Ashtech® Instant-RTK™: A Revolutionary Solution for Surveying Professionals

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ABSTRACT

Real-time Kinematic (RTK) GPS positioning is extensively used in precision positioning and surveying applications. RTK involves carrier phase ambiguity resolution, which is qualified based on three main characteristics; namely, accuracy, reliability and time to fix. The state-of-the-art Ashtech® Instant-RTK™ technology serves all these requirements. The integer ambiguities are initialized instantly allowing for immediate centimeter-accuracy positioning for high-speed productivity. Instant-RTK with ambiguities fixed within five seconds at 99.9% reliability is achievable with PDOP less than five, six or more satellites tracked on both L1 and L2 frequencies, baseline length less than seven kilometers and at locations with no severe multipath sources nearby.

This paper presents test results demonstrating the performance of the Ashtech Instant-RTK technology as featured in the Z-Xtreme™ GPS receiver under different operating conditions and over various baseline lengths. Static and kinematic positioning accuracy of 0.005m+1ppm horizontal and 0.010+1ppm vertical, and 0.010+1ppm horizontal and 0.020+2ppm vertical (standard error), respectively, is demonstrated.

INTRODUCTION

The Ashtech Instant-RTK technology is featured in the latest Ashtech Z-Xtreme survey receiver. The Z-Xtreme is a 12-channel, rugged, weatherproof, dual-frequency GPS receiver designed to provide surveyors and machine control professionals with cost-effective, centimeter-accurate positions in a variety of system configurations. Ashtech Z-Xtreme receiver begins with superior satellite electronics coupled with Ashtech patented Z-Tracking™ to deliver highest level of signal available [Gourevitch 1994, Lorenz et al.]. The receiver has a new RF section that is extremely sensitive. A removable Li-ion battery and a flash memory card provide enough capacity to last all day for maximum utility. Each removable battery is equipped with a processor that communicates directly with the receiver to ensure that accurate, up-to-the-minute capacity levels are always available for the user. In addition, the battery weight is reduced by one third, while the effective runtime of the receiver is doubled over older generation receivers.

Components are completely integrated inside a weatherproof, high impact Xenoy housing as shown in Figure 1. It is designed to meet MIL Spec 810E and it is built to withstand rough operating conditions. A small display and keys are used as the interface on the front panel for important functions such as site information entry, checking survey status, and set-up of RTK base stations without the additional cost of a handheld controller. Also, front panel LED's are used to display satellites tracked, data being recorded to memory and radio status. The Z-Xtreme is available with internal UHF and Spread Spectrum radios for real-time data communication.

All these features are topped by the state-of-the-art Ashtech Instant-RTK technology. Instant-RTK allows for centimeter positioning initialization in a fraction of the time required by conventional RTK systems.

Figure 1: Ashtech Z-Xtreme Receiver

HIGHLIGHTS OF ASHTECH INSTANT-RTK TECHNIQUE

Real-time GPS centimeter positioning is achieved with fast estimation of the integer carrier phase ambiguity. Conventionally, on-the-fly ambiguity resolution techniques have been used. These techniques use several data epochs to resolve the carrier phase ambiguities, which once resolved make centimeter solution available. The Ashtech Instant-RTK technology has raised the bar in this regard as it allows for resolving integer ambiguities using as low as a single epoch of data [Han, 1997]. In this case, however, the degrees of freedom are smaller than in the case of on-the-fly resolution, and hence functional and stochastic modeling, ambiguity fixing validation criteria, and outlier detection, identification and adaptation procedures become more critical to the success of the algorithm.

FUNCTIONAL AND STOCHASTIC MODELS

High-quality estimation results using least squares techniques require the correct selection of the functional and stochastic models. The stochastic model depends on the selected observation functional model, hence the need for different stochastic models when different functional models are used. For example, if the ionospheric delay is considered as an unknown parameter in the functional model, the stochastic model will not be affected by the ionospheric bias. Nevertheless, it is not possible to account for all potential biases within the functional model - it may cause the least squares estimation model to be rank-deficient or may lead to an intolerable computation load. Therefore, the definition of the stochastic model becomes more critical and more complicated.

Ashtech Instant-RTK has successfully overcome functional and stochastic modeling problems through empirical knowledge and real-time adaptation procedures, which are used to update the model in real-time based on the changing operating conditions.

INSTANT-RTK VALIDATION CRITERIA

Based on the results of the ambiguity-float solution, a large number of integer ambiguity sets is included in the search region in the estimated ambiguity domain. In principle, the ambiguity set corresponding to the minimum quadratic form of the residuals should be the correct one. Due to the possible presence of un-modeled biases and noise, however, the quadratic form of the residuals is often biased as well. This makes it more difficult to identify candidate solutions.

In the Ashtech Instant-RTK technique, a series of validation criteria is used, in addition to the commonly used ratio test, which heavily depends on the preset reliability level, number of available satellites, observation time and baseline length. The Instant-RTK validation criteria have successfully dropped the requirement for long observation spans and its performance is less dependent on the preset RTK solution reliability.

Outlier Detection, Identification and Adaptation

Detection and identification of outliers is an important algorithmic task to guard against incorrect integer ambiguities. This is even more critical of an issue for instantaneous ambiguity resolution techniques due to the reduced degrees-of-freedom. Ashtech Instant-RTK successfully addresses this issue and the resulting ambiguity resolution success rate is very high despite of the significantly reduced resolution time.

PERFORMANCE TESTS AND RESULTS

A number of static and kinematic tests were conducted to evaluate the performance of Instant-RTK under different operating conditions and at different locations. The sections below summarize the test procedures and results.

POST-PROCESSING STATIC TEST - CALIFORNIA

Test Site Configuration

Five receiver stations (0001 though 0005) were setup at the locations indicated on the map shown in Figure 2. Seven baseline combinations with lengths ranging from 3.15km to 17.88km were used. The data collected at these sites between August 16 and August 25, 2000 was retrieved via the Internet and was processed using the Instant-RTK software.

Twenty-four hour data from three NGS (National Geodetic Survey, USA) control stations (PPT1, PBL1 and MHCB) was used to calculate the reference coordinates of stations 0001 through 0005 using Ashtech Solution™ software. The WGS84 control coordinates of the reference stations and the processed WGS84 reference coordinates of the five test stations are listed in Table 1.

Figure 2: Static Test Receiver Locations in California

Table 1: WGS84 Coordinates of California Test Stations

Site ID	Latitude	95% Err	Longitude	95% Err	Ht (m)	95%Err
PPT1	37° 11’ 13.48250” N	Fixed	122° 23’ 23.76527” W	Fixed	8.397	Fixed
PBL1	37° 51’ 10.97455” N	Fixed	122° 25’ 08.15018” W	Fixed	-7.501	Fixed
MHCB	37° 20’ 29.49949” N	Fixed	121° 38’ 33.22523” W	Fixed	1262.415	Fixed
0001	37° 13’ 52.26612” N	0.009	121° 48’ 03.78682” W	0.012	30.768	0.023
0002	37° 21’ 04.39813” N	0.008	121° 56’ 07.98602” W	0.012	0.251	0.019
0003	37° 25’ 02.60960” N	0.009	121° 51’ 40.38965” W	0.012	26.929	0.020
0004	37° 20’ 08.37790” N	0.008	121° 57’ 55.22752” W	0.012	8.555	0.019
0005	37° 22’ 25.77339” N	0.008	121° 53’ 25.18825” W	0.012	-9.816	0.018

Data Processing and Analysis

Data was collected using Ashtech Z receivers at the five stations (0001 through 0005) and was post-processed using the Ashtech Instant-RTK software. The contour plots of the percentage of successful ambiguity fixing within 300 seconds are shown for different number of satellites (x-axis) over varying baseline lengths (y-axis) in Figure 3 at the three confidence levels 95%, 99% and 99.9%.

The numeric representation of the contour plots is shown in Table 2. Results achieved with five or more satellites and eight or more satellites are shown. Different rows give the results for different baselines - the first column shows the baseline lengths. Different confidence levels are listed in sub-columns.

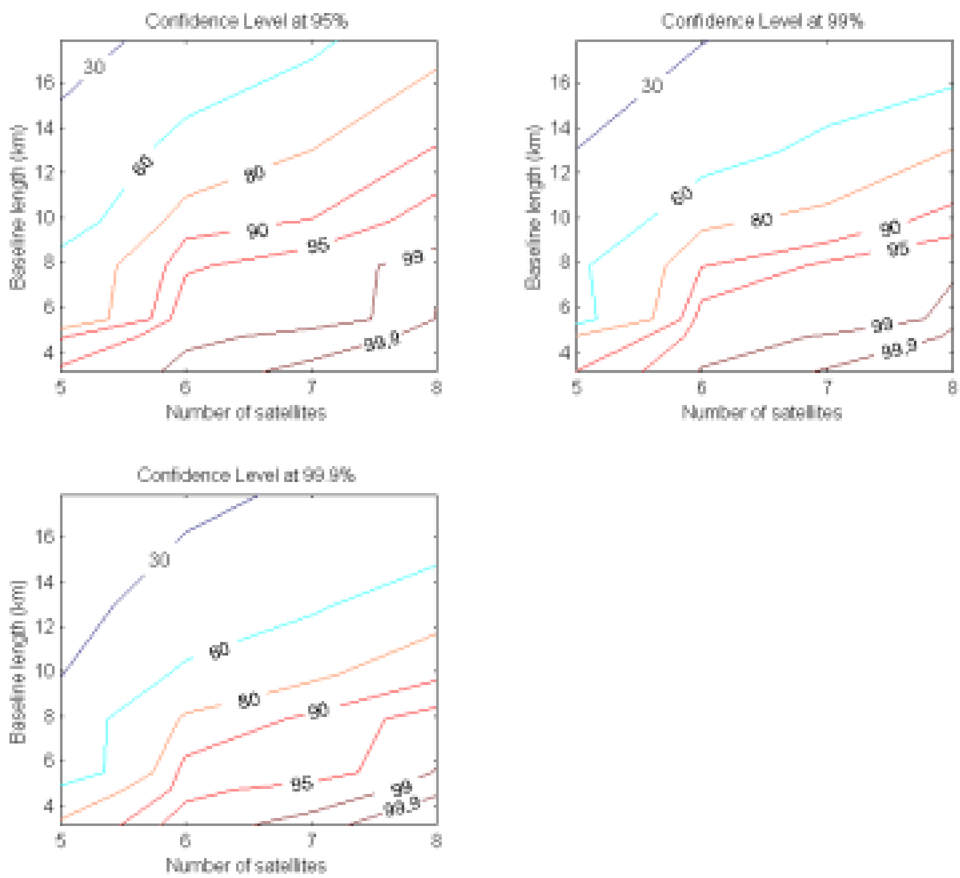

Figure 3: Percentage of Successful Ambiguity Fixing as a function of Number of Satellites and Baseline Length at 95%, 99% and 99.9% Confidence Levels

Table 2: Percentage of Successful Ambiguity Fixing as a Function of Number of Satellites and Baseline Length at 95%, 99% and 99.9% Confidence Levels

Baseline (km)	5 or more satellites			8 or more satellites		
	95%	99%	99.9%	95%	99%	99.9%
3.15	99.667	99.191	98.294	100.00	100.00	100.00
4.73	99.227	98.596	96.617	100.00	99.963	99.880
5.48	97.707	96.179	93.028	99.937	99.820	99.260
7.88	96.017	93.089	88.602	99.784	98.594	97.075
9.86	89.766	82.688	74.988	97.804	93.110	88.988
12.94	75.755	61.648	53.242	90.850	80.642	73.938
17.88	59.493	38.157	31.359	76.311	45.291	35.658

The contour plots shown in Figure 3 and the results shown in Table 2 indicate that, for baseline lengths below eight kilometers, at least 99% of all ambiguity fixes are achieved within 300 seconds using Ashtech Instant-RTK. Baselines longer than eight kilometers experience require longer fixing periods. This is due to ionospheric decorrelation effects, which increase with the baseline length and are further magnified by the increased solar activity at this time in the solar cycle. During high solar activities, ionospheric electron densities increase and vary significantly resulting in varying ionospheric activities at both ends of long baselines.

Focusing on short baseline (less than eight kilometers) and based on 39,214 trials, data analysis confirmed that single-epoch ambiguity fixing is feasible using the Ashtech Instant-RTK technique 99% of the time with eight or more satellites in view at 95% reliability level. Processing the same dataset demonstrated wrong ambiguity fixing only 0.01% of the time and no fixing at all only 0.07% of the time at 95% reliability level. The results for the different reliability levels and different number of satellites are shown in Table 3.

Table 3: Ambiguity Resolution Statistics for Short Baselines - California

	5 or more satellites			8 or more satellites		
	95%	99%	99.9%	95%	99%	99.9%
Number of Trials	111318	111284	111267	39214	39164	39162
% Fix within 300s	98.16	96.78	94.16	99.93	99.60	99.07
% Wrong Fix	0.06	0.02	0.01	0.01	0	0
% No Fix	1.84	3.22	5.84	0.07	0.40	0.93
% Single Epoch Fixing	89.90	85.30	78.93	98.92	97.27	95.51

Shown in Table 3 are the number of trials, percentage of ambiguity fixing within 300 seconds, percentage of wrong ambiguity fixing, percentage of no fixing and percentage of single-epoch ambiguity fixing for baselines shorter than eight kilometers at different confidence levels using 5 or more satellites and 8 or more satellites. The numeric results in Table 3 are represented in the histograms shown in Figure 4 through Figure 6 for the reliability levels 95%, 99% and 99.9%, respectively, for five or more satellites.

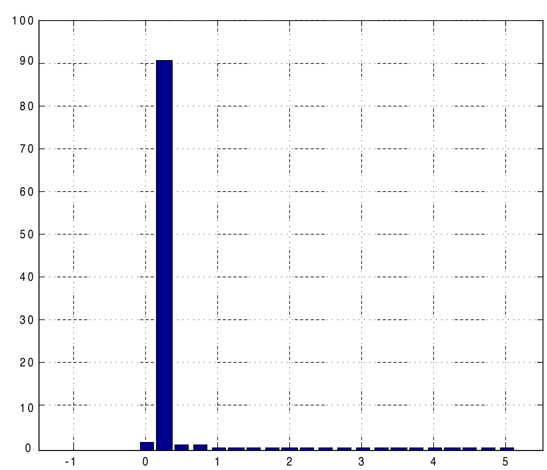

Figure 4: Time to Ambiguity Fix at 95% Confidence Level – California Test

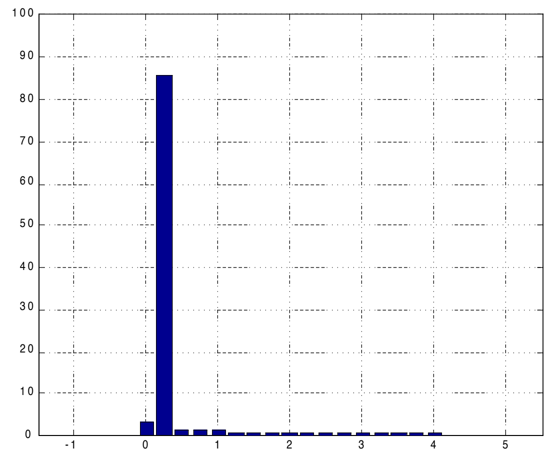

Figure 5: Time to Ambiguity Fix at 99% Confidence Level – California Test

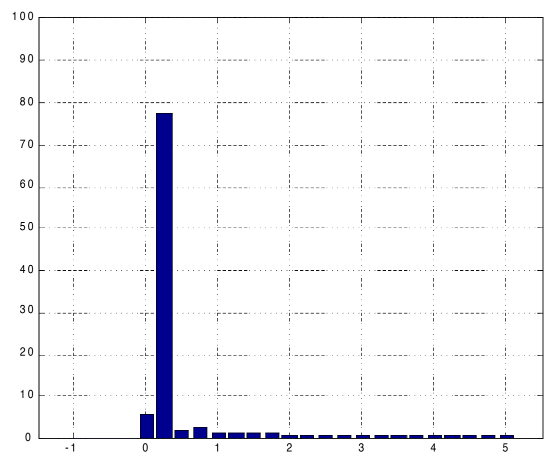

Figure 6: Time to Ambiguity Fix at 99.9% Confidence Level – California Test

FGCS INSTRUMENT WORK GROUP TESTING

From December 4th 2000 to December 7th 2000 the US Federal Geodetic Control Subcommittee (FGCS) conducted tests of the Ashtech Z-Xtreme as well as other Ashtech survey receivers and post processing software. The tests were conducted on stations of the FGCS network, located in the Washington D.C. area. US National Geodetic Survey officials coordinated and observed all the tests. The tests included static, rapid static, post processed kinematic and real-time kinematic runs over well established, and often repeated, baselines used to evaluate manufacturers hardware. Baselines ranged from 100 meters to over 100 kilometers [Magellan Corporation, 2000].

The tests were conducted using the new Ashtech Geodetic IV antenna shown in Figure 7. The Geodetic IV antenna is a rugged, lightweight, dual-frequency antenna that can be used for both static and kinematic surveys. It has an optional large attachable ground plane that was not used in these tests. Electrical phase center testing of the Geodetic IV antenna has been completed at the Corbin, Virginia, National Geodetic Survey testing facility.

Figure 7: Ashtech Geodetic IV Antenna

Also used in the tests was the Ashtech Solutions™ software package for GPS data post-processing. Ashtech Solutions is an easy to use Windows package for processing the field data, export results and generate reports. It is capable of mission planning, processing of static, rapid static and kinematic data, transformations, network adjustments and exporting of data in different formats.

The graph shown in Figure 8 illustrates the satellite and PDOP status at the test site during the observation days.

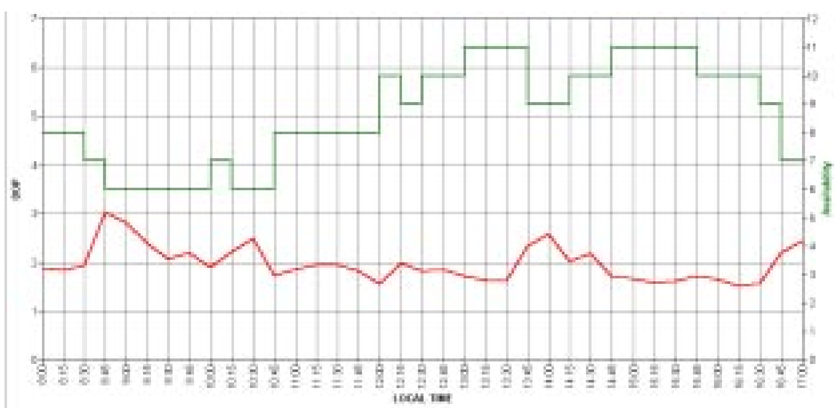

Figure 8: FGCS Test Satellite Visibility and PDOP

Post-Processed Static Results

The chart shown in Figure 9 below shows the repeatability of all static vectors with lengths between zero and 10 km. Repeatability is analyzed by computing the difference of all vectors observed between common points. The difference is presented in the chart as delta East, delta North, and delta Up. A total of 24 repeat vectors were collected during the static portion of this test. In addition to the vectors differences, each chart also includes a line presenting the allowable 1-sigma error and 2-sigma error calculated using the Z-Xtreme receiver accuracy specification of 0.005m+1ppm horizontal and 0.010m+1ppm vertical (standard error).

Analysis of the repeatability charts shows that 77% of the vector component differences are at or below the standard error accuracy specification and 97% fall below the 2-sigma specification.

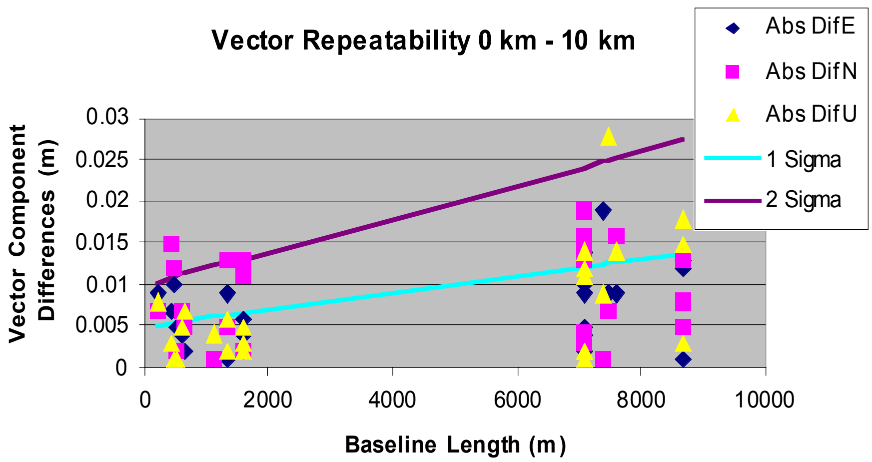

Figure 9: FGCS Static Vector Repeatability for Baseline Lengths 0-10 km

Post-Processed Kinematic Results

On December 6, 2000, a kinematic survey was performed on 14 points ranging from 20 meters to 210 meters from the base station. Each point was observed only once. Of the 14 points, only 9 have known coordinates from previous NGS adjustment. Shown in Table 4 is the difference between the known coordinates and the positions computed using the Z-Xtreme data and Ashtech Solutions™ software for the conducted kinematic survey.

Table 4: Post-Processed Kinematic Results Compared to Known Coordinates

Point ID	Delta Northing (m)	Delta Easting (m)	Delta Height (m)
N102	0.006	0.005	0.003
KIND	0.007	0.005	0.009
KINC	0.004	0.006	0.009
KINB	0.001	0.006	0.006
KINA	0.005	0.003	0.010
KINE	0.005	0.005	0.004
CENA	0.004	0.002	0.015
KINF	0.002	0.003	0.005

Analysis of Table 4 shows a very tight agreement between the published coordinates and the positions post-processed from the kinematic survey. All position differences are well within the system specification of 0.010m+1ppm horizontal and 0.020m+2ppm vertical (standard error).

Real-Time Kinematic (RTK) Results

On December 7, 2000, a real-time kinematic survey was performed on 11 points ranging from 50 m to 7.5 kilometers from a base station. Each point was observed 3 times in succession, with a reset of the initialization between each observation. Shown in Table 5 is the difference between the known coordinates and the Ashtech Z-Xtreme RTK positions.

Table 5: Real-Time Kinematic Results Compared to Known Coordinates

Point ID	Delta Northing (m)	Delta Easting (m)	Delta Height (m)
N102: RTK # 1	0.008	0.001	0.007
N102: RTK # 2	0.011	0.002	0.002
N102: RTK # 3	0.009	0.000	0.007
KIND: RTK # 1	0.011	0.009	0.000
KIND: RTK # 2	0.010	0.009	0.003
KIND: RTK # 3	0.010	0.009	0.004
KINC: RTK # 1	0.005	0.002	0.007
KINC: RTK # 2	0.005	0.003	0.004
KINC: RTK # 3	0.007	0.004	0.004
KINB: RTK # 1	0.004	0.003	0.004
KINB: RTK # 2	0.001	0.002	0.002
KINB: RTK # 3	0.002	0.005	0.006
KINA: RTK # 1	0.008	0.000	0.013
KINA: RTK # 2	0.007	0.000	0.012
KINA: RTK # 3	0.011	0.002	0.018
KINE: RTK # 1	0.007	0.005	0.016
KINE: RTK # 2	0.006	0.005	0.013
KINE: RTK # 3	0.007	0.005	0.015
CENA: RTK # 1	0.001	0.013	0.019
CENA: RTK # 2	0.001	0.016	0.024
CENA: RTK # 3	0.002	0.015	0.009
KINF: RTK # 1	0.004	0.004	0.018
KINF: RTK # 2	0.003	0.002	0.017
KINF: RTK # 3	0.002	0.004	0.021
ORM1: RTK # 1	0.000	0.005	0.031
ORM1: RTK # 2	0.000	0.004	0.030
ORM1: RTK # 3	0.002	0.003	0.030
ANDE: RTK # 1	0.013	0.016	0.006
ANDE: RTK # 2	0.019	0.019	0.009
ANDE: RTK # 3	0.022	0.005	0.006
ATHY: RTK # 1	0.012	0.002	0.016

Examination of Table 5 shows that the published versus computed position comparisons are within the system accuracy specification of 0.010m+1ppm horizontal and 0.020+2ppm vertical (standard error).

CONCLUSIONS

The state-of-the-art Ashtech® Instant-RTK™ technology serves the accuracy, reliability and time to fix requirements of centimeter RTK GPS positioning. The integer ambiguities are initialized instantly allowing for immediate centimeter-accuracy positioning for high-speed productivity. Instant-RTK with ambiguities fixed within five seconds at 99.9% reliability is achievable with PDOP less than five, six or more satellites tracked on both L1 and L2 frequencies, baseline length less than seven kilometers and at locations with no severe multipath sources nearby. Ambiguity fixing using a single epoch of data was successful at least 95% of the time at 99.9% reliability level. Tests conducted in California and Washington D.C. demonstrate the performance of the new Ashtech Z-Xtreme receiver powered with the Ashtech Instant-RTK technology to be better than 0.005m+1ppm horizontal and 0.010+1ppm vertical (standard error) in static, and better than 0.010+1ppm horizontal and 0.020+2ppm vertical (standard error) in kinematic.

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REFERENCES

Gourevitch, S., 1994. Implications of Z Technology for Civilian Positioning. Proceedings of the ION-GPS-94 Meeting, September 1994, Salt Lake City, Utah, pp. 249-255.

Han, S., 1997. Quality Control Issues Relating to Ambiguity Resolution for Real-Time GPS Kinematic Positioning, Journal of Geodesy, 71(6), pp.351-361.

Lorenz et al, US Patent Number 5,134,407

Magellan Corporation, FGCS Test Report, January 2000.

BIOGRAPHICAL NOTES

Dr. Mohamed Abousalem is Director of Marketing. He has a B.Sc. in civil engineering from Alexandria University, Egypt; and M.Sc. and Ph.D. in surveying engineering from The University of Calgary, Canada. Dr. Abousalem has over 11 years of R&D experience in the field of positioning and navigation with special focus on differential GPS positioning. He is the recipient of several national and international research and teaching excellence awards.

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Mr. William Martin is Survey Product Manager. Mr. Martin holds a B.Sc. in Surveying Engineering from the University of Maine. Mr. Martin has over 15 years of experience in the field of GPS surveying and positioning starting with being the operator of the first commercially available GPS receiver, the Macrometer.

Mr. Robert Lemoine is Senior Surveying Products Engineer. Mr. Lemoine has an Associate of Applied Science degree in Forestry and a California Land Surveyor in Training certificate. He has over eighteen years of experience in the land surveying industry and in particular in static control networks, reference station networks, DGPS Hydrographic and RTK surveying.