GPS+GLONASS Surveying

Post-Processed and Real-Time Results

William Martin, *Ashtech Inc.*
Jonathan Ladd, *Ashtech Inc.*

BIOGRAPHIES

Bill Martin is the Marketing Manager for Survey Products at Ashtech Inc., where he has been employed since 1991. Prior to joining Ashtech®, he worked for 6 years in the GPS service industry, including a 2 year period managing operations of a small GPS service firm. His career in GPS began in 1985 at Aero Service, employed as a GPS receiver operator of the first commercially available GPS receiver, the Macrometer. Mr. Martin holds a Bachelors Degree in Surveying Engineering from the University of Maine.

Jon Ladd is Vice President of Marketing at Ashtech Inc. Previously, Jon was Vice President of Engineering at Ashtech and has also served as General Director of Ashtech's Moscow Development Center. Jon has devoted the last 15 years to the use, definition, development and marketing of GPS and GPS+GLONASS™ based geodetic and precision navigation systems. He was a member of the team which developed the first commercial GPS geodetic receiver, the MACROMETER ™, in 1982. Jon holds a BS in Surveying Engineering from the University of Maine and has studied business at Stanford University.

ABSTRACT

There has been a considerable amount of discussion recently regarding the feasibility of combining GPS and the GLObal NAvigation Satellite System (GLONASS) to provide enhanced performance for surveying applications. This has been primarily due to the technical challenges of optimally combining data from the two dissimilar satellite systems.

We will show that GPS+GLONASS technology can indeed deliver significant advantages for surveying. These advantages include dramatic improvements in satellite availability, solution integrity, and operational productivity without sacrificing the measurement accuracy currently achievable with precision GPS systems. We will present real-world field results based on data collected using commercially available equipment which will demonstrate that single-frequency GPS+GLONASS surveying rivals the performance of more expensive dual-frequency GPS systems in many operational environments.

INTRODUCTION

It's been over 15 years since the first experiments determined that signals transmitted by the 24-satellite Global Positioning System (GPS) could be used for sub-centimeter positioning. This gave birth to a revolution in land surveying. Today, satellite based surveying is becoming commonplace. Every passing year brings forth incremental advancements in GPS equipment allowing for further penetration of satellite based surveying into applications where only conventional surveying equipment, i.e. theodolites, EDMs, and levels, were used.

Although considered by some as magic, surveying with GPS does have operational requirements that may limit it's effectiveness in certain applications. The most prominent of these limitations is the requirement for a clear line of sight between the satellites and the antenna of the GPS surveying system. Obstructions reduce the number of satellites available to the system for position computation. In most measurement systems, redundancy of measurements is important to accuracy and integrity. GPS is no different. There is a direct link between the number of satellites observed and positional accuracy, integrity, and overall productivity.

Halfway around the globe, the Russian Space Force has deployed a satellite based positioning very similar to GPS. The planned 24-satellite GLObal NAvigation Satellite System (GLONASS) is currently operational with 15 satellites, providing navigation and positioning data to potential users worldwide.

This leads one to consider the possibilities of augmenting GPS with GLONASS to ultimately produce a 48-satellite system. With such a system, satellite blockage would become less of a limiting factor, allowing for increased measurement redundancy. Unfortunately, there exist significant technological hurdles in combining the two systems into one in order to produce survey grade accuracies. Overcoming these hurdles opens the door to the potential of enhanced performance in surveying applications.

ADVANTAGES OF SATELLITE AVAILABILITY

Ask a surveyor what qualities she/he desires in a precision surveying system. The response includes adjectives like integrity, accuracy, and productivity. For a satellite based surveying system, these qualities are largely dependent on the availability of satellites at the time of data collection.

Productivity

Point occupation times for GPS surveying are based on the amount of time required to determine the correct set of integer phase ambiguities, which facilitates determination of an accurate centimeter-level position. The more data used to determine the ambiguities, i.e. longer observation or more satellites, the greater the integrity of the solution. Users requiring the highest levels of productivity will normally utilize either Rapid Static (post processed) or Kinematic (real-time or post processed) modes of GPS surveying. These modes rely on the ability to quickly determine the correct set of integer ambiguities. As the number of satellites used in the position determination increases, the speed at which these integer ambiguities can be determined increases, enabling the user to spend more time surveying and less time ‘initializing’ the system.

Integrity

The integrity of a surveyed position using a satellite based system depends largely on the number of satellites used in the position computation. This is especially true when the user is seeking the highest levels of productivity, as described in the previous paragraph. High productivity requires determination of the correct set of integer ambiguities as quickly as possible, i.e. using as little data as possible. The risk is the possibility of selecting the wrong set of integer ambiguities, resulting in an inaccurate position determination. Successfully selecting the correct set of ambiguities is directly linked to time and satellite availability. Since the goal is to minimize the time, i.e. increase productivity, the number of available satellites becomes the driving factor. As the number of satellites used in the position determination increases, the likelihood of selecting the incorrect set of integer ambiguities decreases, raising the level of integrity in the system.

Accuracy

The geometry of the observed satellites directly affects the accuracy of the position determination. The various Dilution of Precision (DOP) values are measures of the satellite geometry and can be used to predict attainable accuracy. The lower the DOP value, the more accurate the measurement. Increase the number of satellites observed during data collection and you will find, in most cases, that the geometry improves. Improved geometry lowers DOP values, which in turn increases accuracy.

GPS CONSTELLATION

With 24 GPS satellites, 7 satellites typically are visible 10 degrees or more above the horizon. In mountainous terrain, under tree canopy, among tall buildings, and in open pit mines, the number of visible GPS satellites is reduced. In some cases, blockage can be so severe that the system will fail to determine a position, rendering the area off limits to GPS surveying.

THE GPS+GLONASS ADVANTAGE

Using a combined 48 satellite GPS+GLONASS constellation, a surveyor can expect the number of available satellites to increase to a minimum of 8, an average of 14, and a maximum of 20 above a mask angle of 10 degrees in most parts of the world.

In obstructed areas, the combined system significantly increases the likelihood of satellites being in visible portions of the sky. Locations once deemed off limits to GPS surveying become candidates for GPS+GLONASS.

Clearly, GPS+GLONASS technology has a dramatic effect on satellite availability. The following experiments demonstrate that this increased availability translates into measurable benefits in positional integrity, positional accuracy, and overall productivity.

FIELD RESULTS - POST-PROCESSED RAPID STATIC APPLICATION

This section presents results from data collected with GPS+GLONASS receivers. These data are compared to data collected with GPS only receivers.

On June 11, 1997, a 12 hour observation was performed on a 3.5 km baseline between points TG10 and MG. At point TG10, one antenna was connected to two different receivers, a dual frequency GPS receiver and a single frequency GPS+GLONASS receiver. Point MG had a similar setup.

On June 12, 1997, an identical setup was used to collect a 12 hour observation on a 19 km baseline between points TG10 and BM.

The 3.5 km was processed using all 12 hours of data, holding fixed the known position at TG10. The processing resulted in two solutions for MG, one between the two dual frequency GPS receivers and one between the two single frequency GPS+GLONASS receivers. The 19 km baseline was processed in the same manner.

Table 1 shows the results of this data processing. The position determined for MG and BM are listed twice, one being determined by the GPS receivers and the other being determined by the GPS+GLONASS receivers. The bottom of the table shows the positional difference between the two methods of determining the position. As you can see by the millimeter level differences, there is no adverse effect on the position determination by adding GLONASS to GPS.

Table 1, *Compatibility of GPS and GPS+GLONASS derived positions*

	Point MG 3.5 km baseline	**Point BM 19 km baseline**
Dual Frequency GPS		
Latitude	37 20 30.92594	37 15 08.80695
Longitude	121 59 33.01407	121 50 51.17623
Height	8.780	20.360
Single Frequency GPS+GLONASS		
Latitude	37 20 30.92586	37 15 08.80674
Longitude	121 59 33.01412	121 50 51.17639
Height	8.782	20.364
Delta Position		
Latitude	**0.002 meters**	**-0.006 meters**
Longitude	**-0.001 meters**	**-0.004 meters**
Height	**-0.002 meters**	**-0.004 meters**

For use in later accuracy comparisons, the average of the GPS determined position and the GPS+GLONASS determined position for MG and BM will be considered the known position of these points.

Although the results of the above comparison were interesting, 12 hour observations do not qualify as high productivity. The next step in the analysis was to determine how well the single frequency GPS+GLONASS receivers performed in Rapid Static mode.

For this comparison, the 12 hour GPS and GPS+GLONASS observations on the 3.5 km baseline were segmented into seventy two 10 minute observations. All segments were processed. The GPS segments where processed in two ways; single frequency GPS and dual frequency GPS. The 19 km baseline was segmented in 15 minute observations resulting in 48 separate segments and then processed in the same way.

All processed segments were examined to determine if enough data was present to produce an ambiguities fixed, centimeter level solution. Figure 1 shows the percentage of segments resulting in such a solution.

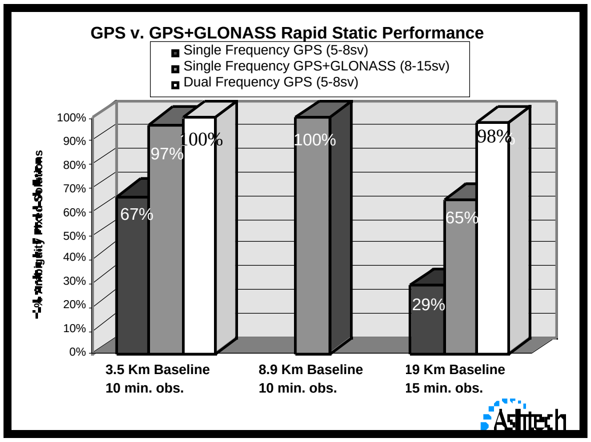

Figure 1, *Comparison of Rapid Static performance between GPS and GPS+GLONASS*

In a separate experiment, 3 hours of GPS+GLONASS data was collected on an 8.9 km baseline. The data was segmented into eighteen 10 minute observations. Each segment was processed. Figure 1 includes the percentage of the 18 segments that produced an ambiguities fixed solution. In this experiment, no dual frequency GPS receiver was used to collect simultaneous data therefore a comparison could not be made. This data is included in the figure to give some idea of the capability of the single frequency GPS+GLONASS system on a medium length baseline.

The following key points can be extracted from figure 1:

- For 'shorter' baselines, single frequency GPS+GLONASS performance approaches that of dual frequency GPS, proving it's viability as a Rapid Static surveying solution.
- For 'longer' baselines, dual frequency GPS clearly outperforms single frequency GPS+GLONASS, probably due to growing systematic errors, e.g. ionosphere.

Next, the accuracy of the 3.5 km and 19 km solutions are compared. The 3.5 km baseline is examined first. As stated earlier, the 12 hour observation was segmented into seventy two 10 minutes segments. Each segment was processed resulting in 72 GPS positions for point MG and 72 GPS+GLONASS positions for point MG. The differences between the known position of point MG (average of 12 hour GPS and GPS+GLONASS solution) and the position determined from each the seventy two 10 minute segments were computed. Figure 4 plots these differences for the dual frequency GPS segments. Figure 5 plots the differences for the single frequency GPS+GLONASS segments. Any segment that did not result in an ambiguities fixed solution was not included in the plots. In this case, only one segment did not fix ambiguities. This was one of the GPS+GLONASS segments. Therefore, figure 2 contains 72 position differences and figure 3 contains 71.

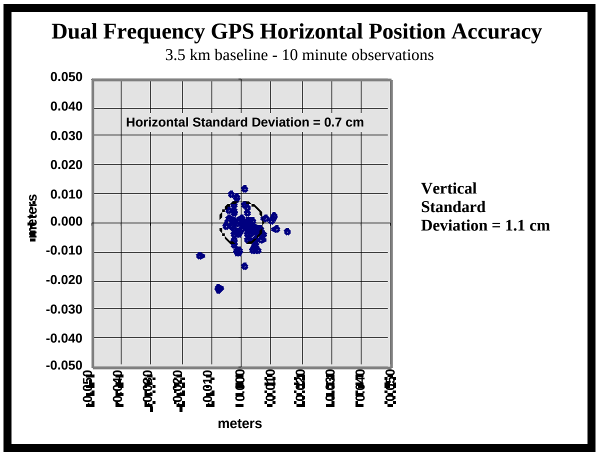

Figure 2, *'Short' baseline position accuracy of Rapid Static observations using dual frequency GPS*

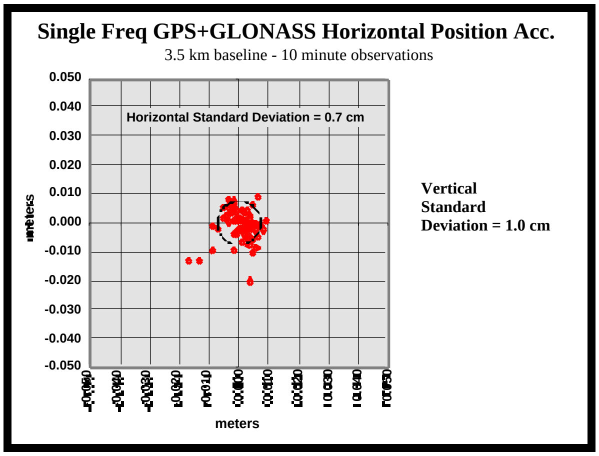

Figure 3, *'Short' baseline position accuracy of Rapid Static observations using single frequency GPS+GLONASS*

The horizontal and vertical standard deviations are listed on each plot. As can be seen from the plots and the listed standard deviations, there is no distinguishable difference in horizontal accuracy between GPS and GPS+GLONASS.

Segmenting the 19 km baseline into 15 minute observations resulted in 48 separate solutions for point BM. Figures 4 and 5 plot the differences between the known position for point BM and the position determined from the 15 minute segments for the GPS and GPS+GLONASS solutions, respectively. Again, those segments not resulting in ambiguities fixed solutions are not plotted. Only one of the dual frequency GPS segments did not fix ambiguities so figure 4 contains 47 separate solutions. Seventeen of the GPS+GLONASS segments did not result in fixed ambiguities therefore figure 5 contains 31 separate solutions.

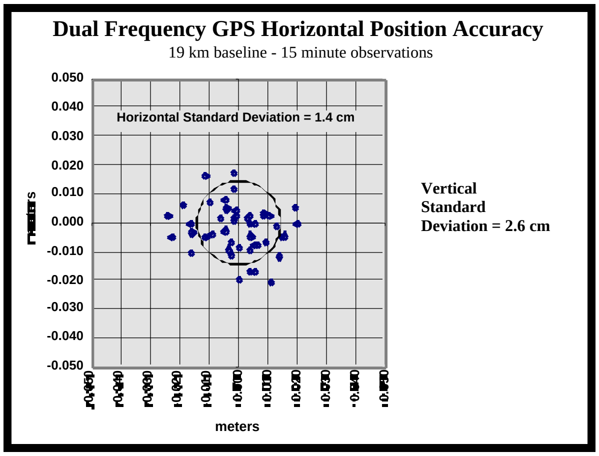

Figure 4, *'Long' baseline position accuracy of Rapid Static observations using dual frequency GPS*

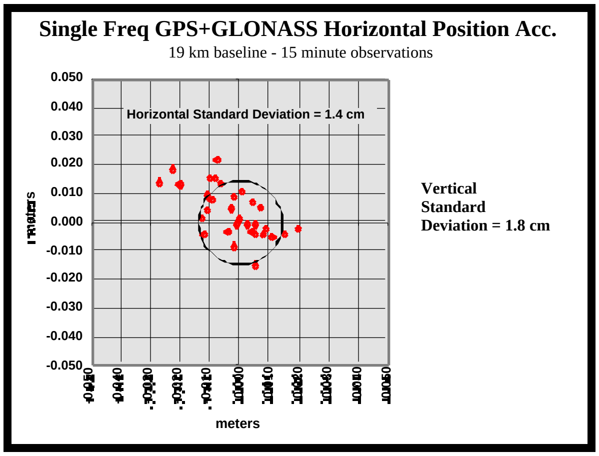

Figure 5, *'Long' baseline position accuracy of Rapid Static observations using single frequency GPS+GLONASS*

The horizontal and vertical standard deviations are again listed on each plot. As in the 3.5 km baseline, the horizontal accuracy between GPS and GPS+GLONASS are identical. The vertical standard deviations, on the other hand, are quite different. The GPS+GLONASS vertical standard deviation seems to be about 30% better. Why? Better geometry.

Figures 6 shows the Horizontal and Vertical DOP values for the GPS satellites for the 12 hour observation currently being analyzed. Figure 7 shows the HDOP and VDOP for the GPS+GLONASS satellites during the same period.

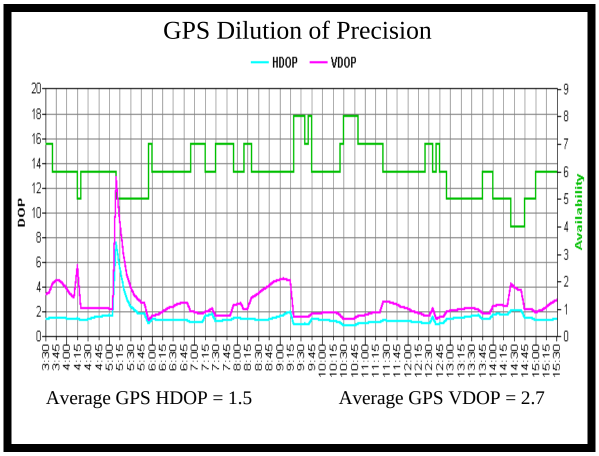

Figure 6, *GPS HDOP and VDOP for test data period*

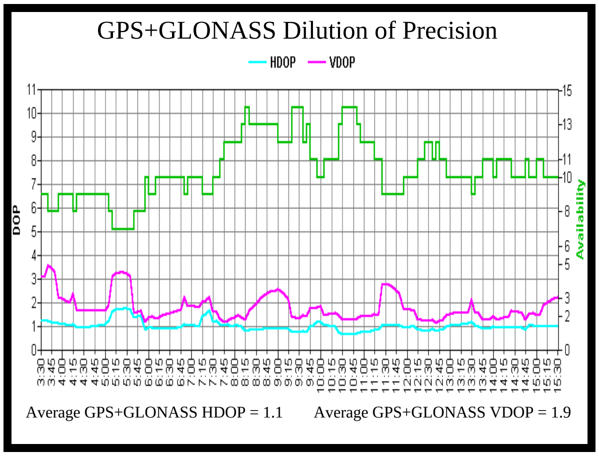

Figure 7, *GPS+GLONASS HDOP and VDOP for test data period*

Listed on each figure is the average HDOP and VDOP. The VDOP for the GPS+GLONASS constellation is approximately 30% better than the VDOP for GPS only, possibly explaining the 30% accuracy improvement. Better geometry results in better accuracy.

Interestingly, the GPS+GLONASS HDOP is also approximately 30% better than the GPS HDOP. Why did this not translate into a better horizontal accuracy for the GPS+GLONASS solutions? This will have to be investigated further.

PRELIMINARY GPS+GLONASS REAL-TIME KINEMATIC RESULTS

The GPS+GLONASS Real-Time Kinematic (GG RTK) results presented here are preliminary. The RTK algorithms have just recently been integrated into the GPS+GLONASS receivers. The focus has been on tuning and testing of the algorithm on short baselines.

During this tuning and testing phase, a significant amount of data has been collected on a well established 7 meter baseline on the roof of the Ashtech building. Following are the compiled results:

GG RTK: 7 meter baseline

- 2 GG-24 receivers running GG RTK algorithm
- Points on Ashtech rooftop test range
- 9921 solutions examined
- 99.6% reliability observed
- 50% of solutions fixed within 2 secs
- 95% of solutions fixed within 97 secs
- Horizontal Standard Deviation = 1 cm

To elaborate on some of the data listed above, 9921 ambiguity fixed solutions were examined. Of these solutions, 99.6% of them correctly fixed ambiguities, 0.4% incorrectly fixed ambiguities resulting in an incorrect solution. This is one area of concentration. The goal is to support 99.9% reliability. Of the 9921 ambiguity fixed solutions, 50% of them fixed ambiguities within 2 seconds after acquiring satellites, 95% fixed ambiguities within 97 secs. These are very fast ambiguity resolution times. Data collected on the same baseline using a dual frequency GPS receiver resulted in a 50% fix time of 35 seconds and a 95% fix time of 125 seconds.

A data set on a slightly longer baseline was collected by one of our beta test sites. Following are the results of their experiment:

GG RTK: 700 meter baseline

- 2 GG-24 receivers running GG RTK algorithm
- Results from a beta site
- 625 solutions examined
- 100% reliability
- 50% of solutions fixed within 2 secs
- Maximum fix time: 138 secs

In more detail, this beta customer collected data on a 700 meter baseline. A total of 625 ambiguities fixed solutions were examined. Of these solutions, 100% fixed ambiguities correctly, none of the 625 solutions were incorrect. Of the 625 solutions, 50% of them fixed ambiguities within 2 seconds after acquiring satellites. Interestingly, this is the same for the 7 meter baseline. The 95% number is not available but the beta site did indicate that the maximum time to fix ambiguities was 138 seconds.

Again, it must be stressed this is preliminary data on the RTK performance. The concentration has been on short baseline testing and tuning of the system. It was hoped that longer baseline results would be available but there is none at this time. Although, there is little doubt that the GG RTK system will function well on longer baselines. This optimism is based partly on the fact that longer baseline data has been analyzed using the GG RTK algorithm running on a PC, prior to integration into the GG-24 receiver. These results look very promising.

CONCLUSION

Our analysis of GPS and GPS+GLONASS data supports the following two points:

1. Single frequency GPS+GLONASS is a viable solution for robust Rapid Static surveying.
2. The added satellite availability inherent in GPS+GLONASS provides improved positional integrity and accuracy, and overall productivity.

Figures 1 clearly shows that single frequency GPS+GLONASS is superior to single frequency GPS in performing Rapid Static surveys. They also show that single frequency GPS+GLONASS is on par with dual frequency GPS in performing Rapid Static surveys on ‘shorter’ baselines. As the baselines get ‘longer’, dual frequency GPS is superior, probably due to the ability to remove systematic errors associated with ionosphere.

Increased productivity was certainly demonstrated when comparing single frequency GPS to single frequency GPS+GLONASS. Comparing single frequency GPS+GLONASS to dual frequency GPS resulted in similar capabilities on ‘shorter’ baselines.

GPS+GLONASS seems to promise improvements in accuracy, mainly due to improved geometry. This proved especially true in the vertical component when analyzing the data used in the experiment. More data will need to be collected to better qualify these potential improvements.

Finally, single frequency GPS+GLONASS promises to be a viable Real-Time Kinematic solution, with the potential of surpassing dual frequency GPS in speed and accuracy on ‘shorter’ baselines.

The enhanced performance demonstrated in these tests can be attributed to one simple fact; more satellites are better. GPS+GLONASS technology simply provides the user today with the advantages of an expanded satellite system.

REFERENCES

William Martin and Frank van Diggelen, “GPS+GLONASS Technology”, *Geomatics Info Magazine*, April 1997, pp. 73-75

S.A. Gourevitch, S.Sila-Novitsky, and F. van Diggelen, “The GG24 Combined GPS+GLONASS Receiver”, *Proceedings of ION GPS-96*, Kansas City, Mo., September, 1996

R.G. Lorenz and S.A. Gourevitch, “The Z-12 Performance Advantage”, *Proceedings of the ION National Technical Meeting*, Anaheim, Ca, January, 1995

J.M. Nolan, I.R. Webster, S.A. Gourevitch, and J.W.Ladd, “Rapid Static Surveying with an Operational GPS System”, , *Proceedings of ION GPS-93*, Salt Lake City, Utah, September, 1993