The UHARS Non-GPS Based Positioning System

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ABSTRACT

The Ultra High Accuracy Reference System (UHARS) is the 746th Test Squadron's next generation reference system, currently under development to meet test and evaluation reference requirements for future navigation and guidance systems. Consisting of a rack mounted, tightly integrated system of navigation sensors/subsystems, data acquisition system, and a post-mission reference trajectory algorithm, UHARS will provide a highly accurate reference solution for airborne and land-based test vehicles in electronic warfare environments where modernized and legacy GPS signals are jammed from friendly or hostile systems. The system will be appropriately sized and constructed for use on-board multiple test-beds including current and future test aircraft and ground vehicles.

Achieving these accurate reference solutions requires a Non-GPS Based Positioning System (NGBPS) subsystem capable of providing sub-meter position accuracy in a GPS-denied (jamming) environment. To this end, UHARS plans to employ a network of ground transceivers and test vehicle rover receivers, manufactured by the Locata Corporation. However, meeting UHARS accuracy requirements necessitates a major upgrade of Locata's existing, commercial capability. Therefore, the 746th Test Squadron awarded Locata a contract to re-design and demonstrate a system delivering longer ranges (both for acquisition and tracking), higher power transmission levels, new antenna designs for aircraft use, and higher aircraft dynamics than previously envisaged.

The contract effort to develop these enhanced capabilities for the 746th Test Squadron is currently underway. This presentation details UHARS development efforts and technical challenges, focusing on the improvements to and validation of Locata Corporation's NGBPS.

INTRODUCTION

The UHARS architecture shown in Figure 1 is comprised of three major subsystems which include the Enhanced Embedded GPS/INS (EGI), NGBPS, and GPS Antenna and Antenna Electronics (AE). Other key technologies include the Data Acquisition System (DAS), Differential GPS (DGPS) Base Station, and Reference Trajectory Algorithm.

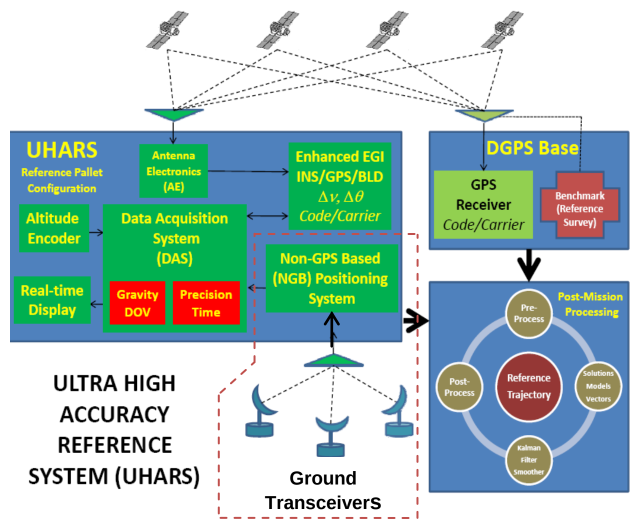

Figure 1: UHARS Architecture

The NGBPS subsystem will provide sub-meter position accuracy in a GPS denied (jamming) environment. 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, 10, 20, and 25 Hz. The system uses a 'TimeLoc' process that effectively removes the clock error between ground transceivers, leaving only the clock difference between the network of LocataLites and the test bed receiver, similar to GPS. Advantages include the use of the 2.4 GHz industrial, scientific, and medical (ISM) frequency band, that allows precise signal transmissions resistant to GPS L1 and L2 jamming. The goal of NGBPS is to achieve a standalone, receiver post-processed positioning accuracy of 10 cm/axis.

KEY TECHNICAL REQUIREMENTS

The following are key 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, compared to a GPS differential Real Time Kinematic (RTK) solution.
2. Rover receivers acquiring and tracking Locata signals at a range greater than 30 miles (48 km).
3. Nanosecond-accurate TimeLoc synchronization when Locata transmitters are at least 30 miles (48 km) apart.
4. Signals transmitted at high power via an external amplifier while maintaining TimeLoc integrity.
5. Rover receiver tracking loops perform adequately under contract specified flight dynamics.
6. Tropospheric models that adequately mitigate the large tropospheric errors experienced by terrestrial signals at these long ranges.
7. Transmitter and receiver antennas which will provide adequate gain and multipath mitigation for an aircraft flight scenario.

TECHNICAL APPROACH

The following Work Breakdown Structure tasks were derived to investigate the NGBPS development for the stated technical requirements:

1. Antenna investigation, research and testing
2. Tropospheric modeling and compensation model development and testing
3. Signal acquisition and tracking model development and software implementation
4. Navigation solution and estimation (filter development) and testing

WIDE AREA TRIAL (WAT)

For many years the Locata system has been used to provide high accuracy position and time for ground-based non-military applications [1-7]. In July 2010, the US Air Force 746th Test Squadron awarded a contract to Locata Corporation for development of a LocataNet system to be used as the non-GPS based component of the squadron's UHARS. The Locata system would allow sub-meter accuracy in a GPS-denied environment. This system would be significantly larger than any previous Locata installation, and would cover nearly 2500 square miles (6475 sq km) of airspace at the White Sands Missile Range (WSMR), in New Mexico (NM). Before the Technical Demonstration in NM, the system would undergo a rigorous USAF Critical Design Review (CDR).

While a full flight trial was not necessary to demonstrate each of the technical requirements, Locata considered it important to directly address any questions regarding the system's capability as a flight reference system. To this end, a large LocataNet was designed and built in the Australian countryside for a Wide Area Trial (WAT) flight test. The data collected was not only to address the technical requirements, but also for Locata's consideration by the International Civil Aviation Organization (ICAO) as an Alternate Position Navigation and Time (APNT) technology – a "backup to GPS".

WAT GROUND SETUP

The LocataNet for the flight trial was setup up South of Canberra, Australia in the area around the town of Cooma. Locata established six test ground station sites (an example of which is shown in Figure 2) each equipped with a LocataLite transmitter, an RF amplifier to enable operation over longer ranges, a router and 3G modem (to enable remote control, monitoring, and data collection), batteries and solar panels for power. Additional supporting equipment included antenna masts, weatherproof housings, cables, power supplies, and at some stations, a meteorological (MET) data gathering capability.

Figure 2: A WAT Ground Site

The sites were located across the country side in an area approximately 27 x 30 miles (44 x 48 km) to simulate the distances required to meet the technical requirements. In Figure 3, an aerial view shows the locations of each transmitter. Four LocataLites are located on the perimeter of the work area, with the remaining two sites in the interior portion along with the Cooma airport. Site A was the highest, located at roughly 4750 feet (1450 meters), and was used as the master site. Site C did not have visibility to the master Site A and thus TimeLoc was cascaded to this device from Site B.

Three of the sites contained the MET stations which would gather readings of temperature, pressure, and relative humidity for calculating the tropospheric corrections across the network.

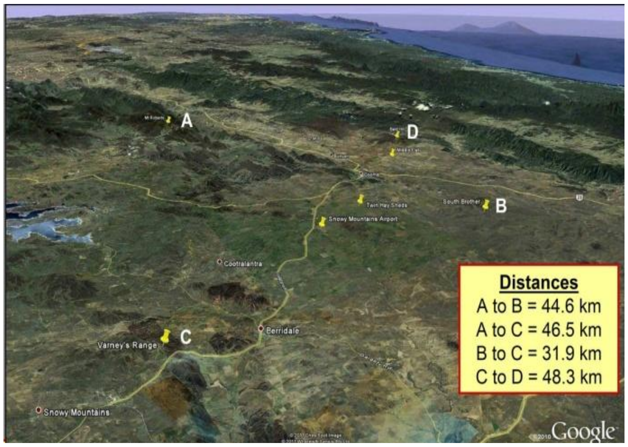

Figure 3: Wide Area Trial Work Area

AIRCRAFT CONFIGURATION

A Piper Seminole obtained from the School of Aviation at the University of New South Wales, shown in Figure 4, was flown for 2 flight trials.

Figure 4: Test Aircraft. Piper Seminole

Figure 5 shows the equipment on the aircraft. Along with the NovAtel Span inertial unit were a Leica RTK-grade GPS unit, a Vaisala MET station, several power supplies, and the Locata receiver (not shown in figure). The Leica RTK-grade GPS unit and the NovAtel SPAN were used as the reference system for comparison against Locata navigation solutions.

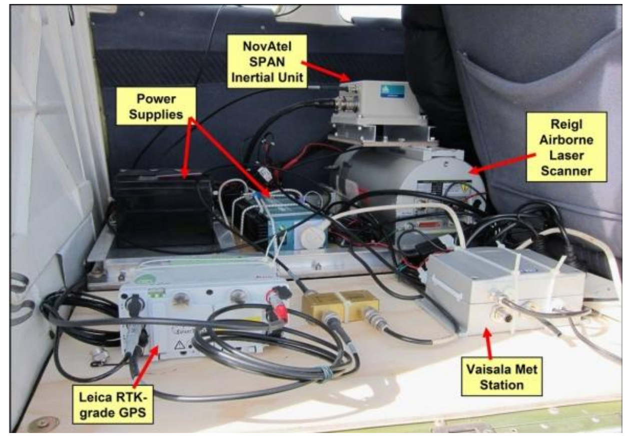

Figure 5: Aircraft Setup

FLIGHT TRIAL RESULTS

The aircraft flew a predetermined flight path set up to address the requirements. Several scenarios were set up such as entering the network, and orbiting within the work area at a height of 7000 ft Above Ground Level (AGL).

The LocataNet demonstrated that TimeLoc was fully capable of synchronizing the network over the large ranges involved, even with TimeLoc hops of a cumulative distance of approximately 50 miles, to site C not visible from master site A.

The amplifiers provided the necessary power to receive the signals over 30 miles without affecting the signals. Using new transmit and receive antennas, the aircraft was able to receive, acquire, and track the signals across the specified 30 mile range. Tropospheric delay was mitigated using the data measured across the range via the MET stations.

More importantly, during the flight path within the work area, it was possible to compare the Locata receiver solution against the GPS solution.

CODE SOLUTION RESULTS

An initial early-stage assessment of the performance of the Locata system was to compare the pseudorange-based (code) solution against a similar GPS code solution. Both code solutions would be compared against the high-precision carrier-phase differential GPS reference.

Table 1 summarizes the 95% RMS values, mean values, and dilution of precision for both the Locata and GPS (NovAtel) code solution. This shows that in the horizontal component, with comparable Horizontal Dilutions of Precision (HDOPs) in both, the Locata and

NovAtel solutions are very similar. In a Locata network which was purpose-designed to provide comparable Vertical Dilution of Precision (VDOP) (e.g. an APNT deployment for aircraft approach and landing) the Locata code solution should be similar in vertical as well. Nevertheless, relative to the high-precision GPS truth the Locata code solution has an error of 2.1 meters RMS horizontal and 3.2 meters RMS vertical.

Code Solution	RMS 95% (m)		Mean Error (m)			Average DOP	
	H.	V.	E.	N.	H.	H.	V.
Locata	2.13	3.19	-0.23	-0.82	-1.14	1.5	3.3
GPS	2.15	0.93	-0.35	0.99	0.23	1.4	1.9

Table 1: Summarization of Locata and NovAtel Code Solutions against High-Precision GPS

CARRIER-PHASE SOLUTION RESULTS

The fundamental technical requirement is to provide a carrier-phase solution with an accuracy of 18cm 3dRMS with a PDOP < 3.

Figure 6 shows the difference in East, North, and Height between the high-precision GPS solution and the Locata carrier-phase solution with Known Point Initialization (KPI) to resolve ambiguities using the GPS reference. The overall 3dRMS is 0.132 meters for an average PDOP of 3.90. This equates to a 3dRMS of 0.102 meters for a PDOP of 3.0, which is well within the 0.18 meters 3dRMS design specification.

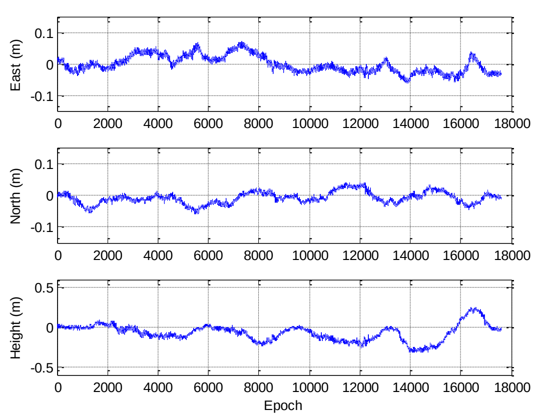

Figure 6 : Difference between High-Precision GPS and Locata KPI Carrier-Phase Solution.

Table 2 summarizes these RMS values together with the standard deviation values of the Locata carrier-phase solution when compared with the high-precision differential GPS reference.

	East	North	Vertical	2D	3D	PDOP = 3
RMS	0.027	0.020	0.127	0.034	0.132	0.102
Mean	-0.002	-0.009	-0.071			
STD	0.027	0.018	0.106	0.033	0.110	0.085

Table 2 : Difference between High-Precision GPS and Locata KPI solution (m)

CONCLUSIONS

The flight tests at the Wide Area Trials in Australia were seen by Locata as a critical step in verifying the contractual performance requirements. A carrier-phase solution less than 18 cm RMS was demonstrated on an aircraft flying over a ground based LocataNet covering more than 800 square miles.

The LocataNet was fully capable of operating over the long ranges as well as cascading TimeLoc to isolated locations. The improvements to the amplifiers, antennas, and tropospheric modeling met the technical requirements.

A Technical Demonstration is scheduled for later this year, where the NGBPS system will be tested at the WSMR under operationally realistic conditions.

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