Precise, Real-Time Dredge Positioning

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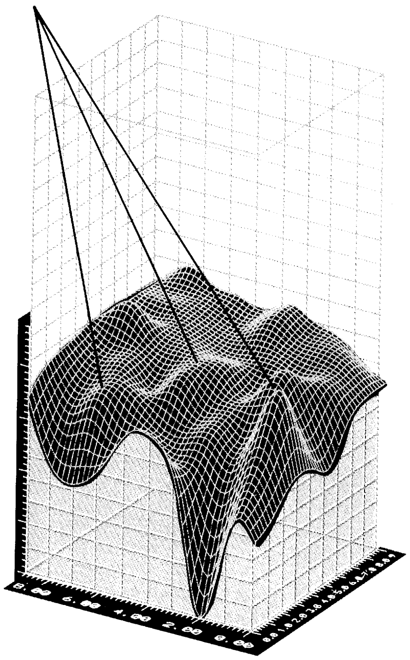

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"Innovation" is a regular column in GPS World *featuring discussion of recent advances in GPS technology, its applications, and the fundamentals of GPS positioning. This time we look at the development of a new high-accuracy system for the marine environment.*

This column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Surveying Engineering at the University of New Brunswick. As always, we welcome your comments and suggestions of topics for future columns.

Since the first issue of *GPS World,* this column has reflected on futuristic positioning and navigation of vessels calling on ports worldwide. In the July/August 1990 issue, "Electronic Charts and GPS" presented the scenario of a vessel safely maneuvering in zero visibility, with positioning to an accuracy of one decimeter and display of the event on a tideless electronic chart having the appropriate resolution. The electronic chart is "tideless" because GPS also serves as an onboard, real-time tide gauge. This article will describe the design of such a positioning system, including a historical perspective of the development of kinematic GPS techniques that led to such precise positioning being possible.

The U.S. Army Corps of Engineers, under its Dredging Research Program, is developing a system to position dredges and hydrographic survey vessels with an accuracy of one decimeter in real time. As with all GPS-based systems, it will be three-dimensional and will operate in all weather conditions, 24 hours per day. The present design schedule calls for delivery of the prototype by September 1993.

REASONS FOR DEVELOPMENT

A major program of the Corps is the dredging of the nation's ports, harbors, and waterways at a cost of about $400 million annually. More than 100 survey crews of the Corps and its contractors work full-time performing hydrographic surveys in support of this mission. More accurate dredge positioning and surveying techniques are needed to properly control the dredging, administer the contracts, and determine fair payment to the dredging contractors.

Current technology positions dredges and hydrographic survey vessels horizontally with systems that electronically measure ranges or ranges and angles from previously established transponder stations on shore. Most systems require the vessel to occupy a calibration point installed near the jobsite each workday either to initialize or calibrate the system or to verify its accuracy. Maintaining these shore stations and calibration points, moving transponders about, and performing the calibration or verification process are extremely expensive and labor-intensive tasks.

Accuracy is another issue to be addressed. The systems described obtain typical accuracies of about three meters. In addition, all dredging and survey operations are vertically referenced to a tide, lake, or river gauge to reduce the depth readings to some datum, for instance, mean lower low water (the average of the lower of the nominally two daily low tides over a suitably long period) in tidal areas. This method assumes that water surface elevations at the gauge site either accurately represent the surface elevations at the survey site, or that some type of zoning model exists to generate corrections.

Current technology limits the surveyor's ability to define this datum to an approximate accuracy of 0.2 meter in many situations. Offshore tide gauges are used as a means to produce mathematical models of the surface characteristics of a body of water. However, these are expensive to install, operate, and maintain. Furthermore, the models produced are limited in accuracy by various tidal characteristics and by meteorological, oceanographic, and hydrological effects.

The Corps's basic design goals for this new system are to

- increase the operational capability for both horizontal and vertical positioning,
- eliminate as many shore-based control stations as possible, and
- provide the system at a cost comparable to existing systems.

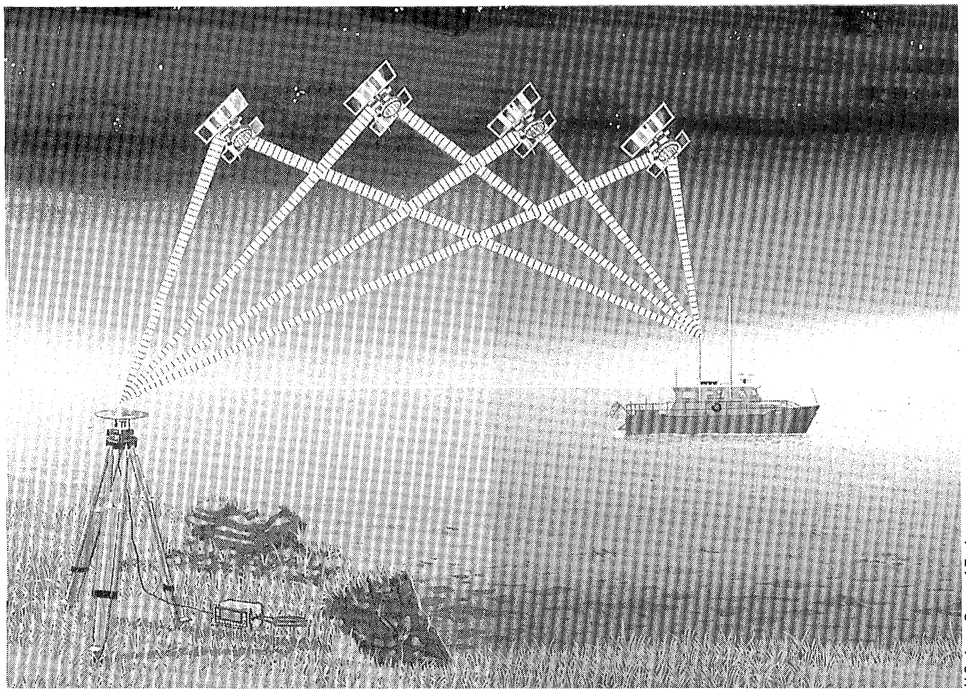
HISTORY OF KINEMATIC GPS

To better understand some of the choices made in designing a real-time positioning system for marine applications such as dredging, it is helpful to know some of the history of the development of kinematic GPS.

In 1985, Benjamin Remondi of the U.S. National Geodetic Survey performed an experiment in which he moved a continuously operating GPS receiver in order to compute positions of a number of discrete, fixed points. The antenna was stationary over each point for a short time, about five minutes. The experiment was successful, and the results were presented in the surveying and navigation literature.

An important accomplishment in this experiment was that Remondi actually tracked, and later computed and plotted, the trajectory of the antenna while it was in motion. Furthermore, he utilized the carrier data for positional computations rather than the code. Although this procedure was termed *stop-and-go kinematic surveying* (or, affectionately, "the Remondi Fox Trot"), its ability to determine an instantaneous three-dimensional position to an accuracy of centimeters was its most promising aspect.

Following this work, several scientists began experiments to position a continuously moving platform with similar accuracies. In 1988, the U.S. Army Corps of Engineers positioned a moving vehicle on the sled track at Holloman Air Force Base in New Mexico with accuracies of 1 to 2 centimeters. This project and others further demonstrated *kinematic positioning*. In this context, kinematic positioning is defined as positioning a continuously moving platform using the carrier-phase data while operating in a differential



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Artist's conception of the proposed system.

mode. The three-dimensional baseline vector between a fixed reference station and the antenna on the moving platform is computed for each epoch of carrier-phase measurements. Typically, the update rate would be once per second, and the signals from each satellite would be measured simultaneously. Because some time-varying errors such as multipath appear in each kinematic solution, the accuracy of a kinematic solution tends to be less than that of a static solution for the same baseline.

Although work since 1985 has been encouraging, the technology is complex and difficult to implement due to a practical problem. To compute a baseline using the kinematic technique requires a solution for the *integer cycle ambiguity,* which is a bias in the whole number of carrier wavelengths between the antenna and satellite at the instant the receiver locks onto a satellite.

The basic method used to resolve this ambiguity is to collect data at two receivers for a period of time while each receiver is stationary. Early survey techniques required about one hour of stationary data. For the case in which the mobile receiver started on a stationary yet unknown position, Remondi introduced several techniques to resolve integer cycle ambiguity. The first, known as the *antenna swap,* reduces the ambiguity resolution time to less than a minute. He also suggested that when the initial positions of the reference and moving antennae are known, it is possible to compute the ambiguities within seconds and use the computations during subsequent motion. This is called the *known baseline* technique. Finally, he developed the *pseudokinematic* technique. With this method, a surveyor computes the ambiguities by revisiting a series of known stations during a survey campaign.

With each of these techniques, however, the static initialization process is not practical for a dredge or hydrographic survey vessel. Fortunately, several scientists have recently introduced techniques to resolve the ambiguity while the receiver is in motion. This contemporary problem is receiving increased attention because it holds the key to numerous applications.

PRELIMINARY DESIGN

The new system we are developing is logically divided into three subsystems: the reference station(s), the vessel receiver and data processing unit, and the communications link. Several studies and experiments have been performed attempting to quantify the major operational constraints, such as vessel dynamics, loss of lock on satellites, and ambiguity resolution; to identify areas requiring additional research; and to define the requirements of each subsystem.

Vessel dynamics. On a dredge or survey boat, the position of the GPS antenna is not the desired final result. Instead, the requirement is to determine the position of another fixed point or piece of equipment, such as a sonar transducer or dredge cutter head. Therefore, additional information on the attitude of the vessel and the relationship of the GPS antenna to the point of interest is required. Attitude can be determined with a variety of techniques, including multiple GPS antennae, inertial systems, accelerometers, and so forth. To choose the most cost-effective solution, we are presently examining the motions expected on the various platforms. Combining the operational environment, expected motion, vessel dimensions, and accuracy requirement will allow selection of the best sensor group to translate the position of the GPS antenna to the point of interest on the vessel.

Loss of lock. The operation of the system depends on continuous reception of signals from at least four satellites. Several possible approaches to the loss-of-lock problem have been investigated in an effort to find a means for aiding the system during times of minimum or insufficient signal reception. The most obvious solution is to have more satellites — literally, the more, the better. Manufacturers have done a superb job of building receivers that rapidly regain lock, assuming at least four other satellites are being tracked.

Another possibility would be to exploit other satellite systems such as the GLONASS constellation or a future geostationary satellite system transmitting GPS-like signals. These systems presently are not being considered because of the added complexity and possible risk associated with integration of GLONASS and the fact that a geostationary GPS-like satellite does not yet exist. This may be a viable option in the future after the industry integrates the additional signals from such satellites into their hardware.

Another option is to use a high-quality frequency standard, such as a rubidium clock, in the system. When calibrated with GPS, this clock could act as an additional satellite, allowing solution when coverage drops to three satellites for short periods of time. This situation could occur, for example, if a small survey vessel were working near large ships that blocked signals from low-altitude satellites. A rubidium clock would also improve the solution for the initial ambiguity resolution.

We plan to use the last option in our system because it is relatively inexpensive, and, in the marine environment, only very limited times will occur when fewer than three satellites are visible in a fully operational GPS constellation.

Finally, we studied the benefits of an inertial system to provide positioning data during loss of GPS signals. This seemed to be an attractive and logical solution at first. However, we soon learned that the inertial system could only maintain sufficient accuracy to recover the L1 integer ambiguities for about two minutes during loss of signal lock. Longer outages would require the system to revert to a full GPS reinitialization process. Given this limitation, the high purchase cost, and maintenance and integration problems, we chose not to use an inertial system to fill in during the loss of GPS signals.

Ambiguity resolution. As previously discussed, at least three techniques require a static initialization process and therefore have limited suitability for the marine environment. Several others permit "on-the-fly" resolution, providing opportunities for development of our system. Typically these techniques use a history of the carrier data or carrier and code data to determine the ambiguity values at an initial epoch or to mathematically search over a limited region of three-dimensional space for the initial integer ambiguities. Each method has various operational constraints, such as maximum range from reference station, minimum resolution time, and P-code availability. They also presently suffer from a lack of actual data for verification of the technique. Although these techniques were developed and simulated by notable scientists, there is no substitute for an actual test of the concepts. A number of experiments are planned in 1991 for just this purpose.

OPERATIONAL CONSTRAINTS

Many pieces of the puzzle remain to be assembled, but none are unusual or overly difficult. The primary "unknown" remaining at this time is the specific ambiguity-resolution technique to be used. Fortunately, some possibilities are on the horizon. One technique, validated by Günter Hein of the University of the Federal Armed Forces in Munich, Germany, is already available. Hein was able to determine the sea surface height by tracking a GPS receiver on a free-floating buoy. The data were postprocessed and the results compared to within a few centimeters of a nearby tide gauge. Another technique, based on recent work by Ron Hatch of the Magnavox Company, uses a priori information to establish bounds within which to search for the initial ambiguities. By the end of 1991, this technique should be validated through a series of experiments using actual data.

Each resolution method requires a certain amount of data to form the solution for the initial ambiguities. This process has been estimated to take from 1 to 45 minutes, based on satellite geometry and redundancy and separation distance between the differential stations.

Another key factor is, of course, the method itself. A long resolution time may cause operational problems should the receivers frequently lose lock. However, there are many marine platforms, such as a large dredge or a floating buoy used as a tide gauge, that should experience little or no loss of signal. The resolution, once accomplished, is no longer an issue, and the position is tracked from that point on. If that solution is not acceptable for a small survey launch operating near obstructions, then techniques requiring less resolution time are needed.

At present, the range between differential stations seems to be limited by unmodeled errors to about 20 kilometers. Current investigations are examining the possibility of establishing a network of reference stations, which would extend the range. The network would be used to model systematic errors, such as orbital or atmospheric delay effects. Although much discussion and study is ongoing in this area, little work has been done to provide models for real-time applications.

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PRACTICAL CONSIDERATIONS

If consideration is given to a specific task (for instance, measuring a tidal datum or dredge positioning), then techniques are available today that exploit GPS positioning. Hein's project documented one technique with accuracies at the few-centimeter level. With some additional engineering development, a fairly robust real-time system could be deployed. Networking reference stations may increase the operational range, thereby reducing the number of reference stations required.

A major component of the system, the data communications link, must be considered for real-time implementation. The data link components are available from many sources. The most suitable data link available today for our purposes is the VHF/UHF radio. The considerations here include frequency allocations, broadcast range, and reliability, none of which should impose serious constraints on our system.

Selective availability is not a major issue with our project because its effects are minimized with differential operation. Antispoofing (P-code encryption), however, does cause some complication. The P-code, although not absolutely necessary, can provide valuable information for the ionospheric modeling process and, subsequently, the ability to use longer baselines.

Finally, the cost of a GPS-based system is surprisingly much less than that of a conventional UHF/microwave positioning system. Typical land-based systems cost $75,000, have ranges of about 20 kilometers, and require two or more reference stations having a line of sight to the vessel. A GPS-based system may cost in the neighborhood of $50,000, has an estimated range of at least 20 kilometers, and requires only one non–line-of-sight reference station.

Although not available as a production tool today, within two to three years real-time decimeter positioning with GPS on marine platforms will be a reality. These new systems will provide improved three-dimensional accuracies, reduced downtime, and lower purchase and operational costs than the systems in use today. ■