Development of an Expendable Real-Time GPS-Based Time-Space-Position Information (TSPI) System Using COTS Hardware

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BIOGRAPHY

James Rogers received his BS in Computer Science from New Mexico Institute of Mining and Technology. James has been a member of the NAWCWD GPS/INS Branch since 2001 and has acted as the primary software engineer for low-cost embedded systems.

Benge Scott received his BS in Engineering from Walla Walla College, and came to NAWCWD China Lake in 1989. Benge has been systems lead for the development of rapid-prototype embedded systems while working as a GPS Systems Engineer for the NAWCWD GPS/INS Branch.

Matt Boggs received his BS in Electrical Engineering from New Mexico Institute of Mining and Technology. Matt has been a member of the NAWCWD GPS/INS Branch since 1989 and has been involved with design and implementation of missile hardware-in-the-loop simulation, navigation error analysis, antenna measurement techniques and GPS jamming efforts. Matt is currently working on low-cost instrumentation techniques for range applications.

Brooke Hoem received her BS in Applied and Computational Mathematical Sciences from University of Washington, and has been at NAWCWD since 2001. Brooke is currently working as a systems analyst for the NAWCWD Weapons Engagement Office, focusing on weapon targeting performance.

ABSTRACT

The GPS/INS Branch of the Naval Air Warfare Center Weapons Division (China Lake, CA) was tasked to develop and field a low-cost Time-Space-Position Information (TSPI) system for ground targets using commercial off the shelf (COTS) technology. The resulting portable system, developed and fielded in 6 weeks, provides real-time TSPI solutions compatible with RCCS II Range Front End format for multiple moving targets. The system telemeters its uncorrected position via a FCC part 15 compliant spread spectrum datalink to a ground station. The ground station corrects the position data via a reverse differential technique and broadcasts TSPI data in standard RCCS II format to NAWCWD´s Range Control Center. Development and replacement costs were minimized through extensive use of COTS technology, resulting in a solution that is affordable enough to be destroyed during weapons testing at NAWCWD´s ranges.

This paper begins with an overview of the requirements that drove development of this TSPI system. A discussion of operational concerns and experiences with this system, including operation over long differential baselines, follows. The paper concludes with an overview of the system-level accuracy study that was performed on data generated by this TSPI system.

INTRODUCTION

The Navy's test and evaluation community continually feels the mandate to do more with smaller budgets. These constraints drive many creative instrumentation solutions at NAWCWD China Lake. An example of a rapid solution to a customer's requirements is the Portable Tracking System (PTS) developed by NAWCWD's GPS/INS Branch.

The PTS was designed and implemented to quickly solve an emerging requirement for expendable TSPI sources that are compatible with existing systems found on NAWCWD's Land Range. The end product of this effort is a flexible system that is capable of providing real-time TSPI data for multiple vehicles with validated positional accuracies on the order of 10-15 cm. The capabilities of the PTS are noteworthy, especially when it is realized that this system was designed, implemented and fielded in a production environment in 6 weeks.

SYSTEM OVERVIEW

PTS is a portable vehicle tracking system consisting of a portable base station and multiple remote rover units, allowing vehicle positioning information in remote areas not otherwise supported by existing range TSPI systems. The PTS is particularly aimed at applications where the target vehicle and its TSPI source are expected to be destroyed.

The base station receives uncorrected GPS data from the rover units and provides real-time, corrected position data to ground personnel in NAWCWD's Range Control Center. The topology of a typical PTS configuration is illustrated below in Figure 1. The base station is typically located at a suitable remote location for the mission, while the rovers are installed in a minimally intrusive manner on the host target. The rover systems are entirely self-contained, and require no parasitic power sources from the host vehicle. The base station is typically deployed in one of the GPS/INS Branch's remote field trucks, all of which feature on-board generators and climate control. The self-contained nature of the PTS allows its rapid deployment in areas otherwise devoid of support infrastructure.

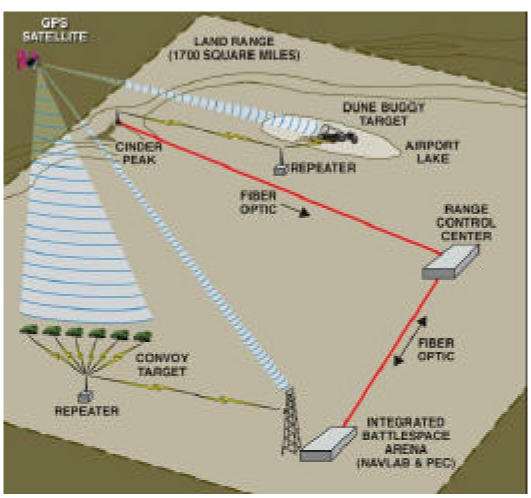

Fig. 1 Typical Topology of PTS Deployment

Due to the low-cost nature of the PTS, the decision was made to use civilian receivers, rather than P(Y)-capable receivers. This decision was driven by the additional life-cycle cost savings due to the diminished logistical cost of maintaining P(Y)-capable receivers in the field. Ashtech Z-12 GPS receivers were used for the PTS. The decision to use these receivers was borne by previous experience with Ashtech receivers in adverse conditions, coupled with the Z-12's carrier-phase tracking, dual frequency architecture.

The position of each rover is determined through a reverse-differential GPS process; each rover broadcasts its observables to the base station, where each rover's corrected position is determined. The use of a reverse differential process is driven by the expectation that the rover unit will be destroyed during testing, and the requirement for the rover's position in the Range Control Center. The rover unit additionally saves raw observable data on an on-board data recorder utilized as a backup data source should the rover not be destroyed. This on-board data recording is additionally supplanted by data logging of both raw and processed data performed at the base station to allow both post-test processing and a playback mode for system integration testing for developmental use. The rover unit is illustrated below in Figure 2.

Fig. 2 PTS Rover Unit

Data processing is performed by a combination of government-developed software and a commercially available processing kernel. The PTS processing software uses a processing kernel based on the widely adopted RTKNav software produced by Waypoint Consulting, Inc. The decision to utilize the RTKNav software kernel was driven by NAWCWD's experience with Waypoint's GrafNav software in prior projects; the short turn-around time of the PTS project essentially mandated that the processing software not be "reinvented."

Despite the use of the RTKNav processing kernel, software developed by the GPS/INS Branch is required to handle the remainder of the real-time data handling requirements. Critical tasks of this software include establishment of datalink connections across potentially multiple networks, error handling, processed data reformatting into RCCS II format, and data filtering to remove artifacts from datalink dropouts. This software additionally provides a real-time moving map display for situational awareness at the base station location (usually geographically separated from the NAWCWD Range Control Center's existing moving map displays), and a local terminal for viewing processed data in ASCII form for debugging purposes).

PTS uses a 2.4 GHz spread-spectrum datalink manufactured by Cirronet, Inc. for transmission of rover data to the base station. This datalink operates as a FCC Part 15 device, allowing the datalink to operate as an unlicensed, low-power device. Because of the propagation characteristics of this band, the base station must either have direct line-of-sight to the rover units, or make use of intermediate repeater sites to provide full coverage in rough terrain or over a large range of operations.

Data yielded by the PTS system is typically injected into the NAWCWD Range communications network as UDP broadcasts from the base station's computer. The data output by the base station's computer is formatted as RCCS II data to be compatible with the NAWCWD Range Control Center's Range Front End. Once distributed to the Range Control Center, the data may be displayed on moving map displays in each test bay.

The PTS was designed to maximize the use of commercial-off-the-shelf (COTS) components. This decision was made based on prior experience with earlier low-cost TSPI systems such as GRIPS1, coupled with the sponsor's required very short delivery timeline. This previous experience indicates the trend that components rated for the commercial temperature range, with careful mechanical integration, can survive environments typical of the military operational regime. This prior experience has been verified by the demonstrated survivability of the PTS in very adverse conditions, as will be seen in the discussion of PTS deployments below.

DEPLOYMENT OF PTS

The PTS system was originally designed to provide TSPI data for two sets of ground targets, isolated by 10 miles and a mountain range. Based on these requirements, the PTS was designed to allow multiple datalink networks and to utilize datalink repeaters. This architecture has proven to provide flexibility for the PTS to be quickly deployed and provide coverage across the varied terrain and long transmission range of NAWCWD's Land Range.

A critical detail to every deployment of the PTS for real-time TSPI support is performing systems engineering to assure sufficient link-margin for the datalink. This is accomplished through use of the Branch's modeling software, including government-developed line-of-site determination software, and commercially available RF propagation software. RF propagation modeling is typically performed using EDX SignalPro, a RF engineering suite used in the civil commercial broadcast engineering community for RF broadcast network design. Using such software, the effects of propagation over a rough-earth model; terrain modeling is driven by NIMA Digital Terrain Elevation Data (DTED) for the area under consideration. The techniques utilized for this propagation modeling and engineering assessments are very similar to those used for pre-test engineering of GPS jamming events. This similarity of analysis allows deployments of the PTS to leverage parallel efforts in support of NAWCWD's GPS jamming work. An example of the type of signal propagation assessment is seen in Figure 3.

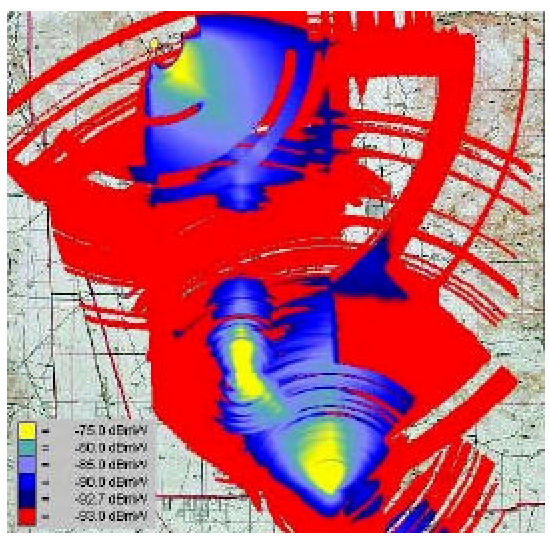

Fig. 3. False-color RF Propagation Map for 2.4 GHz Datalink Coverage of 2 Nodes and 1 Repeater on NAWCWD's Land Range.

Based on the output of the systems engineering stage, datalink repeaters and nodes are placed to provide maximum datalink coverage and provide optimal link margins. Repeaters are routinely deployed on the GPS/INS Branch's mobile tower trailers, which allow the repeaters to be up to 100 feet above surrounding terrain. Datalink nodes are placed to correspond with existing communications infrastructure on the Land Range, and can take advantage of multiple nodes distributed over the area(s) of operation.

The PTS has been deployed in a wide range of operational conditions as part of testing. The first test series that the PTS supported illustrates the often adverse conditions in which the system is deployed.

EXAMPLE DEPLOYMENT

The first test series that the PTS supported involved the requirement to track in real-time multiple vehicle targets as part of an advanced weapon test program. In this test, a set of vehicles in a convoy configuration performing complex vehicle maneuvers was tracked, while in a geographically isolated area, a pair of vehicles were tracked by an external sensor, with the intent of prosecuting a target of opportunity. The PTS system provided real-time positioning data back to the NAWCWD Land Range's Range Control Center, where the positioning data was utilized to drive scoring determination of the validity of target locations yielded by the external sensor system. Based on the target location's variance relative to the positions yielded by the PTS, the weapon under test was authorized to prosecute the target if appropriate.

This deployment took place under severe conditions during the summer months at China Lake, CA. Typical range periods were during peak heat of the day; ambient temperatures routinely peaked at 118^o F. Compounding the extreme temperatures was a highly dusty operating environment as a result of operations in a playa region of the Land Range. Finally, the target vehicles provided a large array of shock and vibration profiles that PTS system had to survive. An illustration of an example target from this deployment is seen in Figure 4.

NAWCWD has a long history of successfully integrating COTS hardware in a manner that allows it to survive a military environment. This experience was of great assistance for the PTS effort; no major failures of the system were experienced during any tests. Unconventional techniques such as the use of mylar radiative shields and super-cooled ice packs were utilized to further mitigate thermal conditions experience during this summer test series.

Fig. 4. Vehicular Target as Used in Example PTS Deployment

VALIDATION TESTING OF PTS

The PTS system was subjected to a battery of tests to characterize and validate its performance. This set of tests was required due to its use as a data source for scoring for systems that relate target locations to a national geolocation grid via WGS-84.

This validation process consisted of a series of tests qualifying the PTS' position solutions relative to a set of baselines and survey monuments. Positional data for these baselines and monuments were provided by the NIMA Survey Office at Edwards AFB. The use of NIMA survey data provided a common local datum relative to a wide range of other surveyed targets and positions found at NAWCWD China Lake and the region. Performance measurements relative to the NIMA data also acted to set the PTS metrics to as absolute of a positional measure as possible.

Beyond the validation of the PTS' position determination relative to NIMA data, a series of tests were conducted to determine sensitivities of the PTS' solutions to variables found within its potential deployment configurations. Key among these variables was the effect of utilizing a relatively long baseline between the basestation and the rovers – a case often imposed due to issues of range safety. To answer this question, a series of tests were conducted with data collected at baselines ranging from 5 km to 40 km. These tests indicated the linear relationship between positional error and baseline length; with baselines longer than 30 km, use of a dual frequency capable receiver for ionospheric corrections proved to be critical for operations. The ultimate solution to long baselines is to minimize their use unless absolutely critical or in cases that high-accuracy position solutions (<25 cm) are not required.

ACKNOWLEDGEMENTS

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[1] B.D. Scott. *Development of a Low-Cost GPS-Based Time-Space-Positioning Information (TSPI) System.* Proceedings of the ION 52nd Annual Meeting. 1996