PPS Positioning in Weak Signal GPS Environments using a TIDGET Sensor

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BIOGRAPHY

Alison Brown is the President and Chief Executive Officer of NAVSYS Corporation, which she founded in 1986. NAVSYS Corporation specializes in developing next generation Global Positioning System (GPS) technology. Dr. Brown has a PhD in Mechanics, Aerospace, and Nuclear Engineering from UCLA, an MS in Aeronautics and Astronautics from MIT, and an MA and BA in Engineering from Cambridge University. She is a fellow of the Institute of Navigation and an Honorary Fellow of Sidney Sussex College, Cambridge.

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ABSTRACT

This paper describes a GPS tracking solution that collects GPS broadband snapshots using NAVSYS' patented TIDGET ("tracking widget") sensor technology and post-processes these snapshots to create a Precise Positioning System (PPS) solution using a SAASM receiver. This approach has the advantages of reducing the size, weight, cost and power of the electronics in the sensor while still producing a SAASM-based solutions for military tracking applications. Since the GPS signals do not have to be processed in real-time, enhanced signal processing algorithms can be applied using the SAASM correlator outputs that allow the digital signals to be optimally reprocessed using network assistance from a GPS base station, maximizing the probability of acquiring the GPS signals in a challenging environment and allowing acquisition at lower signal levels than can be achieved using conventional GPS tracking.

This paper presents test results of this TIDGET-SAASM architecture showing its operation in normal and degraded GPS environments.

INTRODUCTION

Selective Availability Anti Spoof (SAASM) GPS user equipment are required to be used for military operations. These receivers have the advantage of being able to track the broadband P(Y) code signals allowing operation with the GPS Precise Positioning Service (PPS). PPS operation has advantages in terms of anti-jam protection and also provides improved multipath rejection due to the narrower peak of the broadband 10.23 MHz P(Y) code signals compared with the broader correlation peak generated when using the 1.023 MHz C/A code signals.

Current generation SAASM receivers, however, are significantly higher in power than conventional commercial GPS receivers. Also, although the SAASM user equipment are designed to be unclassified when keyed, they still are controlled items. This makes it challenging for SAASM to be deployed for many tracking applications where the GPS user equipment many be unattended and is not under direct control of an operator.

The NAVSYS' TIDGET solution was developed to provide low power tracking solutions using a patented snapshot GPS recording approach[1]. Previously, the TIDGET has been used for applications such as animal tracking[2] or camera photo tagging[3]. The snapshot recording approach has the advantage of allowing the GPS processing to be performed remotely from the sensor when the snapshot device is retrieved. In this paper, we describe how this approach can be applied for processing the GPS snapshots using a SAASM receiver, allowing a PPS positioning solution to be extracted from a tag to track its location using the secure P(Y) code services. Since the PPS position is extracted through post-processing, it is also possible to use enhanced signal processing techniques using data from the SAASM receiver in order to improve the signal/noise ratio and track the GPS signals under degraded conditions.

TIDGET GPS TRACKTAG SENSOR

Figure 1 shows the TIDGET TrackTag configuration, which includes a GPS RF front-end, control circuitry, and built-in flash memory for capturing the TIDGET RF snapshots.

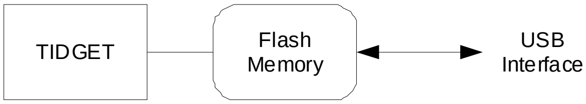

Figure 1 TrackTag TIDGET Configuration

Instead of performing the GPS signal processing internally, the TIDGET device only samples and records the GPS snapshots periodically. While this requires more data to be logged than an actual GPS solution, it significantly reduces the overall power required for the device making this an ideal solution for low-power, long-duration tracking applications.

When the TrackTag unit is recovered and plugged into a USB port, the TIDGET snapshots are uploaded automatically to the server for processing where the TrackTag locations are calculated. A commercial small form factor TrackTag unit is shown in Figure 2 which includes a battery capable of powering the device for two years of data logging.

Figure 2 Commercial TrackTag Unit

The previous commercial TIDGET sensors were designed to capture the C/A code signal spectrum. Using the TIDGET sensor to generate a full PPS solution as well as integration with a SAASM receiver presented unique design constraints on the TIDGET SAASM sensor. Capturing the P(Y) signal requires capturing the 20 MHz GPS bandwidth, and integration with the SAASM receiver requires higher sample rates. Commercial GPS RF front-end integrated circuits are not readily available that cover the full GPS 20 MHz bandwidth. The TIDGET SAASM sensor, therefore, required the development of a new RF/digital design for the RF front-end to sample and record the complete GPS spectrum. This was developed using commercial components.

The TIDGET-SAASM sensor shown in Figure 3 includes a GPS antenna, an RF board, and a Microcontroller Unit (MCU) board and can operate using three AAA batteries. The RF board downconverts the GPS L1 signal to an Intermediate Frequency (IF) and uses an analog to digital converter to transfer single-bit real GPS data to the Flash memory located on MCU board. The MCU stores each snapshot in the 32GB of onboard Flash and provides command and control of the TIDGET unit. The MCU integrates with a real-time clock and alarm that allows the TIDGET to sleep in an ultra-low power mode between snapshots and time-tag each snapshot when it is taken. Operating with snapshots every 30 minutes the TIDGET is capable of storing snapshots and operating for as long as one year on three standard lithium-ion AAA batteries.

Figure 3 TIDGET SAASM Sensor

Both the Digital Antenna Element (DAE) and MCU printed-circuit boards, along with three AAA batteries, are enclosed in a plastic polycarbonate enclosure. The TIDGET may be integrated with either an internal passive GPS antenna or an external active antenna. A USB port on the MCU board provides the user interface to the TIDGET.

TIDGET-SAASM ARCHITECTURE

The TIDGET-SAASM architecture is shown in Figure 4.

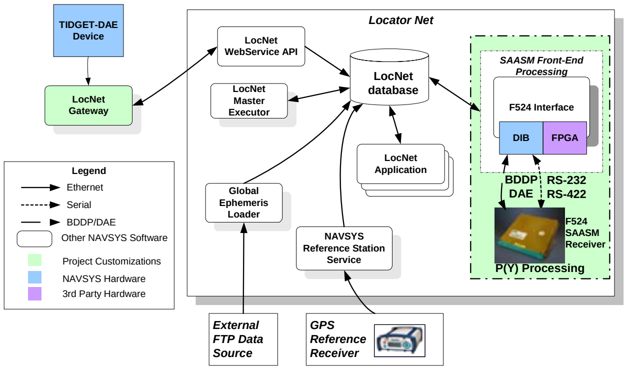

Figure 4 TIDGET-SAASM System Architecture

When a TIDGET-SAASM sensor is retrieved, the data can be uploaded to the TIDGET-SAAM Base Station for processing using a software application loaded onto a local laptop. The TIDGET-SAASM sensor will upload the recorded data through its USB port to the LocatorNet Gateway application which can then connect with the

LocatorNet database in the TIDGET-SAASM Base Station and transfer the recorded data to the base station for processing.

Once the Gateway uploads the recorded snapshots into the LocatorNet database, the TIDGET-SAASM Base Station automatically initiates a data processing sequence to extract the PPS position for each recorded snapshot. To support post-processing of the TIDGET snapshots, the GPS navigation data is also recorded in the LocatorNet database from a reference GPS receiver at the base station. For world-wide tracking operations, GPS navigation data from other reference station sites across the Internet can also be uploaded to the LocatorNet database. The snapshots are queued for processing by the SAASM processor, with the ephemeris data that is needed to initialize the SAASM at the time that each snapshot was recorded.

TIDGET SAASM PROCESSING

The Trimble Force 524 GPS receiver[4] is used to perform the PPS snapshot processing. This receiver includes Trimble's Next Generation SAASM GPS Engine (SGE) 41 and has 24 channels for processing up to 12 satellite L1 and L2 signals. It was selected for the TIDGET-SAASM processing as it also includes a DAE Interface which was designed to allow input of digitized RF GPS signals from external beamforming electronics. This DAE Interface allowed this receiver to be used to process the digital TIDGET snapshots.

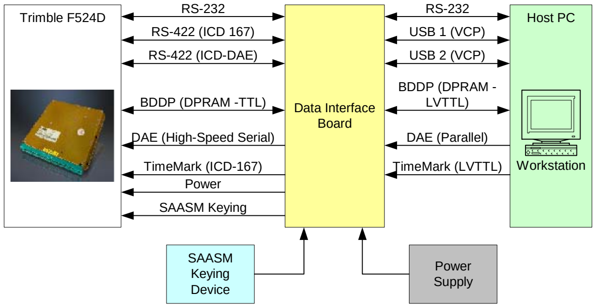

Figure 5 SAASM Interfaces for TIDGET Processing

The SAASM interfaces that are required for processing of the TIDGET data are shown in Figure 5. A Digital Interface Board (DIB) is embedded in the TIDGET-SAASM Base Station PC to handle these interfaces. The SAASM must first be initialized to set its internal time to the time that the snapshot was taken and also must be pre-loaded using an initial estimate of the snapshot location and the GPS ephemeris data in view at that time and location. The initialization of the SAASM receiver is handled through the RS-422 and RS-232 serial interfaces with the SAASM in accordance with the protocol established in ICD-GPS-153C[5]. A 1-pps time mark is used to set the SAASM to the precise time of the snapshot and the digital TIDGET snapshot data is clocked into the DAE high speed serial interface port by the DIB for processing in accordance with ICD-TNL-DAE[6]. The raw correlation outputs for each of the SAASM's 12-channels are output to the DIB through the Bi-Directional Data Port (BDDP) dual-port RAM (DPRAM) interface in accordance with and ICD-TNL-167[7].

The TIDGET SAASM processing sequence is shown in Figure 6. The LocatorNet server can be used to process the initial snapshots to extract the C/A code SPS position as a starting point for the processing. If snapshots are taken periodically, the processing can then be handed over to the SAASM engine for processing the starting and subsequent snapshots by correcting the real-time clock's time mark using the processed PPS results.

Since the GPS snapshots were taken in the past, the SAASM receiver must be initialized to the time and estimated location the snapshot was recorded. A combination of serial input commands, as well as hardware timemark pulses, are used to properly configure the receiver for the snapshot time and approximate position as determined using C/A code tracking. Ephemeris corresponding to the period of the snapshot is input to the SAASM receiver using previously recorded GPS navigation subframe data from the LocatorNet Server. This allow the SAASM to be placed into a "Hot-Start" mode so that Direct P(Y) correlation is performed immediately on the input DAE TIDGET data using the pre-positioning defined by the initial time, location and ephemeris data entered into the SAASM.

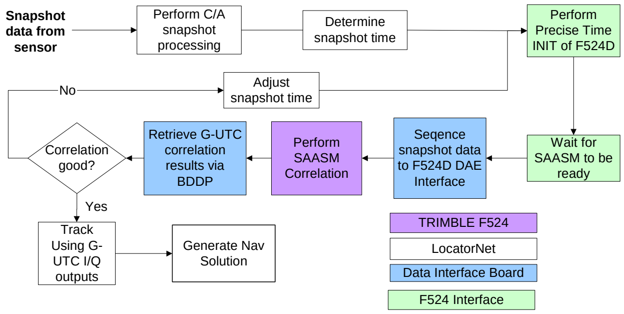

Figure 6 TIDGET SAASM Base Station Software Processing Flow Diagram.

The digital snapshot data is downloaded from the LocatorNet database to memory within the FPGA on the DIB. The snapshot data is then clocked out of the FPGA through a parallel data output to a high-speed serializer/deserializer (SERDES) that inputs the data to the SAASM receiver DAE SERDES input. The SAASM receiver then performs the correlation on the DAE snapshot data and outputs for each of the 12 receiver channels 24 correlator outputs (I and Q) centered at the pre-positioned code phase through the BDDP G-UTC message[7]. These correlation results for the complete snapshot sequence are then uploaded from the DIB to the LocatorNet database for processing to extract the TIDGET PPS pseudo-ranges and calculate the position and precise time for the snapshot location.

SAASM CORRELATION RESULTS

To demonstrate the advantages of the LocatorNet long coherent and non-coherent processing, a comparison was run of the correlation results using G-UTC correlator outputs collected from the TIDGET-SAASM Base Station SAASM processor.

A sample set of 20 msec correlation results that are output from the SAASM under nominal signal conditions are shown in Figure 7, for the first satellite (SV 6). These are aligned with the 50 Hz data bit transitions. This particular satellite was in view with a CN0 of 42 dB-Hz which resulted in a 20 msec SNR of 25 dB.

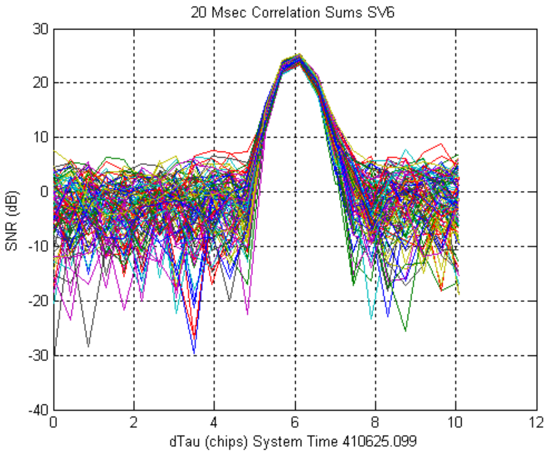

Figure 7 20 msec Accumulation Results (SNR = 25 dB)

In Figure 8, the sum of the 20 msec correlation results are generated over the complete 1.98 seconds (99x20msecs) of correlation data for the same set of correlation data using the following equation.

$$S_{NC} = \sum_{i=1}^{Nnc} I_i^2 + jQ_i^2$$

This results in the same SNR (25 dB) but the noise is much filtered allowing more reliable detection of the correlation peak over the complete set of data.

In Figure 9, the correlation results are shown for a coherent accumulation over the complete snapshot using databits downloaded from the LocatorNet database to remove the 50 Hz databit transitions. An FFT is also used to remove the clock drift.

$$S_C = \left(\sum_{i=1}^{Nc} D_i \left(I_i + jQ_i \right) e^{-j2\pi ft} \right)^2$$

As seen in this plot, the correlation peak improves to 44 dB for this same data set showing how the coherent accumulation, with data bit removal, can further assist in signal detection when the GPS signals are degraded.

It should be noted that the coherent integration period has to be adjusted depending on the tag motion and clock instability during the snapshot recorded interval. Our approach is to perform both coherent and non-coherent integration on the correlation results to detect the best SNR for a particular snapshot. These results show the relative advantages of using the long duration non-coherent and coherent accumulation processing, over a conventional continuous tracking solution.

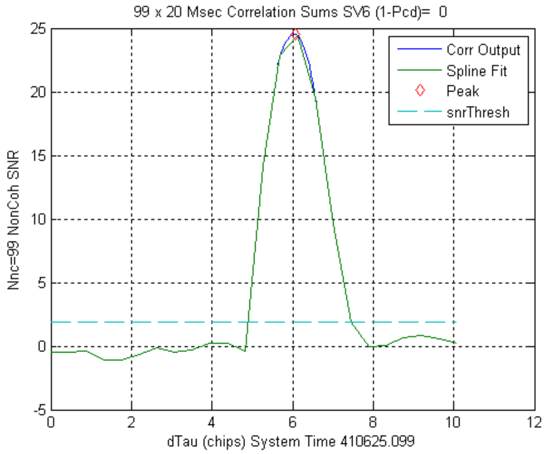

Figure 8 20 msec Non-Coherent Accumulation Results over Complete Snapshot (SNR = 25 dB)

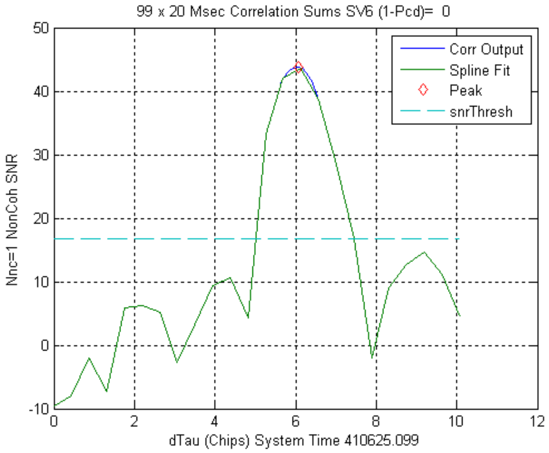

Figure 9 1.98 sec Coherent Accumulation Results over Complete Snapshot (SNR = 44 dB)

WEAK SIGNAL SIMULATOR RESULTS

The weak-signal processing results from the C/A code simulator test indicate the advantages of the LocatorNet long coherent and non-coherent processing of the snapshot data using NAVSYS' Advanced GPS Hybrid Simulator (AGHS)[8]. In this test, the LocatorNet weak signal GPS processing using the TIDGET snapshots was compared to the tracking capability of a NovAtel OEM receiver connected to the same simulator output. The AGHS simulation profile was controlled via a MATLAB Simulink model that cycled the GPS C/A code signal/noise level (CN0) stepping this down and up while snapshots were taken periodically and the NovAtel tracked the simulator signals in real-time. Figure 10 shows the scenario created to compare the LocatorNet processing using C/A code correlation results as compared with the NovAtel receiver real-time tracking.

Over the course of two hours the simulated GPS signal output was reduced from a nominal CN0 of 50 dB-Hz (strong satellite) to a CN0 of 14 dB-Hz signal (extremely weak signal – for example indoors). During the course of testing the NovAtel receiver generally dropped the GPS signals at its tracking threshold of 26 dB-Hz and then reacquired the signal once the signal level increased. As shown in Figure 10, the LocatorNet processing of the TIDGET snapshots allowed tracking of the simulated GPS signals as low as 18 dB-Hz CN0. Also, since the processing required acquisition on the signals for each snapshot, there was no TTFF delay for reacquiring the stronger GPS signals as is generally experienced by a conventional GPS receiver.

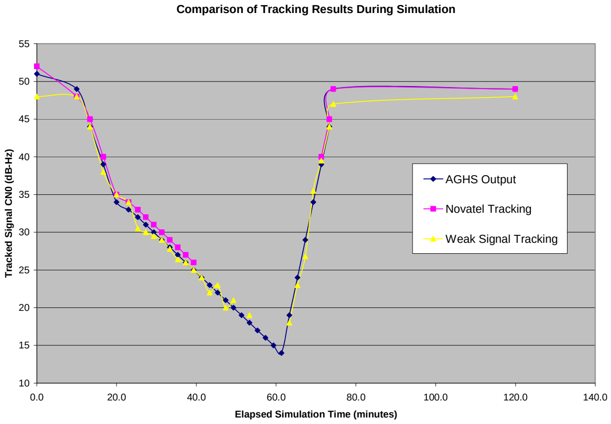

Figure 10 Comparison of Weak Signal Tracking Results for NovAtel (red) and TIDGET (yellow)

As the simulated GPS signal increases from the minimum the TIDGET post-processing once again acquired the signal at 18 dB-Hz CN0. These signal simulator results show that the TIDGET processing achieved an 8 dB tracking improvement over a conventional GPS receiver and allowed operation down to nominal GPS signal levels of -156 dBm.

CONCLUSION

The TIDGET-SAASM system using snapshot data recording at the TIDGET device and post-processing using the TIDGET-SAASM Base Station provides a method for performing PPS positioning of sensors without requiring a SAASM to be deployed in the field. The post-processing of the snapshot data using the TIDGET-SAASM Base Station also allows PPS solutions to be derived when only weak GPS signals are present increasing the availability of the TIDGET sensor positioning results. The TIDGET-SAASM architecture has the following advantages for military tracking applications over using a conventional SAASM receiver in each sensor.

- Lower cost tracking device
- Lower power operation
- No controlled crypto equipment left unattended
- SAASM derived PPS solution generated at base station
- Solution provided under weak signal conditions where a conventional GPS would not have been able to track the GPS signals

ACKNOWLEDGMENTS

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