Epoch-by-Epoch™ Network-Centric Positioning Unit for FCS Testing

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The DoD test community requires Test and Evaluation (T&E) instrumentation to provide Time Space Positioning Information (TSPI) that is one order of magnitude more accurate than articles under test. The Army in particular has such a requirement for FCS testing of dismounted soldier and manned and unmanned vehicles. The challenge is to obtain high-accuracy TSPI with low-cost, miniaturized instrumentation. As illustrated above, such a capability relies heavily on the Global Positioning System (GPS).

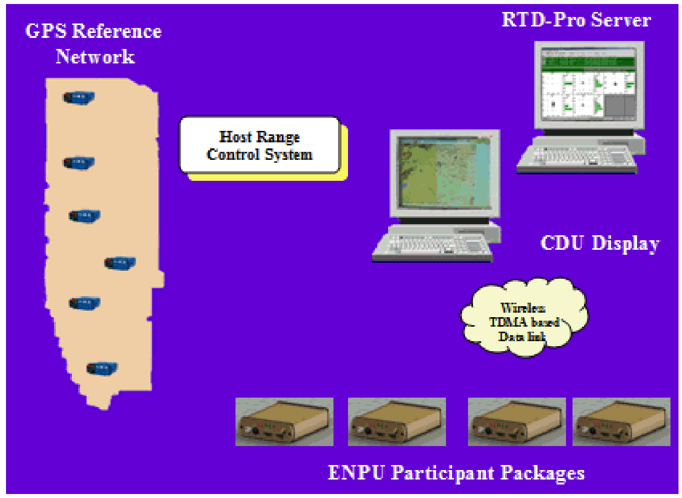
Anticipating the Army's need, the Air Defense Artillery Test Directorate (ADATD) at Ft. Bliss Texas contracted with Geodetics to provide a positioning system, capable of sub-meter accuracy that can be easily carried by dismounted soldiers or mounted on low-dynamic vehicles. Army interest in this capability continued with the award to Geodetics of the Common Range Integrated Instrumentation System Rapid Prototype Initiative (CRIIS-RPI) effort out of White Sands Missile Range (WSMR) designed to leverage "nearly COTS" industry solutions.

This paper describes Geodetics' Epoch-by-Epoch™ Network-Centric Positioning Unit (ENPU) product that was built specifically for test range Future Combat System (FCS) testing of dismounted solider and low-dynamic vehicles and results obtained by the Army during testing of the ENPU.

Our approach combines the concept of GPS reference networks together with low-cost COTS hardware and Geodetics Epoch-by-Epoch™ technology designed specifically for these types of dynamic applications.

The figure below illustrates the components of the system.

The host range, in this example WSMR, is populated with some number of GPS reference receivers (minimum of one). The RTD-Pro reference network management system communicates with the reference receivers through the Host Range Control System, and provides the differential infrastructure required to meet the accuracy requirements. The ADATD provided "Common Data Link" application interfaces RTD-Pro with the wireless data-link to both transmit the GPS observables produced by the reference network to the participant packages for their use in the positioning process, as well as a mapping solution showing the computed location of the participant packages.



Geodetics software on the ENPU units perform Precise Instantaneous Network ("PIN") positioning utilizing data from one or more reference receivers and the internal participant receiver to produce a rigorous network solution at each measurement epoch. PIN positioning is based on Geodetics' Epoch-by-Epoch™ technology. Unlike traditional RTK approaches, there is no need for re-initialization immediately following loss-of-lock problems such as occurs when GPS satellites are occluded from the antenna's view. This feature of instantaneous integer ambiguity resolution is of utmost importance when trying to position a moving object such as a dismounted soldier being affected by foliage and structures in urban terrain, or a low-dynamic vehicle being affected by airframe masking and other occlusions as it maneuvers.

A well functioning set of reference receivers is central to the ability to meet the Army's accuracy requirements. At the Central Facility, RTD performs what Geodetics refers to as Precise Instantaneous GPS ("πGPS"). That is, at each epoch, the GPS measurements from all Reference Receivers are analyzed to estimate independent site positions (relative to one site whose positions are known – in RTD terminology this site is called the "Master") and troposphere delay parameters at each site. In network adjustment terminology, this is referred to a session-mode solution. In RTD these are performed independently at each epoch. Thus, network closure is enforced at each epoch, but not between epochs. As in baseline mode, the independent session solutions can be adjusted over multiple epochs to improve the precision of (static) site positions. This is equivalent to a rigorous least-squares network adjustment since the inverse of the solution covariance matrix from each epoch is used for constructing the weight matrix for the multi-epoch adjustment. All this makes RTD suitable for real-time quality control of the reference network, by being able to continuously adjust for the site positions with a temporal resolution that is set only by the sampling rate of the receiver.

System Testing
The technologies and systems described above have undergone rigorous testing by various organizations within the DoD. The Central Test and Evaluation Investment Program (CTEIP) funded Geodetics in a series of test programs to validate the performance of its technologies for T&E applications. The test results were published in the September/October 2004 International Test and Evaluation (ITEA) Journal in a paper titled, “Epoch-by-Epoch™ Real-Time GPS Positioning in High-Dynamics and at extended ranges”. This paper won the ITEA 2005 Publications Award.

As part of the process used to evaluate the candidate systems for the CRIIS RPI effort mentioned above, WSMR subjected the ENPU to extensive environmental tests including shock and vibration, wind, sand and rain testing, hot and cold drop testing, EMC and EMI testing, solar radiation and positional accuracy testing.

Using a system configuration similar to that described above (not including the CPL application), testing of the ENPU was conducted at the Army Operational Test Command (OTC) Headquarters, Ft. Hood, Texas. A summary of these tests and results is now presented.

Ft. Hood Testing

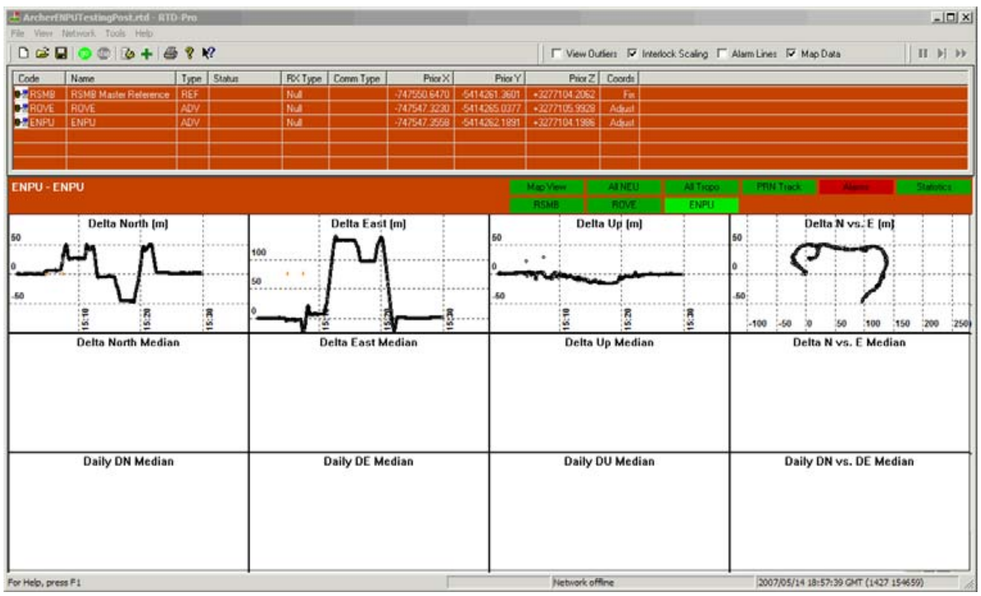
All instrumentation designed to be carried by the dismounted soldier was placed in a vest as shown below:

The image to the right shows the reference receiver and RTD-Pro host laptop computer at the test site.

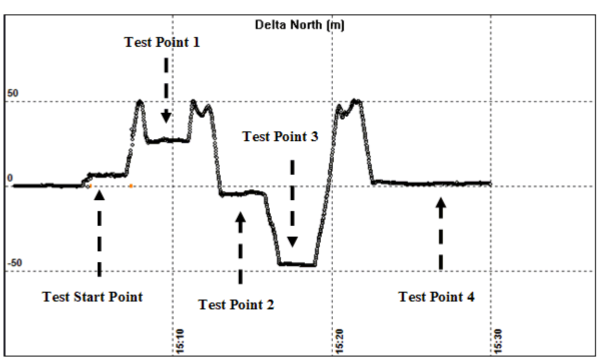
Once the reference receiver and RTD-Pro were operational, tests were run to demonstrate the capabilities of the ENPU under operational test conditions. A test path at the “Rattlesnake Hill” testing area at Ft. Hood was selected to provide a realistic operational test environment consisting of real-world rough terrain including foliage, hills and valleys which are typical of operational testing environments.

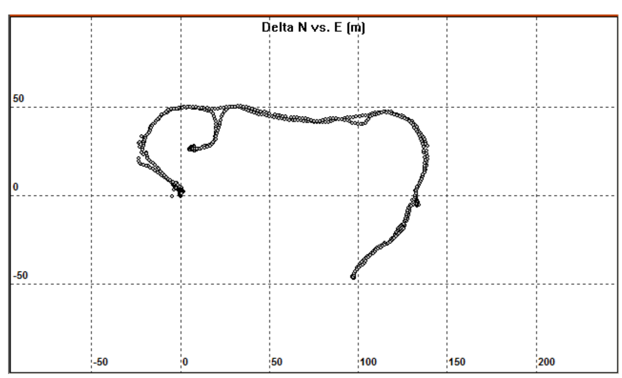
Three independent test runs (walks) were conducted. For each test run, a member of the Ft. Hood staff put on the test instrumentation vest and walked the test path, stopping at each of four test points along the way for approximately two minutes each to allow for the gathering of static data at each test point. The image to the left shows preparations for one run.

The screenshot below shows the North, East, Up and North vs. East components of the ENPU solutions for a single test:

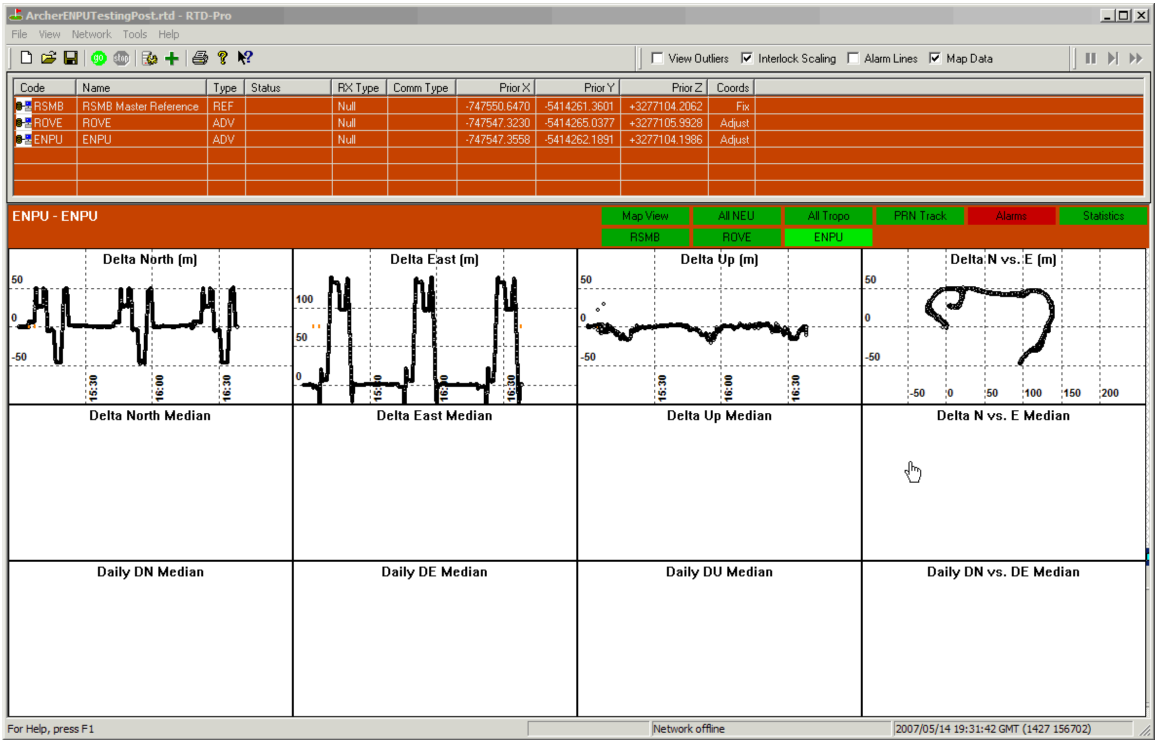


The figure to the left below shows the North component of the test path, highlighting the test points where static data were gathered and the figure to the right below shows the North vs. East (ground track) of the test path.





The screenshot below shows the North, East, Up and North vs. East components of the GPS solutions for all three test runs:



To understand the performance of the systems during the test, we focused on the static test points. This allows us to quantify precision under each of the environments represented by the test points. The table below summarizes the results for the three tests:

Static Point	Start Time	End Time	North Std	East Std	Up Std	Solution Count
1	15:00:00	15:04:20	0.17847	0.19611	0.6316	257 solutions with 0 outliers (0.0%) (0 non-solutions)
2	15:04:55	15:07:02	0.25795	0.21068	1.25746	127 solutions with 12 outliers (9.4%) (0 non-solutions)
3	15:08:33	15:10:55	0.46535	0.71605	2.52087	141 solutions with 0 outliers (0.0%) (0 non-solutions)
4	15:13:00	15:15:47	0.55073	0.31194	2.29712	166 solutions with 0 outliers (0.0%) (0 non-solutions)
1	15:16:45	15:18:55	0.31502	0.20043	0.53291	128 solutions with 0 outliers (0.0%) (0 non-solutions)
2	15:22:47	15:42:40	0.67635	0.34496	1.36438	1191 solutions with 0 outliers (0.0%) (0 non-solutions)
3	15:46:46	15:49:00	0.37978	0.13818	0.481	135 solutions with 11 outliers (8.1%) (0 non-solutions)
4	15:54:21	15:56:35	0.63137	0.4718	2.02862	132 solutions with 1 outliers (0.8%) (0 non-solutions)
1	16:00:50	16:17:00	0.74103	0.28726	1.20048	968 solutions with 15 outliers (1.5%) (0 non-solutions)
2	16:23:45	16:25:40	0.3291	0.42795	1.24109	115 solutions with 3 outliers (2.6%) (0 non-solutions)
3	16:28:05	16:30:00	0.22223	0.11763	0.66406	114 solutions with 16 outliers (14.0%) (0 non-solutions)
4	16:31:35	16:33:40	0.11669	0.15071	0.73627	125 solutions with 0 outliers (0.0%) (0 non-solutions)

Multi-epoch statistics are based on two robust estimators, the median and the interquartile range (IQR), which are less sensitive to data outliers than the traditional mean and standard deviation. The median is used to characterize the central or characteristic value, and the IQR is used to characterize the dispersion of the data about their central value. The IQR is defined as the range of the middle 50% of the data (the difference between the 75th and 25th percentiles). When a data sample is drawn from a normal distribution, its mean very nearly equals its median and *its standard deviation equals ¾ of the IQR*. The standard deviations presented above were computed as ¾ the IQR where data points were considered outliers if they were greater than 4 times the IQR of the dataset.

Typically, when we characterize the accuracy performance of a GPS system, we analyze data gathered over a full 24 hour period. The reason for this is that the performance of the system varies with changes in the GPS constellation. The data provided in the table above illustrate this quite well. The system will perform differently at different times of the day. By analyzing data over 24 hours, we capture these performance changes and get a more realistic picture of the system performance. For this reason it is instructive to look at an average of the standard deviations for all test runs. This gives a more realistic picture of system performance (including repeatability) than any single test. These averages are provided in the following table (note that all measurements are in meters).

ENPU	**North**	**East**	**Up**
Precision (meter)	0.205963	0.173643	0.7025

The table shows that for the tests conducted, the ENPU is provided solutions at about 20 cm horizontal and 70 cm vertical.

Baseline Length and Indoor Results

In addition to the real-world operational test conditions of foliage, hills and valleys described in the tests above, in many operational scenarios, situational awareness for vehicle and dismounted soldier tracking is complicated by the difficulty in maintaining GPS accuracy or coverage due to such things as dense vegetation, caves, tunnels and indoor applications.

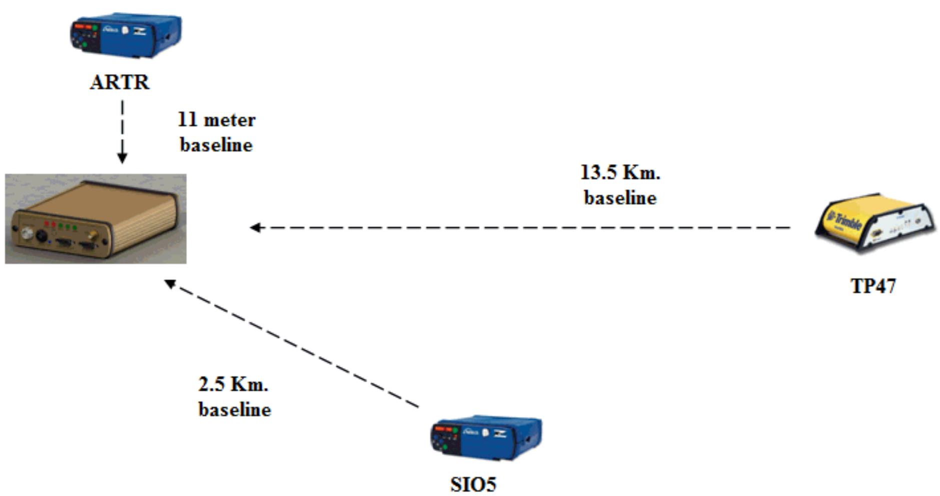
While outside the scope of this paper, a robust solution to the indoor tracking problem will likely involve a multi-sensor fusion approach where several homogeneous and/or non-homogeneous sensors are fused such that the strengths of one solution compensate for the weaknesses of others. The design of the ENPU anticipated these issues. Care was taken in the selection of the GPS sensor used in the version of the ENPU tested and the unit is able to track the GPS constellation at up to -159dBm which means that limited indoor tracking is possible (single story buildings). Additionally, a differential positioning system such as the ENPU relies on data being transmitted from one or more reference receivers. As such, it is informative to evaluate the effects that varying differential baseline lengths have on the precision of the positioning results.

The tests presented below were conducted to evaluate the indoor and outdoor performance of the ENPU under varying baseline lengths.

The images below show the antenna in the indoor configuration. The antenna was placed on the orange cone inside of Geodetics lab facility. The roof of the facility is illustrated in the image to the right. The roof consists of ½ inch plywood covered by tar paper to prevent rain leakage.

In the outdoor configuration, the same antenna was placed on the roof top with clear visibility to the GPS constellation.

Differential reference receiver data was delivered to the ENPU from three reference receivers: ARTR, an Ashtech Z series receiver with a baseline length to the ENPU antenna of approximately 11 meters, SIO5, also an Ashtech Z series receiver with a baseline length to the ENPU antenna of approximately 2.5 Km., and TP47, a Trimble receiver with a baseline length to the ENPU antenna of approximately 13.5 Km. This configuration is illustrated below:



The results obtained in these tests are summarized in the table below.

NPU Outdoor Performance			**Note: All values are in meters**			
	Test Date	**Reference**	**Baseline**	**North StdDev**	**East StdDev**	**Up StdDev**
	4/30/2006	ARTR	11.08218	0.6937	0.59169	1.79606
1	4/30/2006	SIO5	2514.32131	0.64314	0.56589	1.55919
	4/30/2006	P472	13538.93553	0.67077	0.58248	1.62057
NPU Indoor Performance			**Note: All values are in meters**			
	Test Date	**Reference**	**Baseline**	**North StdDev**	**East StdDev**	**Up StdDev**
	5/29/2006	ARTR	10.92737	3.45577	2.8116	7.13446
2	5/29/2006	SIO5	2514.92052	3.42554	2.79797	7.0174
	5/29/2006	P472	13537.00244	3.41271	2.80889	7.06108

Future Work

To improve the capability of the ENPU package to operate in GPS-denied environments such as inside buildings, the multi-sensor fusion approach mentioned in the paper needs to be continued. Fusing results from multiple geo-location techniques such as dead-reckoning, sharing of GPS measurement data between multiple soldiers in a Mobile Ad-Hoc Network, high-sensitivity GPS sensors and RF-Ranging, promises to extend the operational envelope of positioning systems.

Summary

In this paper, we presented our approach to providing accurate TSPI information for dismounted soldiers and low dynamic vehicles. The approach consists of reference receivers and a reference network management solution that together provide the differential infrastructure necessary to achieve the desired accuracy. Data from the reference receivers is processed on the Epoch-by-Epoch™ Network-Centric Positioning Unit to provide the accurate solution. Several tests of the ENPU were presented. The first tests, conducted under operational test conditions at Ft. Hood Texas indicate that the unit provided approximately 20 cm. precision horizontal and 70 cm. vertical. The second tests show that ENPU positioning is essentially invariant to baseline length up-to about 13 km. Further, it shows that the ENPU provides outdoor stand-alone level positioning results indoors with differential positioning. Finally, we briefly discussed an approach to extending the operational envelope of the ENPU to indoor tracking through a multi-sensor fusion approach.

Acknowledgements

We would like to acknowledge the efforts of Mr. Ed Nelson and Mr. Elmer Johnson of TESCO at OTC headquarters, Ft Hood, TX, in the support of these tests.