in 3 epochs. Likewise, the 1 km test saw a success rate of 92%. These results were generally expected as they were conducted under reasonably good observation conditions (7 satellites or more).

Very fast ambiguity determination over distances greater than 10 km is not suggested or encouraged at Waypoint Consulting unless it is necessary to your application. However, the success of the 10.8-kilometer kinematic baseline test shows that it is possible given optimal observation conditions (9 satellites or more), and clean measurements. In that particular trial, KAR was successfully resolved in two epochs or less every time it was engaged.

The centrality of clean phase measurements cannot be overstated in the workings of fast kinematic ambiguity determination algorithms. What follows is an example of an ideal phase measurement:

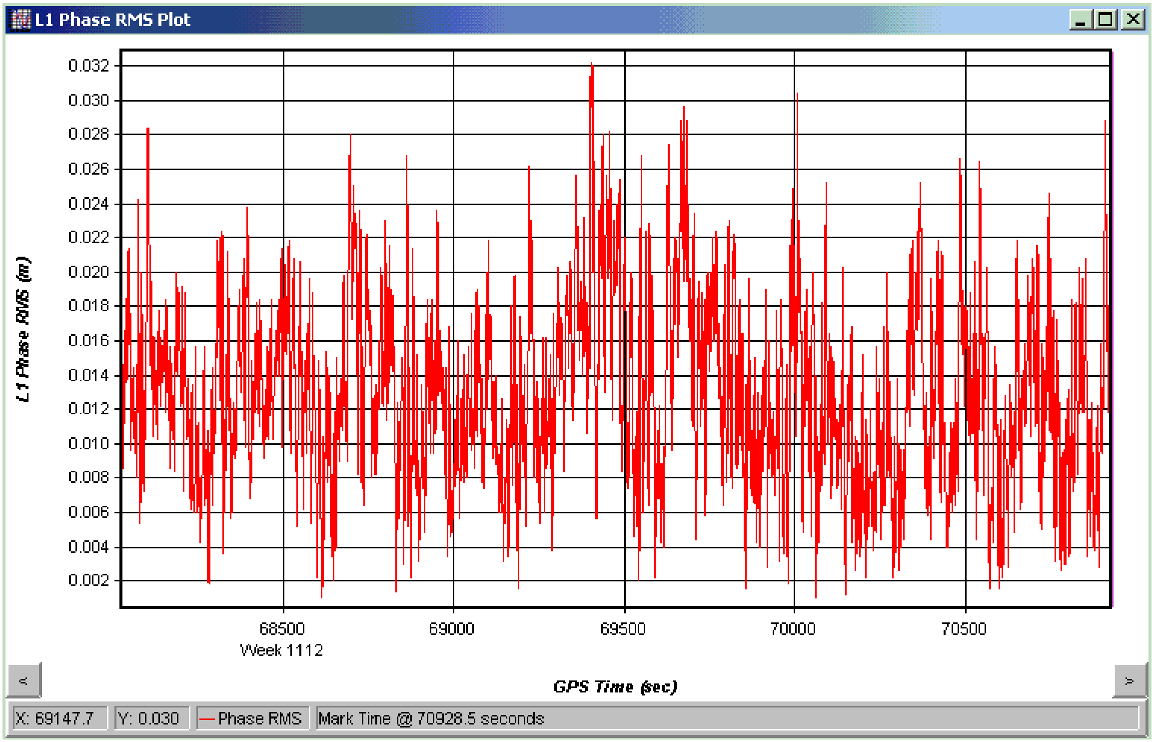

Figure 11: L1 Phase RMS Plot

No ramps or spikes should be evident, and RMS values, as shown, should be at or below the 2 cm mark. The general trend of the plot should show random noise-like properties, with no obvious systematic effects present.

Overall, we feel that very fast on the fly ambiguity resolution can be used reliably for distances below 10 km, given good observation conditions (conservatively estimated at 7 or more satellites) and clean measurements. Achieving suitable observation conditions is generally not a problem, as satellite constellations can be predicted well in advance using mission-planning software. It should be noted, however, that there are a limited number of application for very fast kinematic ambiguity determination. For many GPS applications, it is not of practical consequence whether the ambiguities are determined in a few seconds or a few tens of seconds. For commercial applications it is recommended that conservative field techniques be used wherever possible in order to insure the reliable resolution of the proper phase ambiguities, as some risk is inherent in fast ambiguity resolution.