The UHARS Non-GPS Based Positioning System (NGBPS)

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ABSTRACT

Amid a growing concern about Global Positioning System (GPS) jamming in military areas of operation, testing GPS receivers and antenna systems in a GPS-denied environment is becoming increasingly important to Department of Defense (DoD) agencies. However, since GPS is often the "gold standard" position, navigation and time information that serves as a truth reference during field and flight testing, conducting tests in an area that has no GPS availability because of intense jamming makes it difficult to compare observed position and navigation data to a valid truth source. Moreover, to evaluate system performance with appropriate statistical significance, the reference system against which test results are measured needs to be significantly more accurate than the system under test. Therefore, when the system under test is GPS itself, this poses an interesting problem.

Figure 1: CIGTF Reference System (CRS)

For more than a decade, the 746th Test Squadron (746 TS), also known as the Central Inertial and GPS Test Facility (CIGTF), has met this requirement by employing its CIGTF Reference System (CRS). The CRS **(Figure 1)** is a system of navigation sensors that evaluates combinations of its subsystem measurements in an extended Kalman filter/smoother algorithm to produce an optimal reference trajectory. Delivering sub-meter accuracy in non-GPS-jammed environments and meter-level accuracy in GPS-jammed environments, the CRS is arguably the most accurate reference system in the DoD. However, many future DoD weapons systems are projected to require tighter navigation accuracies in GPS-denied environments, and as these requirements improve, the reference system against which they are evaluated must improve accordingly. To meet these test and evaluation reference requirements in a GPS-denied environment, a new reference system is needed.

Answering this call, the 746 TS embarked on the development of the Ultra High Accuracy Reference System (UHARS), a next generation reference system that meets test and evaluation reference requirements for future navigation and guidance systems. UHARS consists of a rack-mounted, tightly integrated system of improved navigation sensors/subsystems, data acquisition system (DAS) and a new post-mission reference trajectory algorithm. The complete system will provide a significantly more accurate reference solution for future airborne and land-based test vehicles in navigation warfare environments where modernized and legacy GPS signals are jammed from friendly or hostile systems.

Achieving these accurate reference solutions requires a Non-GPS Based Positioning System (NGBPS) subsystem capable of operating and providing sub-meter position accuracy in a GPS-denied (jamming) environment. The NGBPS portion of the UHARS program employs a network of ground "LocataLite" transceivers and test vehicle receivers (also called "rovers") manufactured by the Locata Corporation. Although the NGBPS uses Locata's standard commercial LocataLites and rovers, meeting the demanding UHARS accuracy and distance requirements of better than 18 centimeters accuracy over a 30 mile range in a flight configuration necessitated custom transmit antennas, external signal amplification, custom navigational software for flight, as well as the addition of a centralized command and control (C2) capability.

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PA number: 96TW-2014-0106

Based on successful results of the technical demonstration at the White Sands Missile Range (WSMR) in October 2011 that prototyped the architecture in a real-world end-to-end environment, the USAF proceeded to the NGBPS production and fielding phase. To this end, the 746th Test Squadron awarded two sole-source contracts to Locata Corporation and TMC Design Corporation, respectively. The Locata Corporation was contracted to provide production ground transceivers and rovers, navigation algorithms required for data analysis and subject matter expertise. The TMC Design Corporation, the Locata Technology Integrator (LTI) for this program, was contracted to develop the production hardware to house the Locata hardware, develop the command and control hardware and software, and field the production hardware at WSMR.

This paper details the NGBPS production effort to include an overview of the design, development and network integration.

INTRODUCTION

The UHARS architecture **(Figure 2)** is comprised of three major subsystems which include the Enhanced Embedded GPS/INS (EGI), Locata NGBPS, and GPS Antenna and Antenna Electronics (AE). Other key technologies include the DAS, Differential GPS (DGPS) Base Station and Reference Trajectory Algorithm.

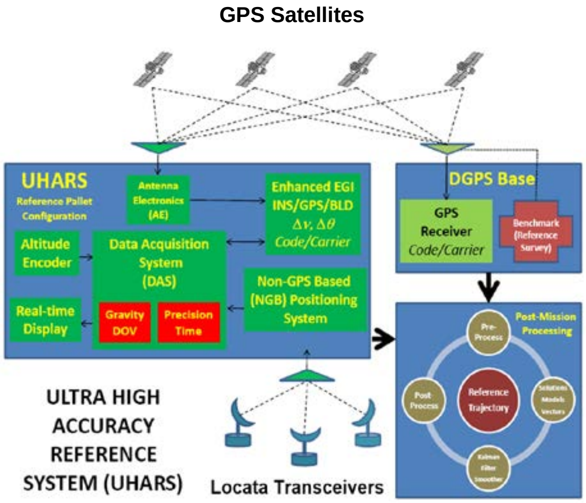

Figure 2: UHARS Architecture

BACKGROUND

The NGBPS is comprised of a network of ground transceivers (LocataLites) and test vehicle rover receivers. The receiver collects 10.23 MHz chipped code pseudorange and carrier-phase measurements at selectable rates of 1, 5, and 10, 20, and 25 Hz. The system uses the patented 'TimeLoc' process which synchronizes the clocks among all LocataLites in the network. With all LocataLites synchronized, data from the test bed receiver can be processed like GPS measurements without the need for differential corrections.

The system transmits on two spatially diverse signals from two separate antennas at two frequencies within the 2.4 GHz industrial, scientific, and medical (ISM) frequency band, 2434.740 MHz and 2462.361 MHz, for a total of four spatially and frequency diverse signals. That signal structure provides precise positioning signals that are both resistant to GPS L1 and L2 jamming and also provide highly accurate positioning.

KEY TECHNICAL REQUIREMENTS

The following are key NGBPS technical requirements:

1. Carrier-phase "truth-reference" solution of < 18 cm Three Dimensional Root Mean Square (3dRMS), with a Position Dilution of Precision (PDOP) < 3.0.
2. Rover receivers acquiring and tracking Locata signals at a range greater than 30 miles (48 km).
3. Accurate and reliable TimeLoc synchronization over the test area, the ability to "cascade" TimeLoc from one LocataLite to another, plus the delivery of nanosecond-accurate time on the Range while GPS time is unavailable because of GPS jamming.
4. External signal amplification to support the extended signal range requirement while still maintaining nanosecond-level TimeLoc integrity.
5. Rover receiver tracking loops perform adequately under flight dynamics.
6. Tropospheric measurement and modeling to ameliorate the large tropospheric errors, approximately 300 ppm uncorrected, experienced by terrestrial signals at these ranges.
7. Transmit and receive antennas that provide both adequate gain and multipath mitigation for an aircraft flight scenario.

OVERVIEW

After successful completion of the technical demonstration in October 2011, in which all of the key technical requirements listed above were demonstrated, the USAF awarded two separate sole-source contracts to Locata Corporation and TMC Design Corporation to develop and field the production NGBPS. TMC Design, a certified LTI, leveraged Locata knowledge-transfer and technology training to design and develop a system architecture that integrates Locata technology with identified Government Furnished Equipment (GFE) and existing commercial-of-the-shelf (COTS) non-proprietary components. The Locata Corporation provided production ground LocataLite transceivers, Locata rovers and the subject matter expertise required to ensure optimal network integration and performance.

The deployed system includes 16 Locata Solar Aluminum Transportable Trailers (LSATT) with flexible power options that integrate both shore power (110V AC) and reusable solar power **(Figure 3)**. The trailer configuration enables easy transportation of major NGBPS components on and off WSMR, allowing for easy reconfiguration of the network or deployment to other test ranges if required.

Figure 3: Locata Solar Aluminum Transportable Trailers (LSATT)

The NGBPS design currently includes 20 geographically separated deployment sites over a 30 x 37 mile area on WSMR-North Range **(Figure 4).**

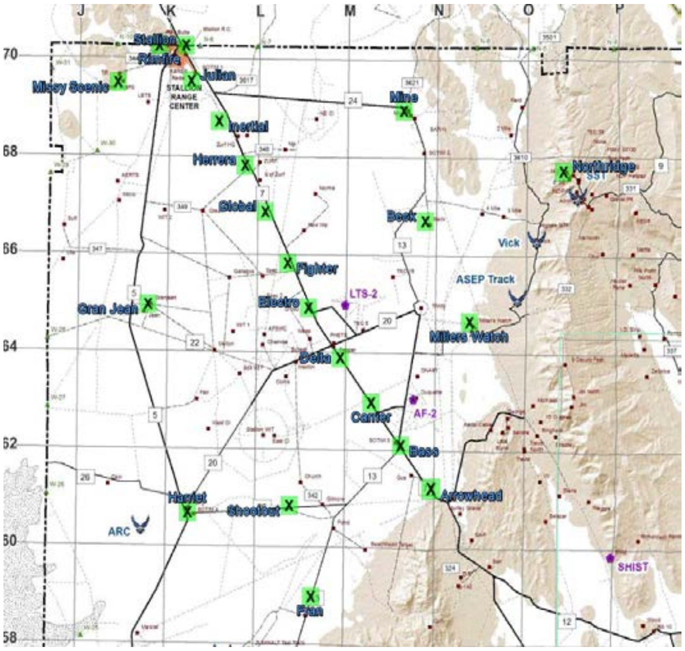

Figure 4: NGBPS Sites: WSMR North Range

Each site contains permanent monumentation for the two spatially diverse transmit antennas (2 monuments per site; 40 total). Each monument is equipped with a quadrifilar helix S-band transmit antenna (made for Locata by Cooper Antennas Ltd from the UK), and one monument also supports the 2.4 GHz receive dish antenna. The monuments and antennas are integrated with an LSATT, UHF-band (350-360 MHz) wireless architecture for the command and control element, and a meteorological (MET) station made by Vaisala **(Figure 5).** The MET measures and collects temperature, pressure and relative humidity data, for calculating the tropospheric corrections across the network.

Figure 5: NGBPS Sites (Integrated)

The system is operated, controlled and monitored using either the fixed C2 center located at the 746th Test Squadron, Holloman AFB, NM or the mobile C2 Center. The mobile C2 is typically located on the WSMR-North Range to support test events. Two repeater stations **(Figure 6)** are installed on WSMR-North Range to enable long distance remote/ wireless C2 communications with the NGBPS constellation or network.

Figure 6: NGBPS C2 Repeater Station

SITE ARCHITECTURE

The LSATT includes integrated hardware and software to produce the NGBPS network. The heart of the NGBPS is the LocataLite transceiver, which provides the ranging signals used by the rover to compute position and time information. The same signals are used by each LocataLite for nanosecond-level 'TimeLoc' synchronization across the network. The MET station, mounted on monumentation along with a Locata transmit antenna, collects temperature, pressure and relative humidity data and relays it to the LocataLite for processing. The LocataLite provides the exciter signal to two 30W Mini-Circuits amplifiers which boost the RF power to each transmit antenna providing signal coverage over the large geographical area of WSMR-North Range. The wireless modem relays Locata and MET data to and from the C2 centers using various package compression techniques to ensure data is not lost during transmission. The modem provides 4 watts of power operating in the UHF-Band with a directional high gain antenna.

Situated in the New Mexico desert, the LSATT is also required to operate during extreme weather conditions, necessitating the employment of moisture and dust resistant enclosures and temperature reducing mechanisms to protect its commercial subsystems. Accordingly, TMC Design developed a filtered fan configuration to mitigate elevated temperatures during operation.

Each LSATT also possesses an intelligent, low power controller that supports the various communication protocols within the equipment enclosure. A comprehensive and expandable feature of the controller design enables a centralized methodology for data collection, health and status information and C2 functions. The controller interfaces with the LocataLite transceiver, MET station, amplifiers, and power supply sources. Information is collected and packetized for efficient transmission via the wireless modem. Commands from the fixed or mobile C2 center are received and implemented by the controller. During non-operating periods, the controller reduces power consumption by shutting down non-essential equipment. Likewise, the controller itself enters a stand-by mode until reactivated by the C2 center via the wireless modem. The controller provides a redundant data archive capability and autonomously manages operations in the unlikely event of a wireless communication outage with the C2 Centers. The controller is programmed to shut down after a definable period if C2 communication links cannot be re-established.

The NGBPS design provides pre-, live- and post-mission support through remote wireless C2 operations. This support includes real-time status monitoring and a net-centric architecture for C2 of remote locations. As C2 outages are detected, the wireless network autonomously attempts to self-repair and return the network to an operational state.

VERIFICATION and VALIDATION

TMC Design Corporation will accomplish a Final System Verification (FSV) on the fully fielded NGBPS system on WSMR, after all network and C2 software activities have been completed. The FSV ensures all contractual requirements are adequately met, prior to release to the 746 TS for government operations. It includes verifying successful communication through the UHF network and ensures that the Locata rover can obtain and process information from each LSATT site in view. Additionally, a mission duration test will be performed to ensure the system can operate for the period of a standard mission window without depleting the battery system.

The FSV will include collaboration between TMC Design, Locata and Government personnel to ensure test expertise and robustness are incorporated. FSV is anticipated to be completed in September 2014.

After successful FSV completion, the 746 TS will conduct a series of flight tests to:

1) Measure the NGBPS PDOP over the WSMR fielded area.
2) Compare the measured PDOP values to the developed PDOP model.
3) Evaluate carrier-phase solution with an objective accuracy of <18cm 3dRMS with a PDOP < 3.

Flight trials will be conducted using the USAF C-12J aircraft **(Figure 7)** integrated with one quadrifilar helix S-band receive antenna. The NGBPS Locata receiver will be integrated in the UHARS flight pallet. A DAS will be connected to the receiver to log specific receiver and health data required for post-test data analysis. Specific flight profiles will be flown at varying altitudes, aircraft speed and time of day in order to test the NGBPS network performance under a wide range of scenarios.

Figure 7: USAF C-12J Aircraft

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Figure 8 illustrates the top down view of the predicted PDOP=3 boundaries across the NGBPS network on WSMR. The PDOP volume coverage is shown in 1000 ft. increments (red lines) from 5K to 30K ft. MSL. The green lines are at 10K, 20K, and 30K ft. Flight profiles will be flown within the PDOP volume footprint to obtain carrier-phase solutions with an accuracy of 18cm 3dRMS.

The UHARS reference system Differential GPS carrier phase solution will be used for comparison to evaluate the Locata navigation carrier–phase solution when the GPS signals are available. Once the Locata system performance is verified in this NGBPS configuration, it will then be used as the primary source of positioning when the GPS signals are denied.

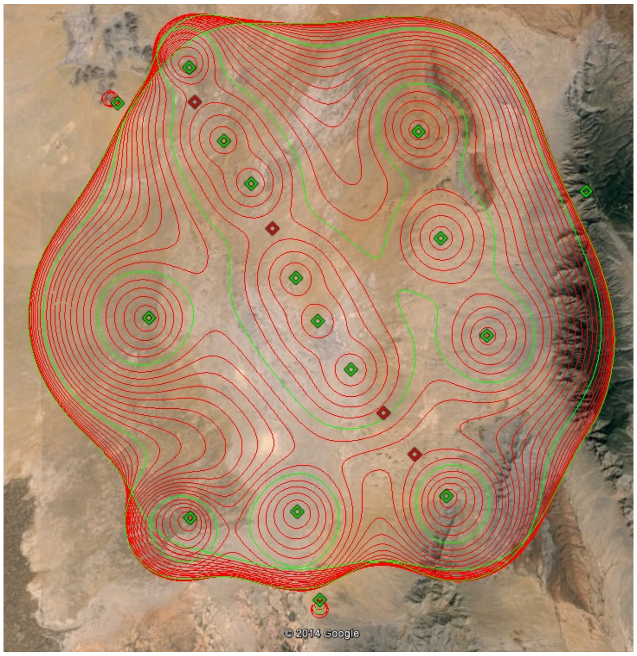

Figure 8: NGBPS PDOP Plot

CONCLUSIONS

Locata Corporation and TMC Design Corporation are providing the DoD with an extremely accurate NGBPS capable of covering a 30 x 37 mile region of WSMR in New Mexico. As designed and deployed, this tailored LocataNet provides 3D positioning accuracy better than 18cm, completely independent of GPS and while traveling in a dynamic aircraft flight profile. This enables the CIGTF to test, evaluate, and assess capabilities in GPS-denied environments. It also demonstrates that there are no theoretical or technical problems in scaling LocataNets to very large areas.

The fielding of the NGBPS on WSMR is currently underway with a planned completion of September 2014. All twenty monument sites have been created, all 16 LSATT trailers have been built and installed in the initial site locations, C2 software development is complete and all sites are running on solar and battery power. The system is self-contained, remotely operated and possesses high quality, reliability and safe operation attributes.

An extensive flight test is scheduled for later this year, where the NGBPS system will be tested under operationally realistic conditions and evaluated to confirm it meets all requirements. Upon successful test completion, UHARS is expected to begin supporting DoD test programs as early as January 2015.

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