Urban/Indoor Navigation using Network Assisted GPS

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BIOGRAPHY

Alison Brown is the President and Chief Executive Officer of NAVSYS Corporation. She has a PhD in Mechanics, Aerospace, and Nuclear Engineering from UCLA, an MS in Aeronautics and Astronautics from MIT, and an MA in Engineering from Cambridge University. In 1986, she founded NAVSYS Corporation. Currently, she is a member of the Interagency GPS Executive Board Independent Advisory Team (IGEB IAT), and an Editor of GPS World Magazine. She is an ION Fellow and an Honorary Fellow of Sidney Sussex College, Cambridge.

Mr. Olson is the Chief of the Positioning, Navigation and Timing Branch, Command and Control Directorate (C2D) of the Communications-Electronics Research, Development and Engineering Center (CERDEC), Fort Monmouth, New Jersey. He has a Bachelors of Science, Electrical & Computer Engineering, Clarkson University, and a Masters of Science, Electrical Engineering, Fairleigh Dickinson. His branch has the responsibility for the development, integration, development and evaluation of positioning/navigation (POS/NAV) and command and control (C2) systems for soldier, ground vehicular and airborne platforms. Mr. Olson has been an author/coauthor for numerous articles/papers having been published and presented in professional organization symposium and journals/magazines including the Joint Services Data Exchange, ION Navigation, IEEE PLANS, Command and Control Research and Technology Symposium and the Army Aviation Association in America (Quad A). Mr. Olson is Vice President (Technical Programs) of Quad A. Mr. Olson has also served as a panel member at symposiums and for a number of professional workshops.

ABSTRACT

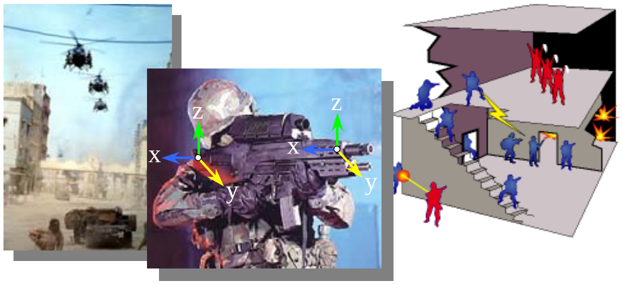
GPS information is an essential element of network centric warfare providing key positioning and timing information in support of communication, positioning and navigation functions. For these networked GPS applications, it is also possible to improve the ability of GPS to operate in challenged environments, such as inside buildings, by using GPS Network Assistance.

This paper describes the Network Assisted (NETASSIST) system architecture and a Software GPS Receiver (SGR) Test Bed that has been developed by NAVSYS Corporation under contract to CERDEC. The SGR is designed to use the positioning, timing and navigation data-aiding from a NETASSIST base station across a secure wireless network. This allows the receiver to apply advanced signal processing algorithms to speed direct P(Y) code acquisition and also allow the receiver to track GPS signals down to significantly lower C/N0 thresholds which enhances the receiver's ability to operate inside buildings.

Test results collected using the NETASSIST SGR Test Bed are also presented in this paper to demonstrate the advantages of this approach for urban operations.

INTRODUCTION

There is an expanding role for positioning and navigation information in the battlefield. Automated high frequency position reporting provides a common blue force deployment picture, adds context to modern digital battlefield systems to enhance: Maneuver and Maneuver Control; Logistics; Intel Data Fusion; Air Defense; Fire Support and Munitions Emplacement. The accuracy and availability of position and motion information directly affects the future Army's C2 and Operational effectiveness.

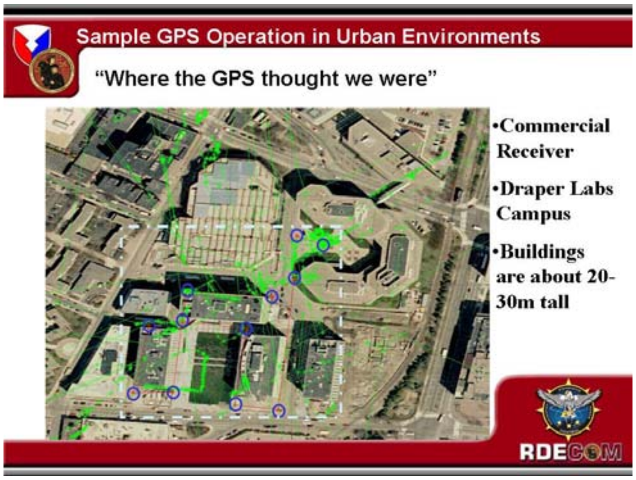


"Engaging enemy forces…at times and places of our choosing. Commanders will accomplish this…using

common situational dominance" (US ARMY, Objective Force White Paper)

A jointly funded 6.2 Advanced Technology Objective-Research (ATO-R) entitled Advanced Positioning/Navigation and Tracking the Future Force, managed by CERDEC and the Simulation and Training Technology Center (STTC) is developing technologies to provide an affordable, reliable, and accurate source of position, orientation, and movement information for soldiers and other platforms operating and training in urban environments or inside buildings. This effort will result in a breadboard demonstration of Position, Location and Tracking technology to demonstrate the capability to precisely locate and track soldiers and platforms for Future Force operations, training and DOT&E. Expected operational benefits for Future Force contributes to: increased maneuver, Situational Awareness, reduction of fratricide, and lethality (coordinating fire effects).

While GPS is a key component of the Advanced Pos/Nav and Tracking solution for the future, it has serious limitations when operating in an urban environment including signal blockage or attenuation, and multipath or signal interference. As an example, Figure 1 shows some test data collected in an urban environment that shows the effect of dropouts and navigation errors when using a commercial GPS receiver. This paper describes the implementation of a Network-Assisted (NETASSIST) GPS approach that improves the ability to operate in an urban environment or track GPS indoors.



Sample GPS Operation in Urban Environments

"Where the GPS thought we were"

- Commercial Receiver
- Draper Labs Campus
- Buildings are about 20-30m tall

Figure 1 Sample GPS Operation in an Urban Environment (Blue - Truth Location; Green – Reported Track)

OVERVIEW OF NETWORK-ASSISTED GPS

With Network-Assisted GPS, a datalink provides a GPS receiver with information from a base station or another user to overcome uncertainties associated with signal acquisition and apply data-aiding to enhance the receiver's ability to track low power GPS signals. This capability greatly bolsters GPS reception in low signal and degraded signal environments (e.g., tunnels, buildings, under tree canopy, and within proximity to RF transmissions). Further, by the virtue of the ability to acquire satellites in degraded environments, continuous tracking is no longer required, and the result is that this technology actually enables low power operation for handheld and PDA-type applications.

With the NETASSIST system architecture delivered to CERDEC, shown in Figure 2, the NETASSIST Base Station provides the following sources of information to other GPS units operating on the network.

1) Time Initialization. This is used to set time on the remote units using Network Time Protocol (NTP). This reduces the time needed for direct P(Y) code search and acquisition.
2) GPS Navigation Data aiding. This provides the GPS ephemeris and almanac data to the remote units, reducing their Time to First Fix (TTFF) and allowing operation during weak signal conditions.
3) Differential GPS (DGPS) Corrections. This improves the accuracy of the navigation solution in the remote units.

The NETASSIST Base Station, shown in Figure 3, consists of a Laptop Computer, a GPS Reference Receiver, and a Harris SecNet-11 802.11b WLAN Point, which allows the network to operate at the Secret classified level.

The NETASSIST remote units, shown in Figure 4, are based on a Software Defined Radio (SDR) design where the C/A and P(Y) code GPS signals are implemented using reprogrammable software and firmware functions. This Software GPS Receiver (SGR) design is described in the following section and was designed to include the following Network-Assisted capabilities for enhancing operation in an urban environment.

- Network Assisted Time Initialization
- Network Assisted NAV Data Aiding
- Fast Direct P(Y) Acquisition
- Low Signal Power Tracking for in-door operation

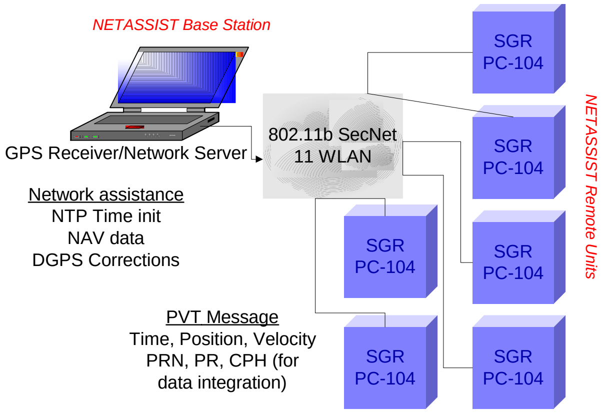


Figure 2 NETASSIST SGR Test Bed System Architecture

Figure 3 NETASSIST Base Station

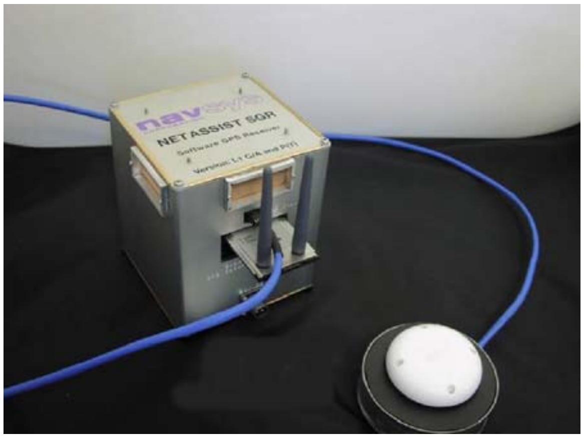


Figure 4 PC/104 Software GPS Receiver

PC/104 SOFTWARE GPS RECEIVER (SGR)

The SGR architecture used to demonstrate the Network-Assisted GPS advantages is shown in Figure 5. This particular SGR implementation included 4 channels of C/A code tracking and 4 channels of P(Y) code tracking. The current generation SGR design has now been expanded to include 6-channels C/A and 6-channels of P(Y) simultaneous tracking.

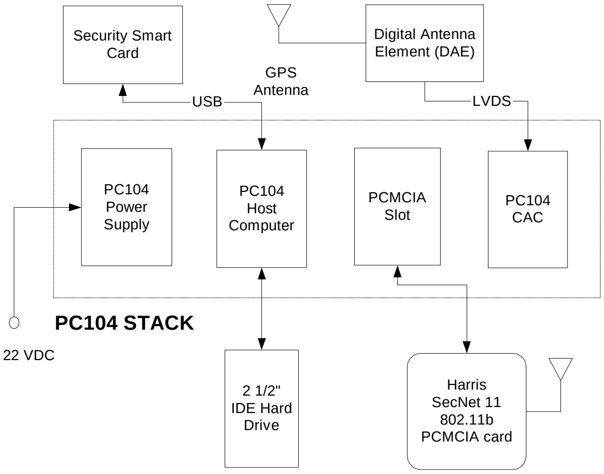


Figure 5 Software GPS Receiver Architecture

The GPS Digital Antenna Element (DAE) depicted in Figure 6 down-converts and samples the GPS RF signals and provides a serial digital output to the Field Programmable Gate Array (FPGA) card on the test bed which performs GPS code generation and correlation. The GPS DAE uses all commercial components but is capable of receiving the complete GPS 20 MHz bandwidth and uses a 40 MHz sample clock for the A/D conversion. The DAE can be installed with the antenna for ease of integration and a digital Low Voltage Differential Signal (LVDS) is used to output the digitized GPS signal samples.

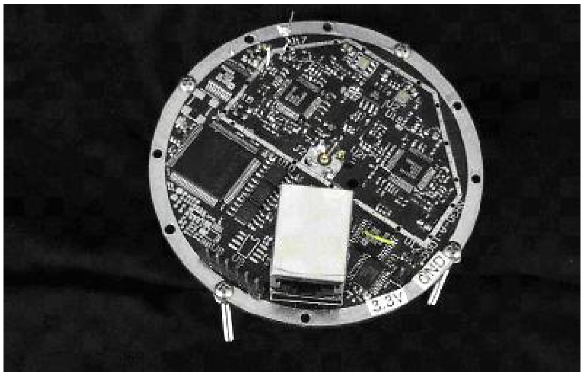


Figure 6 GPS Digital Antenna Element

PC/104-Plus FPGA card developed at NAVSYS interfaces with the DAE and can support high speed digital signal processing. The card, shown in Figure 7, contains three Xilinx Spartan-3 FPGAs used to perform high-speed correlations and firmware-based signal processing. Bit-files loaded on the FPGAs are developed using VHDL.

Figure 7 PC/104-Plus FPGA Card

The FPGA card contains a PCI bus chip to provide high speed interfacing between the FPGAs and the processor card over the PC/104-Plus PCI bus. The PCI bus chip also provides interrupt and DMA capabilities.

A PC/104 Pentium-M based processor board interfaces with the FPGA card to provide higher level processing and user interface control.

The GPS security functions were implemented using software implemented in a Smart Card. When the Smart Card was removed from the stack, the SGR operates in C/A code mode only. When the Smart Card is installed in the stack, then P(Y) code acquisition and tracking could also be performed.

LOW POWER SIGNAL TRACKING

Low power GPS signal tracking techniques have been developed that improve the C/N0 tracking threshold by extending the coherent integration period (see Figure 8[1]). The best performance has previously been achieved using coherent integration intervals aligned with the GPS navigation data bits (20 msec) rather than the 1-msec C/A code repeat interval. A hard problem though is dealing with a mix of strong and weak GPS signals simultaneously, for example, when a single satellite can be viewed through a window or strong multipath reflection. When this occurs, false locks can occur due to the auto-correlation of a C/A code with itself, or cross-correlation between different C/A codes, which gives only 24 dB of signal rejection. This means that if a higher power signal is present, the ability to detect a lower power signal is dominated by the cross-correlation threshold. For example, in a building one or more satellites may be received at near the nominal power level (~48 dB-Hz), either being visible through a window or reflecting off a convenient surface (multipath). This means that the weakest C/A code signal that could be detected without "false-locking" on the cross-correlation with the stronger C/A code signal is only 24 dB-Hz. The military has a major advantage in tracking low power GPS signals in that the P(Y) code does not have this weak cross-correlation problem. This allows detection of weak GPS signals even in the presence of stronger GPS signals avoiding the cross-correlation problem that commercial receivers can experience.

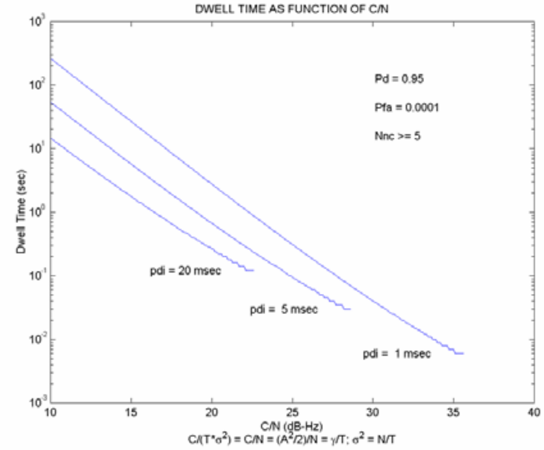


Figure 8 Increased Sensitivity for Low C/N0 Detection [1]

NETWORK-ASSISTED GPS TESTING

The urban and indoor NETASSIST testing was performed using the man-portable test bed configuration shown in Figure 9. The PC/104 SGR stack was placed in a backpack and the GPS antenna was mounted on a helmet.

The navigation accuracy experienced during the testing is shown in Figure 10, with and without the DGPS corrections provided by the NETASSIST base station. As long as we had sufficient satellites to navigate, the DGPS performance was within a few meters.

The TTFF was measured for acquisition using C/A code to P(Y) code handover and also for Direct P(Y) code handover. The NTP time initialization was able to set the time on the remote units to within a few msecs which significantly speeded the time for performing Direct P(Y) code acquisition.

The low power tracking capability was demonstrated by tracking the GPS satellites and observing when the signal dropout occurs. Figure 11 shows that with the Network-Assistance, GPS satellites could be tracked to 24 dB-Hz. Testing was also conducted to observe the SGR capability to track the secure P(Y) code GPS signals inside buildings. Figure 12 shows an example of test data collected by walking through NAVSYS' facilities. This shows that the GPS signals could be tracked down to 21 dB-Hz.

Figure 9 Man-Portable Test Bed Configuration

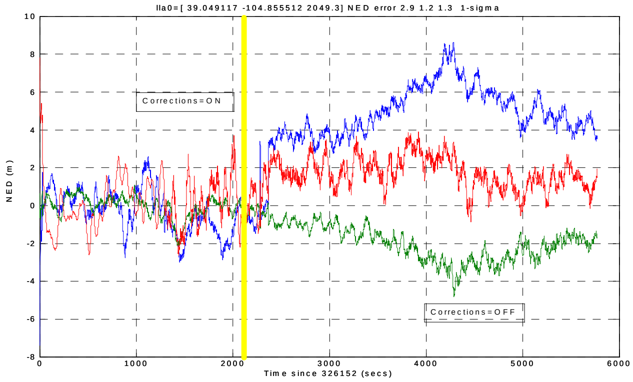


Figure 10 DGPS Correction Accuracy

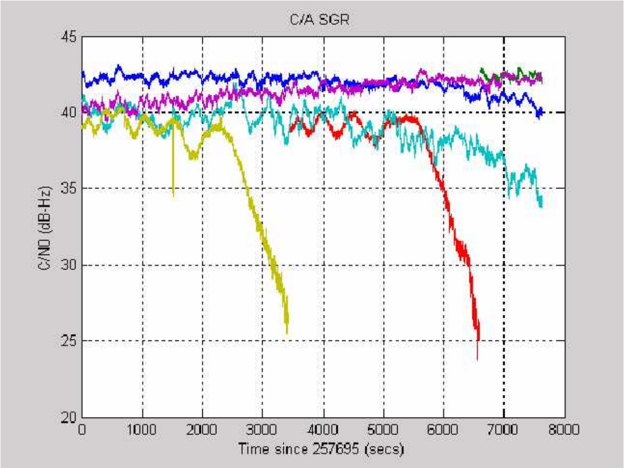


Figure 11 Low Signal GPS Tracking

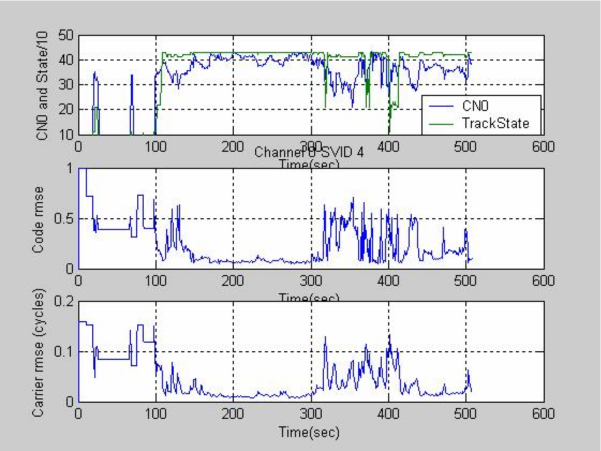


Figure 12 Indoor GPS Tracking (21 dB-Hz threshold)

NEXT GENERATION NETASSIST SOFTWARE GPS RECEIVER

The PC/104 SDR test bed provides a flexible platform for implementing integrated navigation systems, with support for other communication waveforms.[2] The key characteristics of the test bed are summarized below:

Reprogrammability and Multi-Mode Operation: The SDR test bed consists of reconfigurable hardware that can be configured to implement high speed DSP functions. Further a variety of sensors can interface to the test bed for different GPS receiver configurations. The SGR software can also be configured through simple keywords to tune the tracking loops for different environments.

Flexibility and Hardware Scalability: The reprogrammable nature of the test bed allows introduction of new waveforms through firmware and software modifications. The nature of the PC/104 test bed and the SDR approach simplifies the introduction of additional frequency channels, spreading codes, and tracking algorithms. New frequencies are supported by developing a simple Digital Antenna Element RF front end that complies with the PC/104 FPGA board interface.

Use of Standard Hardware and Interfaces: The SGR/SDR test bed uses PC/104 and other PC industry standardized interfaces. The system can be easily upgraded with the addition of PC/104 cards as well as RS-232, USB, and IEEE 1394 FireWire components.

Use of Robust, Inexpensive Development Tools: The test bed is composed of low-cost components and builds upon proven PC processor and chipset technology reducing development time and effort.

NAVSYS is currently upgrading the SGR units to include the ability to integrate in navigation aiding information from the suite of sensors shown in Figure 13. This next-generation SGR test bed includes a GPS DAE, a 900 MHz DAE, an 802.11 data link, and an inertial measurement unit.

The 900 MHz DAE is used to provide a TOA aiding signal to allow "Master" SGRs to act as "Pseudolites" to "Slave" SGRs which cannot track the GPS satellite signals. The broadcast 900 MHz TOA-aiding signal is locked to GPS time derived from tracking the GPS time reference signal. A spread-spectrum signal is used for the TOA aiding to minimize the effects of multipath.

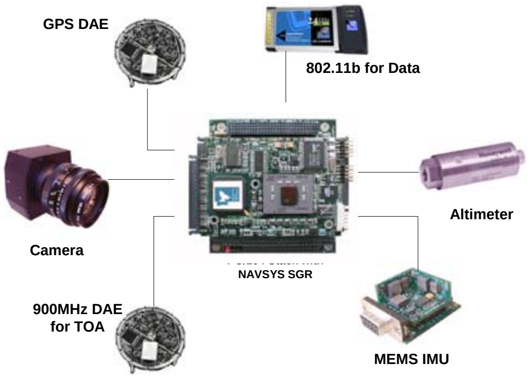


Figure 13 Next Generation SGR with Suite of Aiding Sensors

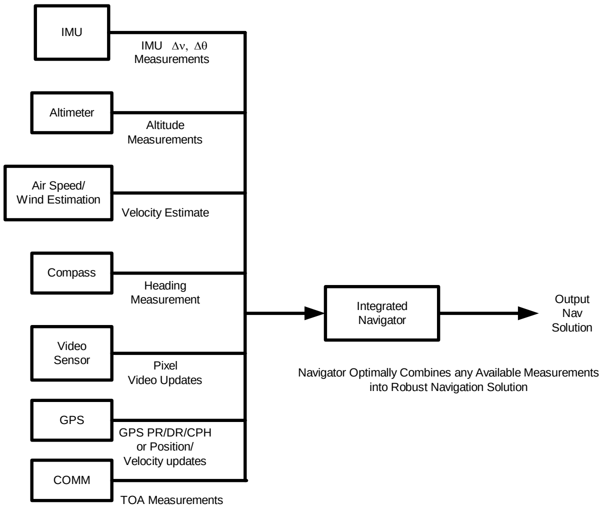


Figure 14 InterNav Alternative Sensor Inputs

The IMU is used to derive an inertial navigation solution which is updated from the GPS signals or TOA aiding signals. The baro-altimeter is used to provide vertical damping to the inertial navigation solution to allow 3-D navigation to be performed during GPS drop-outs. The video camera is used as a truth reference to record the test environment.

The observations from this suite of sensors are integrated using our InterNav Kalman Filter (see Figure 14[3]). The combination of the Network-Assisted GPS and the complementary aiding sensor updates is expected to lead to a robust networked positioning and navigation solution that will further extend the ability to operate in urban and indoor environments.

CONCLUSION

In conclusion, the testing performed under this program has demonstrated that Network Assistance (NETASSIST) enhances GPS receiver performance, particularly in degraded environments such as urban operations.

The NETASSIST capability provides in particular improved:

- Acquisition performance (TTFF)
- Low signal tracking capability for urban operations
- Navigation accuracy

We have implemented the NETASSIST functionality using a PC/104 Software GPS Receiver Test Bed. By including a Smart Card for the security processing, we were able to demonstrate the ability to perform secure P(Y) code processing within the Software Defined Radio. Future upgrades include inertial aiding and RF-Ranging (TOA) aiding for further performance improvements

ACKNOWLEDGMENTS

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