Comprehensive Navigation Analysis for UAVs Using COTS

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BIOGRAPHY

Tim Craychee is a systems engineer in AGI's Sales department. In this capacity, Tim supports AGI technology users from the national Intelligence Community through on-site customer support; training; and technology demonstrations. Prior to his role on the Sales team, Tim was an application support engineer in AGI's Product Support department for one year, with a focus on T3DCOP. Tim has a B.S. and an M.S. in aerospace engineering, both from The Pennsylvania State University.

ABSTRACT

As Unmanned Aerial Vehicles (UAVs) play an ever-increasing role in intelligence gathering, effective and accurate tools are essential for increasing the probability of overall success and maximizing the benefits of these UAVs. Using commercial off-the-shelf (COTS) software tools, the user now has the ability to analyze collections plans; navigation quality; threats and jammers; and communications links in pre-mission planning, real-time operations, and post-mission analysis. This COTS technology allows the user to use readily available and proven technology as the basis for breakthrough mission analysis techniques.

Details of a mission—aircraft position, orientation, and GPS receiver field-of-view—can be analyzed while considering ground visibility limitations such as terrain obscurations, environmental affects, and duration. Detailed navigation analysis can be calculated modeling all GPS spacecraft parameters as well as end-user hardware including antenna and receiver types. Jammer avoidance and interference can be done in the same software in a 3-D environment depicting threat rings and detection domes. During live operations, the software offers real-time visualization into the aforementioned analysis areas to provide instant insight into the situation as it unfolds. This insight can be used by the warfighter to adapt to new situations and opportunities and to make fast, well-informed decisions. Post-mission, the same type of analysis can be done to compare actual results to the plan.

To illustrate these points, a recorded trial will be examined to show this breakthrough navigation analysis.

INTRODUCTION

Unmanned Autonomous Systems (UASs) are playing an increasing role worldwide in intelligence gathering, particularly in the military where the main systems in development and production are Unmanned Aerial Vehicles (UAVs). Currently, the United States employs approximately 10 UAVs operationally, supporting all branches of the military. Dozens more are under development. Operational UAVs conduct Intelligence, Surveillance, and Reconnaissance (ISR) activities such as looking over the next hill to see what might be waiting or determining targets of opportunity. No matter the vehicle, they all play an important role in protecting the armed forces. UAVs are also under development in the commercial and civil environment, only on a much smaller scale and intended to benefit the day-to-day life of average citizens.

The UAVs developed by commercial and civil markets are following the military's lead conceptually. Those developed by the private sector, however, are smaller in scale and differ functionally. These smaller UAVs support the agricultural industry by, for example, providing an aerial view of plots of farmland, flying over fields to take pictures to aid farmers in planning how best to utilize the ground. Additionally, commercial UASs under development, including UAVs, will have security applications ranging from border protection to scanning oil and gas pipelines for problems such as leaks or terror strikes.

The location of a UAS is determined by the Global Positioning System (GPS) constellation synched with a receiver onboard the vehicle. Vehicle location relates directly to where the sensor on the UAS is pointing; this relationship is due to the possibility of an error occurring in the vehicle position calculation, which could result in incorrect information being gathered by the sensor. Understanding the potential for this error plays a key role in decoding what information was planned to be collected versus what was actually collected. Properly understanding this relationship plays a key role in determining whether or not a second collection to verify findings is needed. Knowing that a problem exists introduces a question of what tools are available to provide the answers of position error.

COTS vs. GOTS

Most users have access to two classifications of tools. The first, a government off-the-shelf (GOTS) tool, is initially paid for by a government entity to meet a particular need and is then owned by that government entity. This tool is then made available to any government worker or contractor who needs it, and they can access the tool for "free" for the life of their project. A major drawback of using a GOTS tool is the distinct potential for additional and future fees. Users of the tool may require training, especially if they have to quickly come up to speed; this training may not be readily available and can also carry a fee, including travel costs. Also, the maker of the tool may charge for capability upgrades or, conversely, they may not do frequent upgrades, hindering its longevity and effectiveness. There may be user group membership available for the tool, but this often carries a fee. An additional concern is that the tool may not be verified and validated when there are many resources available to have such quality testing done. As a result, there is a chance that problems, inconsistencies, and bugs can surface and go unresolved. All of these hidden factors contribute to a GOTS tool being less reliable and cost effective in the long run than their alternative, COTS.

Commercial off-the-shelf (COTS) tools allow for requirement and capability specification distinction which can be expanded upon. COTS technology is often verified and validated by organizations such as The Aerospace Corporation, NASA, and academic and research institutions that test capabilities, verify statements made by the developing company, and thus validate technology utility. COTS technology providers often support users with varied resources such as in-class and online training, which are usually free to the user. The tool is paid for through the sale of licenses and annual maintenance fees. As long as the annual maintenance is up to date, any upgrades are free to the user.

Software upgrades play a major role in the effectiveness of a tool, and the way they are handled make the difference between COTS and GOTS technologies. If a feature is requested by multiple COTS users, it is usually added to the tool at no additional cost. However, prioritization and implementation all depend on the vendor. For a GOTS tool, upgrades are granted per individual user, and costs to perform the upgrade are the user's responsibility. GPS GOTS tool upgrades cost approximately "$13,167 per upgrade."[3] USSTRATCOM found that when it comes to a COTS tool "a single NavTK license is more cost-effective" than a GOTS tool.[3] NavTK (Navigation Tool Kit) is a GPS analytical tool developed by Analytical Graphics, Inc. (AGI), the producers of COTS tools such as STK (Satellite Tool Kit).

CASE STUDY

The GPS Operations Center located at Schriever Air Force Base (AFB) outside Colorado Springs, CO, monitors the GPS constellation. As part of its analysis, the GPSOC states which satellites are currently healthy and determines Position Dilution of Precision (PDOP) predictions and post-assessment reports. This analysis is done in two modes. The prediction calculation mode estimates where the satellites will be, whether or not the satellite will be active, and the estimated clock errors of the satellites. Post-assessment mode uses actual satellite positions (almanacs), satellite status, and the actual clock errors in the constellation. The actual information is based from the data collected from the ground stations all over the world. Schriever AFB publishes its calculations in a graphical format so users can determine where the maximum position error will be over the world in 2 degree resolution and over the Continental United States (CONUS) in 0.5 degree resolution; the same regions also produce information about the PDOP.

The GPSOC recently changed from a GOTS tool to a COTS tool to perform their analysis. The primary tool to do the calculations outlined above is NavTK. Additionally, STK is used in 3-D situational awareness of the GPS constellation. These tools will be used as part of this paper to understand why it is important to analyze the behavior of the GPS constellation and as current examples of effective COTS technology.

EVALUATION

This paper will investigate the effects of the GPS constellation on a UAS vehicle for pre-mission planning and post-mission analysis in both commercial and military environments. In this case, the UAS vehicle is a Buster UAV built by SBC Global. The aircraft was flown during a live exercise from October 29 to October 31, 2006, at Camp Roberts, CA, for the Naval Post Graduate School testing and evaluation program. During the various flights, UAV's position and attitude data was recorded and stored to analyze the overall success of the testing. Along with the vehicle data, information was collected for this paper on the GPS constellation. In all, there are three pieces of information that are crucial to the analysis. The same constellation file was used for both the prediction and post-mission analysis to limit the amount of variables in this analysis.

The first piece of information for the analysis is the almanac file for the GPS constellation, which covers the entire time span of the Buster flight. The second piece is the behavior of the GPS signals. There are two files that specify this behavior. The first is the Prediction Support File (PSF) which is "built by multiple data services to provide an estimate of the standard deviation of GPS signal in space performance."[2] This file will only be used in the prediction analysis where the Performance Assessment File (PAF) is used for real-time and post-mission analysis. The PAF file is "built using data collected and processed by a GPS monitoring network to provide an estimate of actual GPS signal in space performance."[2] Both of these files only apply to vehicles that are managed by the United States Air Force.

The final piece of information with significant impact on the final results is data obtained from the GPS receivers. A receiver from both environments was used in the analysis for prediction and post-mission calculations in order to look at the commercial and military environments. For the purposes of this unclassified paper, the default GPS receivers in NavTK (Table 1) are used. The military default receiver is a 12 channel aviation receiver, and the commercial default receiver is a recreational civilian receiver; the properties for both can be found in Table 1.

One environmental property modeled was the terrain below the Buster flight path. The terrain below the flight path was a one-degree by one-degree DTED (a type of terrain file) level-1 tile (a piece of terrain). However, because of the flight location, it is clear the terrain will not have a significant impact on the analysis being performed. The terrain file is mainly used to illustrate that if this UAV were a ground vehicle, NavTK would be flexible enough to model it.

RESULTS

The Buster flight path will be analyzed looking at a few key specific reports and graphs that allow for GPS constellation behaviors to be understood. The key report and graph used is position error—the magnitude of the East, North, and vertical errors—versus time. This information can be obtained for both the prediction and post-mission calculations. However, depending on the calculations, the interpretation of the results will vary. Since the data can be analyzed more in depth in a post-mission environment. it is possible to further understand why the position error results are being obtained. Another data source that allows for more detailed analysis is the Global User Range Error calculation, a combination of the position error in conjunction with the clock error integrated over the entire globe. For this paper the prediction analysis position error will be evaluated for both a civil receiver and a military receiver. It is important to understand potential GPS constellation reactions so that decisions can be made on optimal times to take action. In this case, since the time period being analyzed is only as long as the flight duration, understanding where the aircraft is can be important for intelligence collection. Figure 1 shows that it is very easy to see fluctuation in the results. Due to the accuracy of the civilian receiver, this is anticipated, and the average fluctuation between two and eight meters is considered standard.

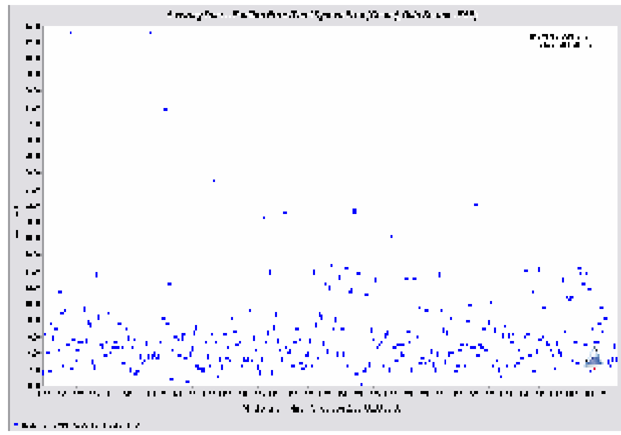

Figure 1: Civil Receiver with Prediction Calculation.

An analyst should look at when optimal image collection times will occur by analyzing when there is the most consistency in the data as well as when lower average position errors occur. From Figure 1, this time would occur from 1,276 minutes after midnight to 1,291 minutes after midnight. The trends that formulate this decision are determined by looking at the grouping and number of minimum position error points. Another trend that supports this decision is that the maximum position error is decreasing during the time period.

Another potential time when optimal image collection could occur would be at the beginning of the flight; however, there are several factors that may limit this as a possibility. First, the data points of 43 to 25 meters of error would need to be investigated further to understand why these points are causing position error. Another factor is the timing and, if this was indeed the optimal collection point, one of two things would need to happen. One possibility is for the vehicle to be launched very close to where the collection would occur. This is especially possible with very small UAVs being flown by individual units for surveillance. Another way to fix timing with a more distant launch point is to fly the plane earlier than planned. This should not have a significant impact on the results because of the altitude of the vehicle. If a ground vehicle was being analyzed then a recalculation would be required due to the interaction between satellite positions and the terrain.

In Figure 2, the military 12 channel receiver is being used for the same flight path. The data clearly shows that there is significantly less fluctuation in the results compared to the civil receiver. This is expected since the GPS constellation was built for the military and therefore the data is more likely to be accurate. Since there are fewer fluctuations in results, polynomial fits can be applied to sections of the results. This is because there is no way to do a constant polynomial fit over the entire time period because of the stepping of the results. Again, this stepping is expected and is due to changes in the satellite position. Changes that cause downward steps in the position error are due to planned updates to specific satellites. Upward steps are caused by satellites with high position error coming into view and satellites with small position error going out of view. Figure 2 shows that the optimal collection time is from 1,273 minutes after midnight to 1,291 minutes after midnight. This collection time has, on average, the minimum amount of position error for the entire flight path. Collection would not require any changes to the flight path since the analysis shows it would be in an optimal position.

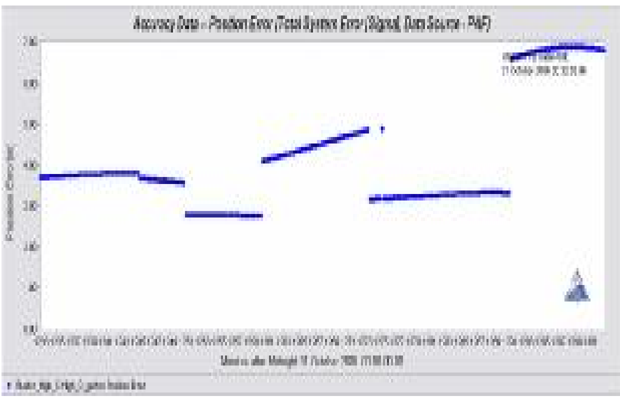

Figure 2: Military 12 Channel Receiver with Prediction Calculation.

After the flight, actual data of the individual satellite positions as well as errors in the system can be assessed. This information can then be analyzed post-mission to understand the constellation behavior; if there are issues with the collections a quick and easy determination of what actually happened can occur. The overall success of the predictions that were made can also be determined, assuming that the aircraft flight path is exactly the same that was used for the prediction and the times match. In reality this will never occur due to the number of variables and forces that come into play.

In Figure 3, the post-mission results of the position error for the civilian receiver are displayed. The first change is the reduction of data fluctuation. This reduction allows for further trends to be deduced and a polynomial fit to be applied. Also, it is important to point out that the over average value of the position error is significantly reduced when compared to that of the prediction values. From Figure 3 it can be seen that the least amount of error occurs from 1,274 minutes after midnight to 1,291 minutes after midnight. The main trend here is that error is not increasing during this time period. The less position error that occurs the better likelihood that correct locations will be imaged, saving time and money. This time period also validates that the analysis of the prediction was correct since the predicted optimal collection times match those obtained from the actual mission data.

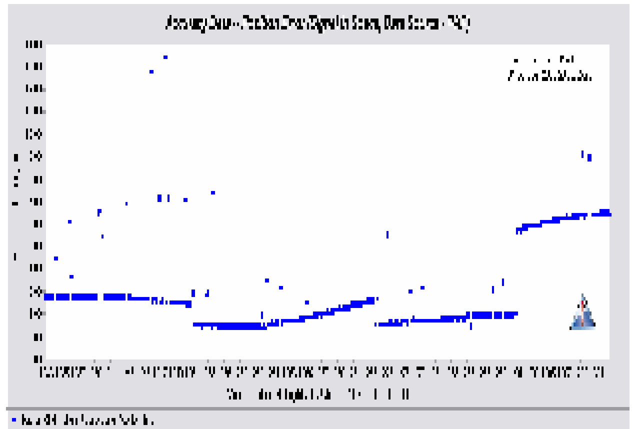

Figure 3: Civil Receiver with Post-Mission Calculation

The military 12 channel post-mission results match those obtained from the prediction values, as seen in Figure 4. Again there is very little fluctuation in the data which is to be expected. One difference between the prediction and the post-mission data is the polynomial fits can be extended for longer periods of time which is true is at the beginning of the flight. In the prediction values there were several predicted increases in the data. Then, after a certain amount of time, the data would be corrected and a step would occur. In the actual data those increases do not occur and a linear fit can be applied.

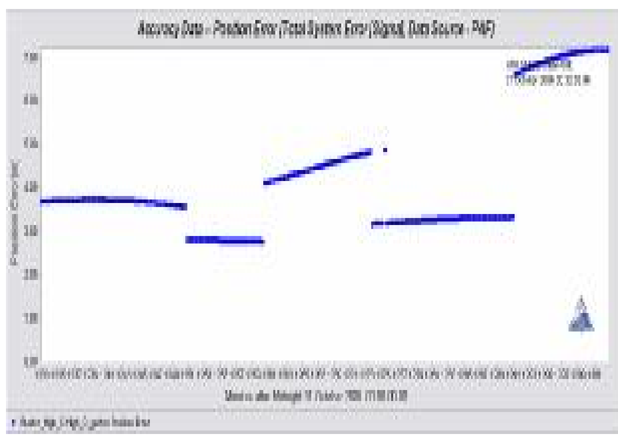

Figure 4: Military 12 Channel Receiver with Post-Mission Calculation.

The optimal image collection times are from 1,273 minutes after midnight to 1,291 minutes after midnight.

As with the civilian receiver, this time period validates the times which were chosen during the pre-mission prediction analysis. Again, this shows that the images collected are going to be the ones expected. This not only saves time and money, but it also plays an important role in intelligence gathering, which leads to accurate decisions being made and often lives being saved.

The last piece of analysis conducted using the post-mission data was the Global User Range Error, seen in Figure 5. This shows how the individual satellites are affecting the position error of the entire system. Note: this figure has been modified to show only those satellites that will have contact to the receiver, whether civil or military, over the Buster's flight path. As the individual satellite error increases or decreases, jumps which were seen in the actual position error reports occur in the overall position error. Range also plays a role so spacecraft directly overhead of the receiver will have more influence on the position error. This is one of the reasons why there is a significant jump in the position error at 1,291 minutes after midnight. For example, in Figure 5, SVN 24 is almost directly overhead during flight path, and the increase at the end of the time period plays a significant role in the position error being reported.

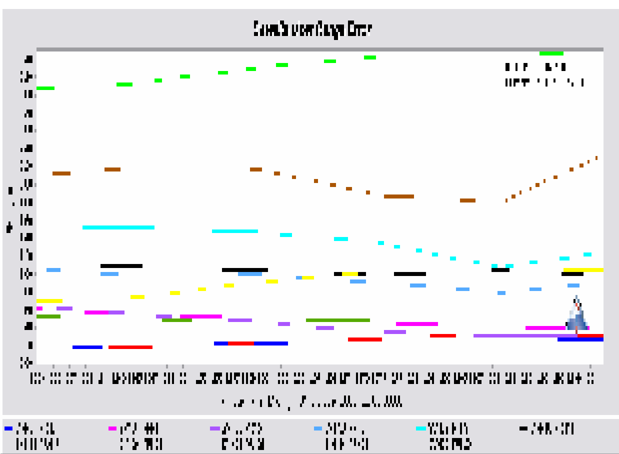

Figure 5: Post-Mission Global User Range Error for Specific Satellites

CONCLUSIONS

The results obtained show that analysis is needed to accurately understand the behavior of the GPS constellation. The need for the analysis is more and more apparent as UASs, particularly UAVs, depend on GPS for navigation. Predicting the behavior allows operators to determine optimal collection times during a mission, and allows them to ensure that key aspects of the mission take place during this time period. Then, after the mission is flown, those same operators can evaluate their predictions so that as future missions arise, they have the expertise to make more informed decisions. With AGI's NavTK technology, operators and analysts can perform these critical duties today.

ACKNOWLEDGMENTS

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1. Daniels, Maj. Chuck., "GPS Help Line: The New GPS Center for Warfighters". *Inside GNSS*. April 2006.
2. Performance Assessment Data, Performance Prediction Data, NavTK Help System.
3. USSTRATCOM/J84, Global Positioning System Modeling Software Evaluation, September 2005.

Table 1: Reciever Properties.

	Civil Recreational	Military 12 Channel
Receiver Type:	SF_CA	DF_PY
Free Space Propagation		
Gain Pre LNA:	-1 dB	-1 dB
Gain LNA:	20 dB	20 dB
Gain Post LNA:	-10 dB	-10 dB
LNA Noise Figure:	3 dB	3 dB
Antenna Equivalent Temp:	75.4 K	75.4 K
LNA Operating Temp:	290 K	290 K
Signal To Noise		
Signal Attenuation:	79%	79%
C/A B Spread:	1.023 MHz	1.023 MHz
P(Y) B Spread:	10.23 MHz	10.23 MHz
Pre Dectection Integration Time:	.02 sec	.02 sec
Max Carrier to Noise:	40 dB	40 dB
Frequency Track		
FLL Filter Order:	1	1
Frequency Loop Filter Noise Bandwidth:	1 Hz	18 Hz
Phase Track		
Phase Loop Filter Noise Bandwidth:	1 Hz	18 Hz
PLL Filter Order:	1	1
Vibration Modulation Frequency:	1 Hz	10 Hz
Oscillator Vibration Sensitivity:	000000001 Parts/G	000000001 Parts/G
Amplitude Vibration Power Function	.006 G^2/Hz	.006 G^2/Hz
Oscillation Snsitivity Frequency		
Upper Boundary:	20 kHz	40 kHz
Lower Boundary:	20 Hz	2 Hz
PLL Track Loss Threshold:	15 deg	45 deg
Allan Deviation	1.00E-11	1.00E-11
G-Sensitivity of the Oscillator	.000006 Delta-f/f per G	.000006 Delta-f/f per G
Code Track		
DLL Discriminator Correlator	Dedicated Early/Late	Dedicated Early/Late
DLL Discriminator Type:	Early/Late	Early/Late
Correlator Spacing:	0.125 Chips	.25 Chips
Code Loop Filter Noise Bandwidth:	18 Hz	15 Hz
DLL Filter Order:	2	1
Carrier Aiding:	Unaided	Aided
Front End Bandwidth:	0 Mhz	40 Mhz
M-Code Upper Null Limit:	0 Mhz	0 Mhz
M-Code Lower Null Limit:	0 Mhz	0 Mhz

Acquisition Threshold:	35 dB	35 dB
Tracking Threshold:	35 dB	35 dB