GPS on the Web: Applications of GPS Pseudolites

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This column provides the web-based GPS resources and their technical background information. Its purpose is to inform the reader about the data, software, electronic documents that are available on-line. This column is coordinated by Dr. Jinling Wang, The University of New South Wales, Sydney. Comments and suggestions are appreciated (jinling.wang@unsw.edu.au).

In this issue's column, Dr. LeMaster – until recently at the Stanford University Aerospace Robotics Laboratory (ARL) and now with Lockheed Martin – discusses many applications of GPS pseudolites. Websites for several of the pseudolite research groups at Stanford and at other institutions are provided.

PSEUDOLITE OVERVIEW

GPS pseudolites, or 'pseudo-satellites,' are small transmitters that transmit GPS-like signals in a local area. Typically ground-based, they can aid in GPS positioning in three main ways. First, they can be used to augment the GPS satellite constellation by providing additional ranging sources when the natural satellite coverage is inadequate. Applications for which this additional coverage is beneficial include navigation in places with limited sky visibility, such as urban canyons and open pit mines, as well as some on-orbit applications involving relative positioning of spacecraft.

Second, pseudolites can be used as an aid to carrier-cycle ambiguity resolution when using carrier-phase differential GPS (CDGPS) for precise positioning. Motion-based integer resolution using only satellites is often a slow process because of the slow rate of change in the line-of-sight vectors to the satellites. In contrast, a receiver in the presence of a local pseudolite can see a large change in the line-of-sight vector with relatively little absolute motion on the part of the receiver. This can yield integer resolution in a matter of seconds.

Third, pseudolites can be used to replace the GPS constellation completely. This is generally done to emulate GPS positioning indoors, although more exotic locales – such as underground or on the surface of other planets – have also been proposed. Most of this final class of applications use CDGPS rather than code-phase positioning because of the relatively small working volume of the pseudolite array.

Depending somewhat on the application, using pseudolites presents four primary challenges to the system designer. First, it is necessary for the receivers to be able to track the non-standard pseudolite signals. This is a factor that clearly depends upon the receivers and pseudolites actually used. Second, the locations of the pseudolites must be determined to the same accuracy as the desired navigational capability of the system. This means that the locations of the pseudolites must be known to centimeter-level accuracy to enable CDGPS positioning, which may or may not present a surveying problem depending on the application. Third, if it is a CDGPS application, a method must be chosen for carrier-phase integer resolution. With pseudolites this is generally done through motion-based techniques. Finally, care must be taken that the signal from nearby pseudolites does not mask the much weaker signal from distant pseudolites or satellites. Although working solutions abound, the optimal solution to this so-called 'near/far' problem is a matter of ongoing research.

Because pseudolites are not a widely-used technology, there are relatively few web-based resources for people doing pseudolite research or applications work. Many of the research labs, however, do publish the papers containing the results of their studies on the web, and it is to these sources that the reader is best directed.

STANFORD PSEUDOLITE RESEARCH

Although pseudolites were first used for testing before the advent of the GPS constellation itself, many of the initial uses of pseudolites in non-standard applications occurred at Stanford University. This section briefly summarizes some of the more significant research at Stanford, in each of the three classes of applications. The web sites of the primary Stanford groups doing pseudolite research are listed here.

- **http://arl.stanford.edu/** The Aerospace Robotics Lab at Stanford. The projects utilizing pseudolites include the Free Flying Robots and the Mars Rover Navigation. Authors to look for in the publications list include Corazzini, LeMaster, and Zimmerman.
- **http://www.stanford.edu/group/GPS/** The Stanford GPS Lab. Look for publications by Cobb, Cohen, Lawrence, Pervan, and Teague.

Work by Stone to augment the satellite constellation by using pseudolites for open pit mining is a prime example of the first class of pseudolite applications. Because the steep walls of these mines frequently block satellite signals, pseudolites perched on the rim become the only viable way to ensure adequate signal coverage at the bottom of the mine.

The second class of pseudolite applications – those that enable rapid integer initialization for CDGPS – is represented by the Integrity-Beacon Landing System (IBLS), the precursor to the U.S. Federal Aviation Administration's Local-Area Augmentation System (LAAS). IBLS/LAAS is a method for precision approach and landing that involves the aircraft flying through the transmission bubble of a pair of pseudolites located near the end of the runway. Another application studied at Stanford is integer resolution for the precision control of automated farm tractors.

The use of pseudolites to replace the satellites for indoor positioning originated with Zimmerman at the Stanford Aerospace Robotics Laboratory (ARL). This work has extended to a series of projects exploring relative navigation and station keeping with formations of vehicles. Research by Zimmerman and Corazzini at the ARL utilized robots floating on an air-bearing table to study GPS-based formation flying of space vehicles, while work by Olsen and Park explored 3-dimensional relative positioning using blimps in an indoor pseudolite environment. This latter work since moved to MIT: Details may be found at **http://www.mit.edu/people/jhow/ff.html.**

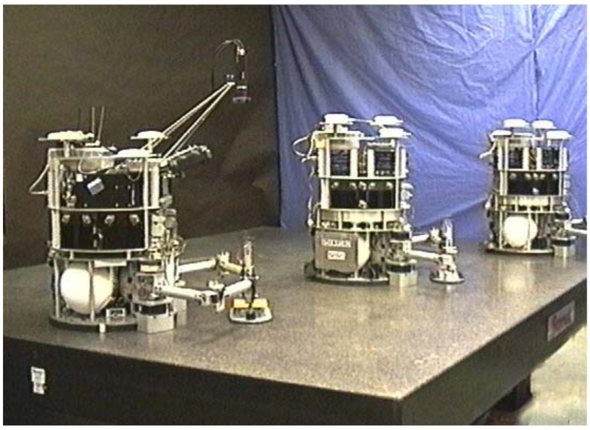

Figure 1: The ARL free-floating robot testbed. Pseudolites on the ceiling of the room provide position and attitude information.

As was mentioned previously, when using pseudolites it is necessary to know the location of the devices themselves to reasonably high accuracy. This is generally accomplished either through manual surveying, or through the use of other á priori position information. Recent work at the ARL by the author has overcome this difficulty by using GPS transceivers (containing separate pseudolites and receivers) to determine the locations of all of the GPS devices in the array. The resulting Self-Calibrating Pseudolite Array (SCPA) is intended for use as a navigation aid for future Mars rovers.

Figure 2: The Stanford SCPA Prototype with the NASA Ames K9 Mars Rover

INTERNATIONAL WORKING GROUP ON PSEUDOLITE APPLICATIONS

An effort to improve communication and facilitate the sharing of ideas among pseudolite researchers has begun under the auspices of the International Association of Geodesy. The web site of this international working group, listed here, provides a bibliography of relevant papers and links to many related sites.

http://www.gmat.unsw.edu.au/pseudolite

The goal of this group is to study new concepts of pseudolite-related positioning and, in particular, applications of pseudolites in engineering geodesy. Major objectives of the research activities are to study:

(a) Pseudolite augmentation of GPS
(b) Pseudolite-only positioning scenarios
(c) Integration of pseudolites with other sensors, such as INS

OTHER PSEUDOLITE RELATED WEBSITES

The following are a few other notable pseudolite-related websites hosted by research groups, organizations, and manufacturers.

- http://www.helinet.polito.it/NAVIGATION/default.htm The Communications and Navigation Research Group at Politecnico di Torino, Italy is considering high-altitude aerial pseudolites for both GPS and Galileo augmentation.
- http://ifen.bauv.unibw-muenchen.de/ The Institute of Geodesy and Navigation, University FAF Munich, Germany, is examining pseudolite augmentation for aircraft applications.
- http://www.gmat.unsw.edu.au/snap/work/pseudolite.htm The pseudolite research page for the Satellite Navigation and Positioning Group at the University of New South Wales, Australia.
- http://www.geomatics.ucalgary.ca/GPSRes/first.html The Satellite-Based Positioning and Navigation Group at the University of Calgary, Canada, has studied the use of inverted pseudolite arrays.
- http://gps.snu.ac.kr/snugl.htm The Seoul National University GPS Lab has developed an indoor pseudolite system.
- http://www.integrinautics.com/ Started as a byproduct of the IBLS research at Stanford, IntegriNautics is one of the first manufacturers of commercial pseudolites.
- http://www.navicom.co.kr/english/product/b-4-3.asp Navicom, a Korean company, has recently started a line of pseudolite products.
- http://www.ion.org/ The majority of the published pseudolite research appears in various Institute of Navigation publications.
- http://www.ieee.org/ Several of the other notable papers on pseudolites appear in the proceedings of the IEEE Position, Location, and Navigation Symposium (PLANS).

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