Starplus Software's Star*Net GPS

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I have been asked to prepare a review of Starplus Software's "Star*Net GPS." If it were not my belief that the matching of the least squares method to affordable computers is second only to GPS as the most valuable addition to the tools of our profession over the last decade, I would certainly find something more interesting to do with my time. Because I have been using Star*Net and, more recently, Star*Net GPS in my surveying operations for nearly 10 years and am probably one of its heartiest advocates, I feel somewhat like the chairman of the local chamber of commerce being asked to review the merits of his town.

I have watched the progression of this software from the days when it could perform a least squares adjustment of a relatively small number of "plane" observations (angles and distances only), through three-dimensional adjustments, then state plane coordinate support, and on into the world of GPS. During that time, the user's manual has also progressed from an easy half dozen pages to a somewhat imposing 275 pages. This is the price of increased capabilities.

Star*Net is a least squares adjustment package for surveyors. Least squares is a mathematical method used to evaluate a set of observations containing redundancies, applying the least amount of corrections possible in the most logical locations, to make the entire set fit together. Star*Net GPS contains all of the conventional survey adjustment facilities of the previous versions, while adding the ability to incorporate GPS Vectors from a number of GPS systems. The software can then adjust them solely as a GPS network, or incorporate the GPS data with all types of conventional survey measurements in a single homogeneous adjustment.

Why Use Least Squares?

In discussing this software and least squares in general among my fellow professionals, some of the statements I recall are: "I've been using the compass adjustment all my life. It's good enough!" or "I don't need least squares because I don't do any of that 'geodetic' stuff." In general, if the only thing a surveyor does is single-loop closed traverses, the compass adjustment will get about the same answers as least squares.

A little over 30 years ago, when I started my first surveying job, one of the first things that my party chief drilled into me was that angles to short sights were "no damn good," something to be avoided at all costs. Over the course of my career, I have found that I can not always avoid short sights, but they are in fact weaker than the long sights in the same traverse. Using the compass rule, all angles are adjusted the same amount, regardless of length-of-sight. Star*Net has the ability to apply adjustments to angles or directions appropriate to the length of the sights. This alone is worth the price of the lower-end versions of Star*Net. Another problem with the compass rule adjustment is that it lacks the capability to work with redundant measurements. The compass adjustment begins to fail as soon as the first cross traverse tie is added to the simple loop. The surveyor is left to his own imagination to try to "guess" the best way to apply any mis-closures. Geodetic stuff? Here are a few of the things we have done in the past with Star*Net that has nothing to do with "Geodetic" stuff.

Finds "Blunder" Type Errors

One of the greatest benefits of using Star*Net in our business is its ability to pinpoint the location of blunderous type errors in our surveys. Almost all surveys have some amount of redundancy, that is, more data than is actually needed to obtain a coordinate for any particular point. For instance, a simple closed loop has redundancy. You don't actually need that last closing angle and distance to obtain positions on all points. It is there as a check, a redundancy. Cross ties, or distances or angles measured twice, or angles to a natural sight, can all add redundancies to the survey. A very economical source of redundancy in any conventional survey is the vertical aspect. Total stations measure horizontal directions, slope distance *and* zenith angles. Many surveyors use the zenith information only to reduce the slope to horizontal. In fact, the total station generally records the zenith angles along with the other measurements. If the surveyor measures and records his instrument and target heights, the vertical closure of the traverse or network adds a complete set of redundant measurements, which many times can pinpoint the location of a problem in the survey data. More important, this redundant information can be used to isolate the erroneous portion of the data and give confidence to the correct portions of the data, thereby eliminating unnecessary additional (and expensive) trips to the field for checks. An additional side-benefit of this process is that you will develop the elevation differences between all of your survey points without any additional field time invested (read free!).

Given some redundancy, Star*Net can point to the parts of the data set that do not fit the other data. The more redundancy, the easier and more dramatic this blunder detection will become. In many cases, use of this feature has saved our firm from sending crews back to the field to recheck the field work. This error detection ability has saved the price of the software many, many times over.

Evaluation of Record Data

The use of the software is not restricted to measurements we made yesterday. It will work with 100-year-old data just as well. One of our projects required retracing a slightly winding road that had been monumented by the San Bernardino County Surveyor in 1929. Our crews had located some of the original monuments and determined that others were lost. It became obvious that there was a bust somewhere in the original survey by about three feet. We entered the angles and distances from the original survey into Star*Net. Our surveyed coordinates for the found monuments were held as "fixed" stations. The program, using the geometric relationships of the 60-plus-year-old data, pointed directly to the line which, if changed by three feet would make the entire set fit together as would be expected from a survey of that time.

Star*Net can also be used for the determination of "dynamic" search coordinates for boundary surveys. With the advent of real-time-kinematic GPS (RTK), we have been able to navigate to a predetermined coordinate or position very accurately, generally more accurately than the coordinates we historically have computed from the records to send with our crews for monument search. Star*Net has a data-entry op-

STATISTICAL SUMMARY

Number of Stations =	33	Number of Unknowns =	108
Number of Observations =	633	Number of Redundant Obs =	525

Observation	Count	Sum Squares of StdRes	Error Factor
Coordinates	12	0.00	0.00
Directions	198	74.77	0.67
Distances	103	70.26	0.91
Zeniths	194	159.44	1.00
GPS Deltas	126	100.34	0.98
Total	633	404.82	0.88

Adjustment Passes the Chi Square Test at 5% Level

Figure 1

tion that allows entry of bearings and distances from maps. It then automatically converts this data to angles and distances. In Southern California, we often find a number of record maps in an area, surveyed by different surveyors, which often have entirely different "basis of bearings." Using the angle calc mode, we can enter all the data from the various records which might affect the area of our interest. Since the software converts all of the entered map data to angles and distances, the basis of bearings problem falls out. The previously described error detection finds any problem areas before we go to the field, and we have a homogenous set of data defining the coordinates to begin our monument search.

Once in the field, with RTK GPS and a notebook computer, we can upgrade our dynamic coordinate file any time we develop better information. Thus, as we find and position monuments shown on the previous record maps, our computed location of the un-found monuments, and our ability to navigate directly to them, gets better and better. We have used this method with great success during the past year.

Cadastral Surveys

Star*Net has a mode to allow entry of "Geodetic Bearings." It also has a method of allowing a multiplier to be applied to all distance entries. For those who live and work in Public Land Survey states, this allows entry of the original survey data directly from the government notes or plats to produce state plane coordinates (government plat bearings essentially equal geodetic bearings, a multiplier of 66 will make feet out of chains input, and those really progressive souls can use a multiplier of 20.1168 to convert the chains to meters). Once the procedure is understood by the user, state plane coordinates can be computed for all of the standard corners for an entire township in about an hour. Coordination of all the topo calls might take another hour, depending on the area. Might this be of value?

Before you start your "letters to the editor" on this, let me add that the coordinates determined from the record data, of course, are only as accurate as the record surveys, and should only be used for search locations. The computed positions certainly do not eliminate the necessity to evaluate the evidence found in the field and establish the corners on the ground in accordance with the procedures set out in the "Manual." We have used this mode, along with RTK GPS, very successfully in a resurvey involving six sections, which required resurveying much of a township in Southwestern South Dakota. The GLO data, along with the topo calls, was input into Star*Net. Not only did we have an idea of where to look for corner evidence in a grassland area with no fences and few roads, but the adjustment was invaluable in harmonizing all of the various record information. We would have spent a greater amount of time had we not been able to load the "looking ties" into the data collector.

Star*Net GPS has the ability to perform a pre-analysis evaluation of a network without actual measurements. The user prepares an input file with the approximate coordinates of the points to be located, specifies the fixed stations he will use as a basis, and the network connections he proposes to use to tie them together. The connections can be by conventional survey, GPS or a combination of methods. The user sets his default standard errors just as he would in a normal adjustment. The software performs an analysis and produces a listing of the station-standard deviations and 95 percent confidence regions which would be obtained by a survey using the design, equipment and standard errors specified by the user. This is a planning tool with which the user can fine-tune the manpower and equipment to perform the job to the desired accuracies or specifications. We have recently used this tool effectively in showing agencies how we can perform their projects. It also is a good tool to use to evaluate the time estimates we have made in performing projects to the required accuracy-specifications.

Conversion to New Control Systems

A situation that California surveyors probably contend with more than the rest of the country is a trend to have a new and better coordinate control system about every 2-3 years, due to the coastal portion of the state constantly trying to move to the Oregon area. Since we departed from the familiar NAD27 control system in 1986, our state and local counties have had 1986, 1988, 1989, 1990, 1991.35, 1992.9 and 1995.5 "official" adjustments of the North American Datum of 1983. While the coordinates seem to be in a constant state of flux due to tectonic plate movement, our *local* field measurements made over the past 20 years are still as valid as the day we made them. Our firm performed a city control project tied to NAD27 control stations in 1980. In the past few years, we have re-entered all of the original control survey measurements and many subsequent projects into a Star*Net data file in order to convert to NAD83. This project currently contains 4,975 observations to position approximately 1,250 points—a compilation of 21 years of surveys using every type of equipment from chains to GPS. Now that the data is in a Star*Net format, any time the "powers that be" issue a new "official" coordinate basis, our city net can be converted by simply changing the "fixed" coordinates and rerunning the adjustment. It is a process of about an hour to update or re-coordinate 1,250 stations!

But, I digress. Let's get back to the nuts and bolts of what makes this software work. The software is a DOS-based, menu-driven program which will run on any 386 or higher computer. The larger adjustments may take additional memory. The city control project mentioned above will no longer run on the six meg machine it began on, but will still run on an eight meg machine. So, let's take a quick tour through an adjustment:

A Typical Project

Open a Project: Enter the project name, which can be any standard eight-character or less DOS name. As the adjustment or project proceeds, the software will automatically make several files with this same name with different extensions for various functions.

Set the Options: Run through the Options Menus to set the default options for this particular project. In these menus, you can set the standard errors expected for the types of measurements you have. These standard errors can be taken from the instrument manufacturer's specs or from your own experience; it is your choice. You can also set the angle measurement order to the method you use, From-At-To or At-From-To. You can set it to work in meters, U.S. Survey feet, International feet, local coordinates, state plane and Universal Transverse Mercator (UTM), according to your preference or project requirements.

Prepare the Input File: The input data file is a simple ASCII-format file, using a data code as the first entry-per-data line. Data can be manually entered or electronically downloaded from most total stations. Starplus offers optional "link" software to convert from the popular brands of data collectors. Now available are TDS, Sokkia SDR33, SMI, WildSoft and MapTech. Conversion from Geodimeter and Leica's LISCAD should be available soon.

If you have GPS data, it must first be reduced to baselines using the manufacturer's download and baseline processing software. Included in the Star*Net GPS package is a baseline importer that will very quickly convert the manufacturers' baseline files to Star*Net data format. This routine currently converts from Trimble, Ashtech, Leica, Sercel and Geodimeter baseline files, as well as National Geodetic Survey Bluebook G-File Data Records. Conversion routines from some other baseline formats should be available soon, including Magellan, Topcon and Trimble's RTK Data Collector (TDC). Once the processed baseline files are in the computer, all the user has to do is to give Star*Net the path to find them. As the importer brings in each GPS vector, it assigns a vector ID number. This becomes very useful in isolating problems in the data later in the adjustment process.

Perhaps this would be a good time to reiterate, what, in my opinion, is one of the best features of the package. The GPS data and the conventional data can be integrated into the same file and adjusted simultaneously. Additionally, GPS data from different manufacturers can also be easily intermixed in the same adjustment.

In addition to the default standard errors assigned to the various types of measurement data in the options menu, you can also set individual standard errors to override the defaults for individual pieces of data in the input file.

Run the Adjustment: A simple push of a button and, if all the options and data are correctly entered, the adjustment will run in a matter of seconds. I might note here that Starplus has done a remarkable job of reducing the time involved in actually running an adjustment. Having tested Star*Net GPS against our GPS manufacturer's adjustment package, I have observed that Star*Net runs in a small fraction of the time, and with the same results. Since most adjustments will be run many times during the course of de-bugging and honing the adjustment to the user's satisfaction, this elapsed time becomes important.

The software has many error messages to help you get through this "de-bugging" stage. If the adjustment runs, the last screen at the end of the adjustment will show the "Standard Error Factor" of the adjustment. If you have good data and the standard errors set in your options or individually in the data file are correct, you will get a number very close to one.

Reviewing the Adjustment

The software produces a listing file which is the complete record of the adjustment. An abbreviated listing file has been included as Figure 1. A review of the listing file will tell the informed user everything he would ever want to know about the survey. A quick trip through the listing:

Summary of Files Used—Provides a record of the computer files containing all the data used in the adjustment run.

Adjustment Options and Default Instrument Standard Error Settings—Shows how the user had set the default options prior to running the adjustment.

Summary of Unadjusted Input Observations—Shows all the data to be adjusted, along with the standard errors computed for each piece of data from either the default standard errors selected by the user in the options menu or the individual standard errors set by the user in the input file.

Adjustment Results—Shows the final adjusted positions (coordinates). Elevations are shown if it is a 3D job. Geodetic positions are shown if it is a state plane project. Ellipsoid heights and geoid heights are shown if the project is based on NAD83 state plane.

The Most Important Part

The Statistical Summary (see Figure 1) is a small, but mighty, section of the listing that gives a quick overview of the results of the entire adjustment. It shows the number of stations (points), the number of observations, unknowns, and redundant observations, the number of each type of observation, and the error factor for each type of observation plus the overall error factor (remember, we are looking for a number close to one here).

Adjusted Observations and Residuals (see Figure 2)—This is the area in the listing file to find any localized blunders. The far-right column in this section shows the standardized error for each value (the residual for the measurement divided by the standard error of the measurement). If the actual adjustment matches the expected error, this value will be one. A value between one and zero means the value is better than expected. A value greater than one indicates an adjustment larger than expected. Generally, if there is a blunderous error in the data, this value will be in the 100s or 1000s, or larger. As an aid, the software marks any value over a three with an asterisk to draw the user's attention to a possible problem area.

A quick review through this section will allow the user to see any problems with individual measurements. I normally scan the last column first to see if I have any high standardized residuals (again, if the world is good, these will be close to one or less). After reviewing the last column, I will also check the residual column to make sure that the adjustments are within the magnitude that I would expect for the type of survey and equipment used.

Note that the GPS vectors and their residuals are shown in north, east, and up. GPS actually works in XYZ Cartesian coordinates, which are difficult for the normal user to visualize while trying to evaluate or de-bug his project. Star*Net's ability to show this data in a familiar format is a great boon to those of us who generally stand and work perpendicular to the earth's surface. For those who insist on seeing XYZ Cartesian coordinates, a simple option switch will put those in the listing also.

GPS Residual Summary—This is a listing that shows all of the residual data for each GPS vector on a single line. It is sorted to show the vectors with the largest residuals at the top of the list. This can be extremely helpful in isolating problem vectors in a project with many vectors. The user has several options as to which column to sort on, that is, by "2D" residuals, "3D" residuals or "Up" residuals, depending on the user's interest. The vector ID number in the last column allows the user to easily find the vector in his input file, instruct the software to ignore that vector or establish a different weighting for that particular vector. As the GPS projects get larger and more complex, this vector ID system becomes very valuable.

Adjusted Bearings and Horizontal Distances—Shows the adjusted bearings (or azimuths, depending on the user's option settings) and distances along with the statistical 95 percent confidence region for each.

State Plane Information

Convergence Angles and Grid Factors at Stations (see Figure 3)—This portion only appears on state plane projects. It shows the computed mapping angle, scale factor, reduction factor and combination factor for

ADJUSTED OBSERVATIONS AND RESIDUALS

Adjusted Measured Distance Observations (US Feet)

From	To	Distance	Residual	StdErr	StdRes
236	275	383.3796	-0.0004	0.0083	0.0

Adjusted Zenith Observations

From	To	Zenith	Residual	StdErr	StdRes
236	275	90-08-58.14	-0-00-15.86	17.00	0.9

Adjusted Measured Geodetic Direction Observations

From	To	Direction	Residual	StdErr	StdRes
236	275	359-59-58.08	0-00-00.08	5.38	0.0

Adjusted GPS Vector Observations (US Feet)

From To	Component	Adj Value	Residual	StdErr	StdRes
(V1 Day214(0) 15:13 00007966.SSF)					
4391	Delta-N	575.7868	0.0038	0.0108	0.4
236	Delta-E	689.4587	0.0024	0.0099	0.2
	Delta-U	28.0529	-0.0285	0.0345	0.8
	Length	898.7050			

Figure 2

each station, along with the average of all of the stations in the project.

Error Propagation—Consists of two listings. The first shows the standard deviations associated with each station by north, east, and elevation. This is also a representation of the 68 percent confidence region for each station. The second listing shows the station coordinate error ellipses and confidence region 95 percent. These two listings give the user a method to evaluate the results of his survey based on each point. This is also the listing that may be the proof needed to show that the user has performed the project to the accuracies specified by the contract.

Elapsed Time—This is a little "brag" information by Starplus to show the speed of their program. It is fast! For example, the project from which the example listing file was extracted contains 633 separate measurements and it took 9 seconds on a 486 computer to adjust. See if your COGO software can match that!

Other Features Worthy of Note

Some other features of the software worthy of note:

- You can assign any text editor with which you are comfortable in editing the data files. The software includes a basic text editor, but the advanced user will want to use their own.
- Graphics Function to display the network geometry. This graphics screen will also show the relative size and shape of the error ellipses for the points or the lines. This is very handy in helping to visualize the overall geometry. Also, it can be very handy in de-bugging the project. The software will convert the graphic displayed in this function to a DXF file for transferring network drawings to other CAD systems.
- State Plane and UTM Support. As briefly mentioned above, the user can specify adjustment on any of the state plane grid zones in the country, both NAD27 and NAD83. You can also specify UTM zones worldwide. The zone factors are built into the software for all zones. If that isn't enough, you can make up your own Lambert of Transverse Mercator projection if you have a need (such as trying to plot all of the HARN stations on a state-wide map in a state with six individual state plane zones and two UTM zones).
- When using the state plane options, the software computes a separate scale factor and elevation reduction factor for each line in the adjustment. This allows for adjusting your data on the state plane grid without degrading the measurements due to averaged grid and reduction factors.
- While working in state plane or UTM, with the inclusion of an in-line switch in the data file, the software will also produce a ground-based local coordinate system for your further use, in addition to the state plane/UTM projection coordinates and geographic positions.
- The software has the ability to read and interpret the geoid models published by the National Geodetic Survey. This is an absolute "must" if you are using GPS to determine elevations or if you are mixing GPS and conventional data in a three-dimensional project.
- The software allows a different weight for the vertical portion of GPS vectors than is used on the horizontal portion. This can be quite useful in smoothing out vertical problems (read poor HI's) in a network in which only the horizontal position is important to the project. This feature is also

valuable in evaluating projects in which the vertical is the desired end result, such as in subsidence monitoring.

- The software allows changing of defaults with "in-line" options in the data file. This allows for appropriate weighting of data measured with different instruments, techniques, personnel, or periods in history.
- In many parts of the country, there is a drive to make all surveys and plats metric. A simple ".MULT .30480061" at the beginning of any of your good old "foot" data input files will convert the entire file to meters. This in-line switch can also allow the various measurement units to be easily incorporated in the same project. This feature will become more valuable as we progress into metrics, since we will no doubt be mixing units on a daily basis due to adding new data to old or comparing "record" to "measured."

Software Has Few Shortcomings

Some of the things we would like to see addressed at this time:

- When zooming in on the graphics screen, there is a limit where the software will no longer zoom. This can be a frustrating limitation on large projects with detailed areas.
- The software is not a Windows application. While many may feel this is a negative, most of us who have watched our computers grind to a near halt after converting to Windows, might feel the speed of the adjustment is worth staying with DOS for a while longer. Starplus indicates a Windows version should be available in the next year or so.

So what have we learned about Star*Net? It's a tool for surveyors. It's a tool used to find and eliminate errors in both new and old surveys. It's a tool used to adjust surveys on state plane, UTM or custom projections. It is a tool that can convert government cadastral "astro" based surveys to a "plane" system. It is a tool to combine many types of survey measurements made with many types of equipment, or measured during different periods of history. It's a planning tool and a sales tool. Oh, and yes, it can also do that "geodetic stuff." We have also learned that it is user- friendly, works with many vendors' digital files, gives concise answers to complex problems, is reliable, accurate, fast, and can save time, money and brain strain. I believe the truly professional surveyor will be using this software as we enter the new millennium. ■

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Convergence Angles & Grid Factors • Error Propagation

Convergence Angles and Grid Factors at Stations

(Grid Azimuth = Geodetic Azimuth - Convergence
(Elevation Factor Includes a Geoid Height Correction at Each Station)

Station	Convergence Angle	Factors: Scale	x Elevation =	Combined
236	-0-46-45.81	0.99995998	0.99999403	0.99995401
Project Averages:	-0-46-46.69	0.99995991	0.99999467	0.99995458

Error Propagation

Station Coordinate Standard Deviations (US Feet)

Station	N	E	Elev
236	0.00807	0.00730	0.02240

Station Coordinate Error Ellipses (US Feet)

Confidence Region = 95%

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Elev
236	0.02093	0.01647	147-35	0.04390

Elapsed Time = 00:00:09

Figure 3