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Rapid Static Surveying Using the Global Positioning System

An NCHRP digest of the results of NCHRP Project 20-23, "Kinematic Differential GPS Satellite Surveying," prepared by Lloyd R. Crowther.

This Research Results Digest (RRD) is an update on *RRD Number 185: NCHRP Supports Advances in Differential GPS Satellite Surveying*, published in April 1992. The research has resulted in a technique by which highway engineers and surveyors may rapidly obtain precise positions necessary to maintain geodetic control. The technique uses measurements of the Global Positioning System (GPS), commercially available GPS receivers, and personal computers for data processing. Users of this technique need to occupy each point to be surveyed for only 1 or 2 min, without concern for cycle slips or other phase discontinuities in the phase data that commonly occur. Thus, this technique provides an efficient means to quickly and precisely survey a large number of points. Horizontal accuracies of 1 cm and vertical accuracies of 3 cm have been demonstrated. The software has been written to run on most available personal computers and can be operated with no special skills required.

INTRODUCTION

NCHRP Project 20-23 is now completed. The previous digest of the status of this project (*RRD Number 185*) described a civilian application of the Navigation Satellite Timing and Ranging (NAVSTAR) system. Also known as the Global Positioning System (GPS), this satellite system was developed by the Department of Defense under Air Force management. Presently, 21 satellites are in orbit, providing very precise three-dimensional information on a continuous basis.

Background

The GPS has made possible a revolution in the art of navigation, positioning, and surveying. In September 1988, NCHRP contracted for research by GPS Services, Inc. and the National Geodetic Survey Division of Charting and Geodetic Services of the National Ocean Service, National Oceanic and Atmospheric Administration, to improve the civilian applications of the GPS in land surveying.

Equipment on the market in 1988 provided point positioning using a single receiver/antenna. Measurements were made in real time with accuracies ranging from an estimated 10 to 30 m. Point positioning could be accomplished in a static mode, where the antenna occupies a single spot, or in a kinematic mode, where a mobile antenna is continuously positioned. Point positioning data, using the signals from several satellites to determine the location of a point in space, could be used by DOTs with a geographic information system (GIS) for such activities as highway inventories, accident locations, and maintenance operations.

Because systems providing levels of accuracy acceptable for some of these activities already existed or were imminent at the time NCHRP Project 20-23 research was initiated, no research was proposed in this area. However, opportunities did exist in the area of precise relative (also called differential) positioning using the GPS with two receivers/antennas, one stationary on a known point and the other mobile. Differential positioning defines the three-dimensional relationship between two points with a high degree of accuracy.

Use of the available satellite constellation had shown that precise relative or differential positioning measurements with accuracies of a few parts per million were possible in 30 min or less of point occupation for data acquisition. Preliminary work, involving the use of the GPS for rapid differential positioning of ground-based survey points, indicated the feasibility of greatly reducing the time required to accomplish the equivalent of geodetic traversing. This process uses a differential GPS measurement mode where the time needed for static data collecting from the mobile antenna over each specific point is measured in seconds instead of minutes or hours. Considering the amount of geodetic traverses being conducted by the state DOTs, the benefits of such a process are considerable.

RESEARCH APPROACH

Differential GPS Techniques

The NCHRP-funded research originally concentrated on using differential GPS techniques to determine the kinematic position of a moving antenna—continuous, uninterrupted contact with satellites and a reference antenna/receiver being required. Initial conditions that had to be established could be done by (1) occupying a monument with a previously determined position, (2) performing an antenna swap maneuver, or (3) occupying the initial positions for a sufficient time (approximately 15 to 30 min) to permit a "bias-fixed" solution.

These differential GPS techniques determine changes in the position of the mobile antenna from changes in the observed carrier phase. They accomplish these changes by measuring the three-dimensional distance variations from a base point (reference antenna/receiver), using changes in the continuous reception of the transmissions from several satellites at the same time. Under these circumstances, the continuity of the satellite phases is critical; no cycle slips or other nongeometric changes in phase may be permitted that might be falsely interpreted as antenna movement. It is clear that while the kinematic differential GPS techniques offer great potential for a wide variety of applications, there are some severe maintenance-of-phase-continuity operational constraints that may limit the practical applications of those techniques.

The Ambiguity Function Technique

A recently developed ambiguity function technique—more accurately described as a rapid-static technique rather than a kinematic GPS technique because the moving antenna is not in continuous contact with the satellites when it is moving between monuments—was subsequently investigated by the researchers. The principal benefits of this technique are the speed and accuracy with which it may be used and its immunity to cycle slips or other discontinuities in the phase data that commonly occur. The technique requires measurements from only a single epoch (instant in time) but, in practice, monument occupations of 1 to 2 min are more common. Depending on the number of satellites observed and the number of frequencies recorded, only a single occupation may be necessary.

THE OMNI PROGRAM

As part of this project, OMNI—a computer program created by the National Geodetic Survey Division—was enhanced by using the ambiguity function technique described previously for phase initialization that depends only on phase measurements. This technique can work using either the data from only a single epoch or averaged data from several epochs. The conditions required to use this technique on a single epoch will be met by the complete GPS constellation and any dual-frequency receiver capable of tracking seven or more satellites. However, rapid-static applications may make use of single- or dual-frequency receivers and require fewer satellites if multiple occupations of a monument are feasible.

Briefly, the ambiguity function technique is a trial-and-error procedure. It is a measure of how closely the phase biases of the satellites observed by the GPS receivers approach integer values. Measurements at different frequencies, and over different satellites and at different epochs as the satellites move across the sky, will yield a combination of intersecting surfaces that interfere constructively at the correct position and, as enough measurements are combined, interfere destructively at all other positions. The correct position emerges as a clearly recognizable peak as the ambiguity is computed over a volume of space that includes the correct position.

The more frequencies and directions in the sky that can be combined to compute the ambiguity function, the faster a unique solution will appear. About 14 observations are sufficient to suppress the ambiguity function at all but the correct position. However, the research shows that at least 16 satellite observations are required to give reliable results for some particular satellite geometries. Clearly, dual-frequency observations, using both the L1 and L2 GPS frequencies transmitted from each satellite, will achieve a faster solution than single-frequency observations because observations of eight L1 observations must be made at each of two epochs sufficiently separated in time to adequately change the satellite geometry. Thus, there is a requirement for two occupations of each point if single-frequency data are used.

Other combinations of single- or dual-frequency data that yield at least 16 observations will also produce successful ambiguity function solutions. However, the researchers no longer recommend single-frequency observations because the number of observations at any given epoch would be half those made by dual receivers. This, of course, doubles the amount of site occupations necessary to reach the recommended 16 observations, making this static GPS surveying much less rapid and more liable to some of the time constraints listed below. Practically continuous seven or greater satellite visibility is possible with the present GPS constellation, thereby providing suitable conditions for the proper application of the ambiguity function using a single epoch.

The ambiguity function technique requires an initial estimate of the correct mobile antenna position and a specification of the search volume size (of three-dimensional physical space) around that estimated position. If the search volume does not include the correct position, the technique will fail. Search time is a function of search volume; therefore, estimating the correct position as closely as possible is an important step. The computer program improves upon the conventional double difference solution for locating the point in space by using the rate of change of the double differences, which the researchers have found rapidly puts the true position well within a reasonable search volume.

Constraints of the Ambiguity Function Technique

In practice, additional research has found several constraints to the approach described above. The surveyor will need an appreciation of the observations necessary to make the technique work along with information on the various satellite scenarios, the station configuration, and reference station locations. Some specific constraints are as follows:

1. Although there are few periods during the day when there are insufficient satellites to do meaningful survey work, a prediction of satellite availability on the days the survey is to be conducted is essential for planning how to obtain the required minimum number of observations.

2. The geometry of the satellites during proposed station occupations should be considered because poor geometry may require extra observations.

3. For occupations lasting about 2 min, there are generally not enough GPS satellites visible during a single occupation to give a good solution. Such situations require at least one additional occupation. If the occupation lasts about 10 to 15 min, the same satellites may have moved far enough across the sky to effectively be treated as two occupations of 1 to 2 min each at the beginning and end of the actual occupation.

4. The first version of the software required the user to specify the reference satellite to be used for double differencing. That same reference satellite must be used for all occupations of a station. The field operators must know the time frame within which they need to perform the required occupations.

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5. The reference receiver must not be more than 10-15 km from any of the stations it serves because of ionosphere distortions. However, stations located using the original base location may be used as additional base locations for surveys covering a larger area.

6. Knowledge of the offset of the phase center (antenna) from the occupied monument is critical to the success of this surveying method. To control this eccentricity, the antenna is often mounted on a fixed-length pole that can quickly be leveled over the monument, making all eccentricities vertical and identical. Otherwise, each eccentricity must be carefully measured and recorded.

7. Field logs are required for imputing information during the data processing. They must record the start and stop time of each occupation, and the name of the station occupied; the satellites being tracked; receiver status messages; and pertinent site information such as obstructions.

8. The data recorded in the GPS receiver are in the binary receiver format for the particular receiver being used. The data must be downloaded into a PC containing OMNI, the GPS processing software, and reformatted to one of the two standard formats (ARGO or RINEX) that can be read by the MERGE program contained within OMNI. RINEX is the format of choice because it is the manufacturers' responsibility to provide their customers with the software to produce a RINEX data file from the receiver data. OMNI can then read this standard product without OMNI revisions to account for any changes the vendors may make to their data formats.

9. OMNI is incompatible with High Memory managers such as those found in DOS 5.0 and WINDOWS. When the original OMNI programs were written, those programs were not available. The simplest solution is to remove the memory managers from the computing system.

HOW TO USE OMNI

The following items are needed to execute the OMNI program: a 386-based personal computer or better with a) 640 kbytes of RAM on the motherboard; b) at least 4 Mbytes of available RAM; c) a math co-processor (required with any type computer); and d) M/S DOS 3.3 or higher.

OMNI is by no means a finished set of programs. Besides the bugs that occasionally need to be fixed, there are also some major enhancements being planned for future versions. To keep the OMNI users as up to date as possible and to minimize the burden at NOAA, the OMNI software is available through the computer network INTERNET. Users are advised to scan this directory periodically to check for new program updates.

INTERNET is an information database run by the National Science Foundation (NSF) in Washington, DC. It caters to academic institutions, but is also available to others. Some state governments are already connected to INTERNET, as are all major universities, either directly or indirectly through gateways of other networks. Details on joining INTERNET can be obtained by contacting the nearest university and asking for the name of the local Midlevel Network representative. Additional information on using INTERNET is available by calling NSFNET Network Service Center (NNSC) at 617/873-3400.

To access OMNI on the INTERNET computer network, access must be available on the PC via the file transfer program (ftp). Then, go to the directory where the OMNI programs will reside, e.g., C:\OMNI, and type the following sequence of commands. (Note: ftp is case sensitive—so please use lower case as shown.)

C:\OMNI> *ftp cors.grdl.noaa.gov*
login: *anonymous*
password: *[user's name]*
ftp> *cd dist*
ftp> *cd omni*
ftp> *bin*
200 Type set to 1
ftp> *prompt*
Interactive mode off
ftp> *mget *.**
wait while files are transferred
ftp> *bye*
C:\OMNI>

In July 1993, the basic program files available through INTERNET required 7.7 Mbytes of memory. Two subdirectories included with the basic program increased the total required memory to almost 10 Mbytes. At the present time, these requirements may differ somewhat because the program is being updated periodically as improvements are developed. GPS data will also consume a fair amount of disk space. A minimum available hard disk capacity of 40 Mbytes is advisable.

OMNI installation also requires a PATH parameter in the AUTOEXEC.BAT, i.e.,

PATH=C:\DOS;...;C:\OMNI;...

and the following parameters in the CONFIG.SYS:

DEVICE=C:\DOS\ANSI.SYS
FILES=64
BUFFERS=64

Please direct any problems or inquires via FAX 301/713-4475, ATTN: Dr. Gerald L. Mader.

Course Available

The National Geodetic Survey (NGS) is under no responsibility to provide telephone support for the OMNI program. However, it plans to offer a short course seminar for rapid-static and kinematic processing. Although the course will provide background material to explain how the algorithms work, which is essential to understanding how and why to set various program parameters, it will concentrate mainly on processing representative data sets in class and under supervision. The classes will probably last 2-3 days and be relatively inexpensive (enough to cover the classroom and computer rentals). For up-to-date course information, contact Dr. Mader, Geodesist, Geodetic Research and Development Laboratory, NGS, at 301/713-2854.

Publications Available

A loan copy is available of the second version of the *OMNI 2.00 User's Guide*, which describes the program and its use, and of the *User's Guide to Rapid GPS Surveying*, which describes the field procedures to be followed for implementing the rapid-static solutions software contained within the OMNI GPS software. The second publication is a product of NCHRP Project 20-23. These copies are available from

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A loan copy of the unedited Final Report for NCHRP Project 20-23, *Rapid Static Surveying Using the Global Positioning System*, is also available from the same address.