Surveying at Ground

Getting GPS and Conventional Measurements to Agree

By Thomas Hoppe O.L.S. & Bill Stahl P.L.S.

With the recent increased application of GPS technology to everyday surveying tasks, many surveyors are experiencing great gains in productivity. Many surveyors are also experiencing the frustrations of getting the right answers out of their black boxes. There is a general confusion amongst some professional surveyors as to why they would need to identify a coordinate system any further than stating a starting coordinate of 1000 N, 1000 E, and 100 Elevation. Though this is perfectly acceptable for small surveys, the advent of long range survey systems such as GPS and the desire to represent survey data on a Geographic Information System (GIS) requires the surveyor to give thought as to how the survey data is represented.

Before a solution can be given, the cause of the problem must be explained.

The problem presents itself when the surveyor starts to compare the distances derived from conventional means against the distances derived by GPS. There have been many calls asking why there would be any difference between the two, and how to deal with it. Before a solution can be given, the cause of the problem must be explained.

Surveyors generally assume that all conventionally measured distances are reduced to a common plane that represents "ground". The distances are actually reduced to the horizontal at the elevation of the observed vertical angle, that is, at the elevation of the instrument station. The resultant distance is rarely reduced to a common elevation plane, and thus the surveyor is left with a series of horizontal distances located at various elevations in space. This is particularly pronounced when surveys are done in areas of large elevation changes. A good example could be a project for a ski resort with facilities being staked out at the base and at the summit of the resort. In this situation, when the surveyor closes a traverse mathematically, the distances that have not been reduced to a common project elevation cause a portion of the misclosure.

Each datum has a unique point of origin, which is why one point displayed in two different datums ... yields two different sets of coordinates.

To further exaggerate the problem, there are also errors associated with this measuring technology that are at times ignored. Errors such as:

- Steel tape temperature and tension
- EDM constant, scale, temperature and pressure
- Reflector constant
- Tribrach and optical plummets
- Prism pole level bubble
- Slope distances properly reduced

GPS operates on the WGS-84 ellipsoid (Datum), and ellipsoidal heights. The WGS-84 reference ellipsoid can be described as the mathematical model of the shape of the earth. There are many different reference ellipsoids from which to choose. Each is appropriate depending upon the map projection and region in which you are collecting data.

Datums or reference ellipsoids are also fundamental to map projections. Each datum has a unique point of origin, which is why one point displayed in two different datums (NAD-83 vs. NAD-27) yields two different sets of coordinates. Each datum provides different representations of the earth's shape, therefore, the relationship between WGS-84 (reference datum for GPS) and other datums are usually predefined by government agencies or scientific committees. When we refer to a coordinate system, we are referring to a system of coordinates based on a particular map projection. A map projection is the representation of a portion of the earth's curved surface on a flat plane. To compare GPS data with locations from an existing map, the datum and projection used to construct the map must be identified and used. GPS users need only choose the correct reference ellipsoid and projection to convert their data to the datum matching their existing GIS/Mapping database.

GPS and conventional surveys measure essentially the same slope distance. The Trimble Real-Time Kinematic (RTK) GPS system projects grid coordinates to the ellipsoid height of the base or the first point in a calibration. In all cases the system reduces the GPS points to a common reference elevation/ellipsoid height, which is specified by the projection and coordinate system chosen by the user.

GPS as a measurement tool also has inherent errors that the surveyor must deal with.

Since conventional surveys rarely have observed distances reduced to a common plane of elevation, differences between the two systems' origin elevation should be considered when evaluating an inverse of a ground distance from the RTK system versus the local grid/ground coordinates. GPS as a measurement tool also has inherent errors that the surveyor must deal with. They are:

- Selective Availability (SA) and Anti-Spoofing (AS)
- Multipath
- Ionospheric noise
- Tropospheric delay
- Correct initialization
- Availability and accuracy of local geoid model
- Satellite geometry
- Radio interference sources (RTK applications)
- Base station is accurately set-up over a known point in the desired coordinate system*

*For every 10m your base position is in error from the true position, you will incorporate an additional 1PPM error times the baseline length. For every 33m your base position is in error from the true ellipsoidal height, you will incorporate an additional 4 PPM error in the baseline length.

Many of these errors as well as others not mentioned are removed by carrier phase differential correction; however, others are variable and change over a short period of time. Identification and employment of proper survey methods removes the latter.

SOLUTIONS

As mentioned earlier, surveyors wish to utilize both conventional and GPS technology together. The problem as stated, was that the conventional data was rarely reduced to a common elevation, whereas, the GPS data is most usually presented in some type of predefined coordinate system. If the pre-defined coordinate system is reduced to sea level or ellipsoid height, how then can the surveyor have a direct comparison of conventionally derived coordinates with GPS derived coordinates?

There are two ways to tackle this problem. First, the surveyor can use the GPS site calibration option to define the relationship of the local coordinate system to the WGS-84 latitude and longitude of the GPS system. With the Trimble Real-Time GPS Total StationTM, a calibration reports the orientation and scale of the two systems and the residuals of the transformed GPS points as compared to the local points. Ideally these residuals should be within the measurement error expected from both GPS and conventional surveys. The scale factor reported in the calibration is not the scale of the projection, but the ratio between the distance derived from the inverse of the grid coordinates, and the inverse of the grid coordinates calculated from the GPS observation. This scale factor should approach one, and can be used as one measure of the accuracy of the calibration.

The second option is to set-up a unique coordinate system that best fits the survey site, and, that is also defined at the average elevation of the site. This is the preferable method, however, if the surveyor finds that an existing coordinate system must be used, then the calibration option will be the more reasonable option. This unique projection can be used repeatedly in other projects that cover the same area. This will allow you to expand on your current surveys while maintaining a consistent projection and coordinate system in the area. Using a regional projection also allows you to provide information to many different clients that can then work amongst themselves with the confidence that their data is compatible.

While this gets the job done today, how will it effect you tomorrow?

Since projection systems are designed to represent a curved surface on a flat plane, there will be certain distortions caused by this presentation. Each projection system then, is designed to feature certain desirable aspects of what is being represented. In some cases, it is scale and direction. In others, it is shape or area. In Ontario, there are two basic types of projections in use, the Transverse Mercator or the Modified Transverse Mercator. In the United States, the United States Plane system is combination of Transverse Mercator and 2 Parallel Lambert Conical projections.

The Transverse Mercator projection is used when there is a large north-south dimension, and the conical is used when there is a large east-west dimension. In both cases, the governing body of the Province/State defines the parameters of these projections. You can use the published criteria to correctly set-up your coordinate system. One thing to remember about these projections is that all coordinates are reduced down to a common datum, which is usually the reference ellipsoid (Datum) of the projection. The surveyor can easily configure an existing projection to represent ground distances. Inflating the reference ellipsoid (Datum) to the average elevation of the site does this. Use of specific software such as the Coordinate System Manager within Trimble Survey Office™ Software V1.5 can provide a solution by enabling you to define your coordinate system. Mapping projection systems as well as reference ellipsoids are provided. In addition, you can customize these projections to take care of issues such as having a common vertical datum for reducing your horizontal distances. This will allow you to inverse your coordinates derived from both conventional and GPS survey, and be able to observe a similar value.

This unique projection can be saved in Coordinate System Manager and can be used repeatedly in other projects that cover the same area.

For small surveys of a few square miles, selecting "No Projection/No Datum" and using a single point with an artificial northing and easting may be appropriate. While this gets the job done today, how will it effect you tomorrow? One must ask: "What happens when a job grows beyond its original size?" "Will the projection be adequate?" "Can I use GPS to make original measurements in areas that have no local control with which to calibrate and how can I do this?" By spending a little time to understand datums, projections and coordinates systems, you can control how the job is setup by defining a ground coordinate system that accurately relates GPS observed points with the local terrain. In addition you will know why the coordinate system behaves the way it does.

Your clients and other professionals will want to know what methods you used to define your coordinate system.

In the next few years "Meta-Data" will become increasingly important. These are the parameters from which your information was based. Your clients and other professionals will want to know what methods you used to define your coordinate system. If you start creating projects with datums and projections that you fully understand, then you will be able to respond to these requests. Your data will also become more valuable because it can be easily shared with other professionals. The day will come when several of your surveys come together, and by taking the time to take charge of your coordinate systems now, will mean a greater ease in bringing these various surveys together.

CONCLUSION

In conclusion, choosing a proper projection such as Mercator or Parallel Lambert in addition to computing a scale factor that will project coordinates to an average project ellipsoid height will provide the following benefits:

- There can be virtually no limit to the extent of the survey.
- Data can be readily shared with other professional organizations.
- Calibration reports will show residuals based on measurement only.
- By using existing control, unnecessary PPM errors can be avoided.
- When several projects come together it will be easier to bring them into one coordinate system.

With an understanding of projection systems and how they behave, the average surveyor can now use modern technology to establish and maintain accurate coordinate systems. This will be realized as not only a benefit to the surveyor, but also a benefit to whoever should use the data now or in the future.

Bill Stahl is a licensed professional surveyor in the State of California, United States of America. He has worked with Trimble's Technical Assistance Center providing on-line solutions to Trimble Surveying and Mapping customers for the past 4 years.

Thomas Hoppe is a licensed professional surveyor in the Province of Ontario, Canada. He has worked with Trimble's training department-providing training on Trimble's Surveying and Mapping products for the past year.

This paper is based on a presentation given at the Trimble Worldwide User's Conference in San Jose California in October 1998.