PRACTICAL USE OF THE GLOBAL POSITIONING SYSTEM

by William M. Harris and David W. Bennett

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ABSTRACT

The U.S. Geological Survey has been interested in and involved with the development of Global Positioning System (GPS) equipment because of the many applications envisioned by the various disciplines within the Survey. Further, the Geological Survey has had a keen interest in GPS since its inception, due to the promise of cost-effective geodetic control surveys in support of the National Mapping Program. The Survey's Mid-Continent Mapping Center has applied GPS receivers for establishing horizontal control on a number of different mapping projects since early 1986. The experiences gained in performing those surveys and the problems encountered are described in order to help other surveyors avoid these same basic operational problems.

INTRODUCTION

Horizontal control surveys are performed by the U.S. Geological Survey both for original mapping, revision, and for map accuracy testing. Obtaining this control can be involved, time-consuming, and costly, especially where maps cover dense forest, high mountains, nearly impenetrable swamps, and remote deserts. Traditionally, to obtain positional values, terrain had to be traversed, with direction and distance measurements carefully made and recorded along the way. Satellite surveying using the current Global Positioning System (GPS) promises to change much of this activity. Access might still be a problem to some degree, but much of the traverse requirement is eliminated; the struggle to reach point B from point A is reduced to the travel time needed between stations. However, along with this promise, USGS has encountered certain practical problems using GPS and has developed solutions for these problems.

BACKGROUND

To provide horizontal control for a 7.5-minute quadrangle map, latitudinal and longitudinal positions must be established at features photoidentifiable on compilation-scale photographs at intervals sufficient to support aerotriangulation. Choice of horizontal control point location is flexible, but horizontal bridging techniques generally demand field-established control within 15-minute spans of longitude and latitude. Presently, GPS is being used to establish geodetic coordinates for map control points--monumented stations (basic control) are not being established. USGS map control surveys adhere to second-order, class II standards of accuracy, as specified by the Federal Geodetic Control Committee (FGCC). These standards are 1 part in 20,000.

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To obtain this accuracy by conventional surveys, we generally perform a procedure known as electronic traverse. Simply stated, our survey lines originate and close on second-order, or better, control and are run using electronic distance-measuring (EDM) instruments, and 1-second theodolites.

First time 7.5-minute map coverage for the 48 conterminous States is nearly complete and our revision program will begin to assume priority. GPS is often our method of choice for obtaining additional field surveyed control for maps being revised.

As maps are revised, map bases and map content are found to be reusable to varying degrees. Depending on vintage and methods employed to determine map scale, quadrangle bases undergo horizontal accuracy testing to ensure compliance with National Map Accuracy Standards. As the revision program escalates, more field control will be needed to support this horizontal testing. GPS is being used extensively for this purpose.

GLOBAL POSITIONING SYSTEM

The GPS is under development by the Department of Defense to provide worldwide navigation capability for the Nation's military ships, planes, and land vehicles. When completed in 1991, it will consist of 18 NAVSTAR (Navigation by Satellite Timing and Ranging) satellites orbiting the earth such that at least 4 will be electronically "visible" simultaneously from any location on the earth's surface. Presently, only seven usable satellites are in orbit and they provide sufficient coverage for obtaining position measurements for a period of only 5 hours each day.

GPS surveying seems a logical approach to expedite map control surveys. The procedure used to establish control is simple in theory--GPS instruments are operated at both ends of a survey line (vector) and each receives and processes radio signals of the GPS satellite vehicles (SV's). The resulting data are used to compute coordinate differences (ΔX, ΔY, ΔZ) of the two points.

Our GPS surveys resemble conventional surveys in that they are traversed in leap-frog fashion, beginning and closing on basic control. Line-of-sight between ground points is not necessary, nor is it necessary to observe vectors in any particular order. Only one person is needed per receiver, and a brief tracking time will render a position of third-order accuracy or better. GPS surveys, it would seem, require little effort, much less time than conventional surveys, and sufficient accuracy is easily obtained.

The GPS is capable of rapid third-order and better positioning, but we found operating and coordinating a GPS survey was not always as routine as GPS literature sometimes implies. Further, the system has limitations which, depending on the characteristics of the project area, often require collateral conventional surveying.

APPLICATIONS

The USGS has employed the GPS on a total of about 50 separate projects; the Survey's Mid-Continent Mapping Center (MCMC) has used the system on 15 field control assignments--8 projects were in support of our 7.5-minute map revision program, and 7 were horizontal accuracy test projects. MCMC projects have resulted in a total of 125 GPS generated horizontal positions. An example will be made of a number of these projects.

Given in Table 1 are data that describe a sample of GPS projects. Two TI-4100 satellite receivers were used in all surveys with a data collection interval of 30 minutes and postprocessing was done on microcomputers using the TI GEOMARK software. A typical GPS control survey is given in Figure 1. General rules followed in designing the survey network were:

- Lines not to exceed 35 km.
- Cross ties made whenever practical.
- At least two existing geodetic stations included in survey.
- No radials or single-point positioning.

Despite wide variance in geography, our approach to satellite surveying was similar on all projects. As problems unique to GPS surveys surfaced, field personnel became more skilled, procedures became more streamlined, and new techniques evolved. The need for more detailed site reconnaissance soon became apparent. Most operational problems were keyed to visibility, access, communication, and satellite signal reception, and all of these were made more controllable by careful planning using detail site information.

Preliminary work included the development of tentative control schemes based on proposed GPS station sites and the geographic characteristics of the project area. Actual GPS site selection was defined by two unalterable factors: 1) the need for a nearly unobstructed electronic view of the horizon; and, 2) the physical characteristics (weight, size, and power requirements) of the receiving unit.

The availability and extent of basic control was investigated to ensure adequate control to reference the GPS survey and still maintain short baseline vectors (less than 35 km). New control sites were visited during reconnaissance operations, and using compass and clinometer, station locations that met satellite visibility requirements were marked.

Routinely, data were collected for 30 minutes (1 cassette), but it was ensured that at least 20 minutes of simultaneous data were collected at each vector end. If one party logged on several minutes later than the other, a second cassette would have to be activated. This would usually guarantee sufficient data, but it also meant that our next session (time available to receive signals) would begin late unless ample time had been allowed to reach the next station and complete equipment set-up. Equipment set ups were usually routine, though occasionally the receiving antenna had to be elevated. The receiving antenna could be raised several feet by using telescopic poles affixed to the supporting tripod. Meteorological data were not recorded. Given short baseline measurements, our desired positional accuracy (second-order, class II) could be determined without atmospheric corrections.

The current GPS orbital configurations are such that the visual horizon (line where sky seems to meet Earth) must be visible within a vertical range of approximately 20^{o} from the observer's location. Tracking four SV's

Table 1--Sample of USGS GPS project parameters

PROJECT	Points needed / GPS points	Vectors / ave length (km)	Sessions per day	No. of circuits	Circuit length (km)	Closure
Belleville, Il Revision	18/15	19/17.8	2.4	3	102.5 142.4 138.2	1: 74,000 1: 39,000 1: 71,000
Davenport, Il Revision	17/9	15/21.7	2.1	4	143.1 68.0 39.8 139.9	1:233,000 1:601,000 1: 43,000 1: 93,000
Nevada, Mo Revision	11/6	11/16.3	2.8	2	72.1 109.7	1: 42,000 1:674,000
W. St. Louis, Mo Accuracy Test	2/1	2/12.7	2.0	1	25.4	1: 55,000
Kentucky (site 1) Accuracy Test	9/6	9/23.8	2.0	1	214.0	1:228,000
Kentucky (site 2) Accuracy Test	10/5	4/34.3	1.2	1	137.2	1:253,000

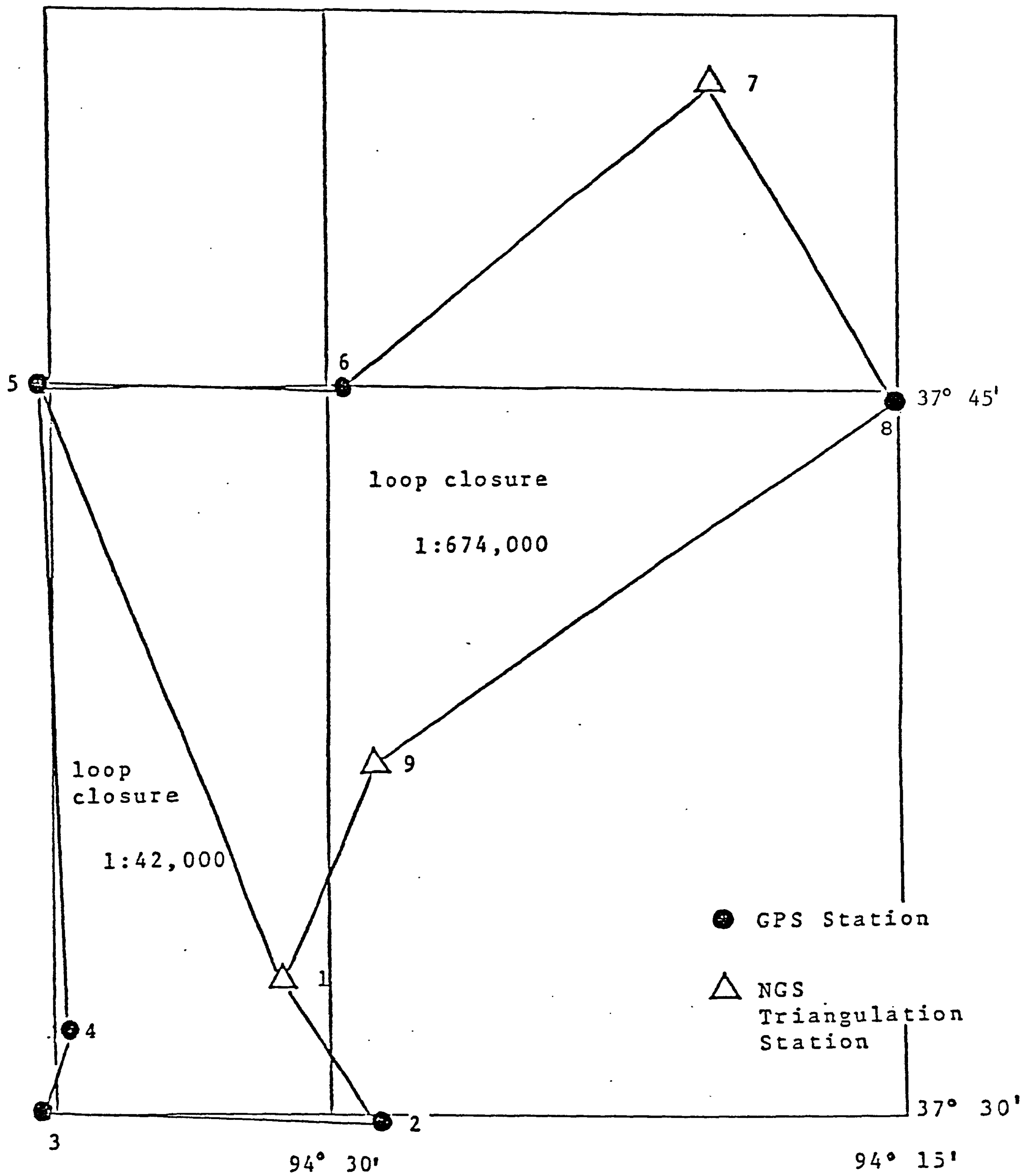

Figure 1--Control net used during Nevada, Mo., USGS GPS horizontal control project

simultaneously demands a wide field of view. During reconnaissance every attempt was made to ensure visibility within a span of about 270° ranging from the southwest to the southeast. Barriers to broadcast signals are myriad within cities and often impenetrable in timbered terrain.

All projects noted above were in heavily populated areas; for the most part, easily accessed. Still, even in these densely cultured areas, basic control triangulation stations were sometimes located at places restricted to truck travel. If carrying heavy equipment was to be avoided, points occupied had to be located within 200 feet (length of coaxial cable) of our vehicles.

Existing geodetic control stations were often found too near buildings or other manmade obstructions, blocking SV signals. A traverse can be run to establish a GPS station at a location in clear view of the orbiting SV's, but this complicates and slows the operation. Fortunately, other existing control was prevalent, and alternate points could be chosen. This will certainly not be true of all projects.

The Nevada project required visits to 10 triangulation station sites to find three usable control marks; on the Davenport project we visited 20 and needed four. For these projects control recovery impacted project cost significantly--it influenced equipment and manpower requirements and dictated to a large extent the geometry of the control network.

On all projects, it should be noted that several map control points were positioned by conventional methods--62 percent by GPS and 38 percent conventional. There are two reasons for this:

1. The point required could not be occupied because of physical obstructions. GPS stations offset from the desired point could be observed and a traverse run to the actual picture point location. This approach was usually more time consuming than a conventional traverse from an existing triangulation station. This is because of the need for a beginning azimuth--to provide azimuth yet another GPS point would have to be established, or astronomical observations must be made.

2. The required picture point was near enough to existing control or the terrain type was such that picture points could be observed quickly by radial shots from an existing geodetic station. In which case, the picture point could be positioned faster, as accurately, and more cost effectively than by GPS methods.

Both reasons cited make obvious this point--projects cannot be completed by GPS methods alone. Conventional equipment and expertise are required to complete sophisticated control surveys on time and at low cost.

On all our GPS projects, two-way radios were used. Often communications proved unreliable when occupying long baselines. When this occurred, our approach was simply to collect twice the normal amount of data. In this way we were ensuring enough simultaneously received SV transmissions for accurate positioning.

One of our most recurring system problems was the failure to obtain a navigational lock (signal acquisition) on all four predicted satellites. A particular session on the Kentucky Accuracy Test project illustrates this problem. We occupied a GPS point clear of all obstructions to radio signals. SV's selected were in optimum geometric configuration for simultaneous reception of broadcast signals and subsequent "differencing" between stations and SV's. Tracking procedures began and three SV's locked at the prescribed time. The fourth SV would not lock. Initialization procedures were checked and rechecked, and power source and power strength were checked. There were no hardware problems and no human error. The SV was supposed to be healthy (functioning). All was in order, yet the fourth SV would not lock. Ultimately, the session was lost. The next day, the station was reoccupied and no problems were encountered. This failure to lock a full constellation of SV's occurred sporadically and its cause could not be definitively determined. Data collection software used in the receiver is constantly being improved, so this should become less of a problem in time--still, this failure to "lock" is a recurring problem and a time-loss factor is an item that we have to consider during GPS project planning.

Systems problems were often the result of unfamiliarity with the process, or simply lack of practice. During field operations on the Davenport, Iowa-Illinois, project, slight almanac inconsistencies between two receivers seemed to preclude signal acquisition. This disparity was a result of satellite almanac data (SV positional data) being recorded 1 day before on one receiver and 1 day after the beginning of a new GPS week on the other. Broadcast ephemerides are updated on Wednesdays and Saturdays of each week. Wednesday, noon, begins a new GPS week. Actual positional data varied only slightly between the two receivers, but the GPS week differed. Several attempts were made to update the epoch, but the current GPS week designation would not input with positional data generated in the week previous. Theoretically, this should not have prevented signal acquisition, yet a navigational lock could not be effected and a session was lost. The following day we reprogrammed and developed new almanac data. This was not the only signal acquisition problem resulting from SV positional updates. The almanac update which occurs at 2200 (GMT) on Saturday of each week was the apparent cause of signal acquisition problems in the first session of each Sunday on several GPS assignments.

Also on the Davenport project, a poor power cable connection resulted in the loss of almanac data which necessitated a "cold start"; that is, we loaded into the receiver's memory the data collection program tape and tracked at least one SV until new almanac data for all healthy SV's were generated. Another electrical failure occurred because of a loss of battery charge. Again the almanac was lost and the receiver had to be reprogrammed and another almanac developed. Given our distrust of varying almanac data, we made it a practice of always generating almanac data by tracking, not by entering positional data from a previous log.

On the Belleville, Illinois, project we learned to check on the satellites prior to observations. At this time it was not our routine, as it should have been, to contact the Department of Defense (DOD) for a satellite status report. Too often we chose sessions without this essential check. On one occasion we were able to obtain a navigational lock on three of the four selected SV's. Because both receivers failed to lock the same SV (SV's are identified by number during receiver initialization), we immediately suspected an unhealthy SV. A subsequent check confirmed our suspicion, but the session had been lost. Had we made the necessary inquiries, our plans could have been changed accordingly.

Occasionally DOD will experiment with the SV message during actual tracking operations; or DOD will execute periodic SV position adjustments. A position adjustment occurred during tracking operations on the Belleville project. It was noticed when positional data being monitored on the receiver display suddenly became erratic and nonsensical. This was happening on both receivers, so the problem was assumed to be with the SV's, not our equipment. A new session was planned for the following day after adjustments by Satellite Control were completed. Both receivers were reprogrammed and a new almanac generated.

On any project, using any surveying technique, delays are inevitable. With GPS surveys, delays can become not only disruptive but extremely costly. We were always working within strict time limits. How much time does an instrument setup take? How much time will it take to drive between stations? Because the number of GPS satellites allow only about 5 hours tracking time in a 24-hour period, sessions must be chosen well to maximize the use of time available.

Time, or lack of it, is a problem typical to all GPS projects. Plans had called for the West St. Louis, Missouri, project to be a 1-day assignment. Three horizontal points were to be obtained and the proposed control scheme specified a closed loop traverse. A navigational lock problem was encountered on one vector, and no alternate session was practical given driving time between stations. Because equipment scheduling would not allow us another day at the project site, one point was dropped and the closed loop became a traverse ending at an existing geodetic control station. Also, because of time restrictions, a baseline check was not done, but existing control was verified by direction observations.

Just a few delays quickly made obvious the need for early establishment of alternate plans. Position Dilution of Precision (PDOP) values are a measure of the position accuracy, and visibility charts list azimuths and elevations of SV's along their orbital path. We came to realize that it must be standard operating procedure to become familiar with PDOP listings and visibility charts and recognize all workable SV group configurations. In this way we were able to determine, by inspection, working scenarios, make our plans using optimum times; then, develop alternate sessions to prepare for delays.

Not discussed here, but certainly noteworthy, is the fact that work must sometimes be done at unorthodox hours to take advantage of satellite visibility. We have had occasion to work at such times as 1 a.m. to 6 a.m. These times can and did present their own set of problems.

SUMMARY

The USGS has had some practical experience with the GPS. We know the system's capabilities and limitations and have come to recognize GPS as a significant advancement in control surveys. We intend to expand our application of GPS and are purchasing additional receivers. These new GPS receivers are compact, transportable units, and include microcomputer data reduction software.

We will continue to use GPS for horizontal stereomodel control and hope to include vertical map control operations by GPS on future field operations. Further, we expect technology to advance, increasing GPS's cartographic applications. Planimetric feature positioning is a very real possibility--significant here is the fact that the data collected digitally by GPS will merge naturally with USGS automated cartography programs.

When the full constellation of GPS satellites (18 operational SV's) are deployed, observations will be possible 24 hours a day. Operational problems noted previously will remain but will become much more controllable when "time" becomes less the ruling element in GPS operations. Time at present is a critical factor.