A Precise 3D Method for Total Station Field Data Collection

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You will learn:

1) A 3D method that helps prevent field blunders and gives immediate quality control
2) How to practically eliminate the largest sources of error in total station work
3) How to derive defensible standard errors on your in-house equipment.

Introduction

The 2005 ACSM/ALTA standard requires a relative positional accuracy of 0.07' + 50ppm at 95% confidence level between any two located points[1] as calculated with a properly weighted network least squares adjustment. To routinely and provably perform work to that standard would seem to require a better and more rigorous field data collection method than the traditional traverse. There are both practical and mathematical arguments for this position.

Background

In this method, every instrument setup is a resection ("free station") using the least squares routines in the data collector. We use a Leica 1203 total station, which has an onboard data collector. Some people prefer a separate data collector, or different software. We encourage you to try this with whatever equipment you have.

A classical resection uses only angles; what we are doing would more properly be called a "free station" since it also uses distances; hereafter when we say "resection" we mean "free station". After the initial 2 point setup, we use 3 or more targets at every subsequent setup. This allows the least squares routine to calculate an error ellipse for the occupied position and residuals for each measurement, which are important features of the method. Before delving into the theory, let's walk through a set-by-step explanation of the method.

At The Job Site

The boss has given the loyal crew an assignment: "Get me data that passes the ALTA specification, with the redundancy to prove it, and while you're at it, get me vertical control that is as tight as a differential level, and shoot topo." It's a tall order but we can do it.

When we arrive at the job site, we first establish a random baseline. This could be done using a rod & glass over a pair of street monuments, but lately we are using tacks in vertical surfaces along with reflectorless EDM. We perform an initial free stationing (angle, 2

1 There is some debate as whether "any two points" means boundary markers, boundaries and structures, any two observations, or truly any two located points. We would prefer to err on the side of caution.

distances)[2] and an inverse between the two points that establishes "job north" for our assumed coordinate system. We then set as many new control points as we can usefully see from the first setup. At our next station and at all further setups, we will use no less than three targets to solve for the instrument's position and orientation via the onboard least squares resection routine.

Using the least squares free stationing in the data collector for every total station setup gives us a 1-sigma error ellipse for the station itself, along with residuals for the measurements used to calculate the setup. If the error ellipse for the setup position is any larger than about 0.02', we stop and check our setup and our targets. If an individual measurement for the setup has a larger than expected residual, we stop and check that also. This gives the crew or solo practitioner confidence that the setup is good before making further observations and moving forward.

The Resection routine in the Leica 1200 Setup program allows you to toggle between unweighted ("least squares") and weighted ("robust") solutions that are based on the differences between the expected coordinates and the coordinates calculated from the current set of measurements. If they are the same, your setup is as good as the reported error ellipse. If the weighted and unweighted residuals differ, it is a good idea to check your setup and your targets.

The advantages of working this way rather than the conventional traverse are that you have immediate feedback about your position and orientation. We are working in azimuths based on "job north" rather than forgetting to set zero, and we have more confidence than a single backsight distance check. We know how much error we will be propagating forward, and we can decide if it is an acceptable amount for the job at hand.

A key point to make about this field method is that although we use the onboard least squares for preventing field blunders, the collected raw data is re-analyzed in the office[3] using a full-featured Network Least Squares Analysis package (NLSA). The rudimentary least squares in the data collector is only used to help gather blunder-free data for later analysis, and is not a substitute for later desktop Network Least Squares Analysis of the raw data.

If the goal of the fieldwork is to produce data for network least squares analysis back in the office, the fieldwork needs to produce redundant measurements and cross ties by design, and using multiple control points for every setup helps achieve this easily.

Why we developed this method

Early experiences with traverse in surveying class showed that the traditional traverse can be fraught with peril: You and your crew can spend all day traversing, and although your backsight distances may check, you have no clue how well you will close. When there is a large error of closure it becomes a time-consuming puzzle to figure out where the error is. If there is more than one error, traditional methods of traverse analysis do not help. It is often faster to redo the fieldwork than to track down the errors(s).

It was clear that we needed a better method. It was also clear that the tools (data

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2 A side-angle-side triangle. For redundancy and vertical precision, D&R would make it 4 horizontal readings, 4 distances, and 4 zeniths.

3 Where "office" can also mean a laptop computer on-site or back at the truck.

collectors with least squares resection routines) and the techniques (free stationing) were available. When we learned of the ALTA/ACSM 2005 RPA requirements, we saw that there was an even greater need for such a method.

We found that one of the best ways to increase horizontal precision is to eliminate instrument centering errors. According to Ghilani, instrument and target centering errors are the two greatest sources of error in a total station setup, and cannot be eliminated with additional sets at a single setup in the traditional methods. [Ghilani] In our method, instrument centering errors are eliminated by not setting up over a point. Instead, the point currently occupied by the center of the instrument circles is solved for via least squares . This is a commonly used industrial metrology technique that has not previously had widespread use in land surveying.

Verticals

Using the onboard least squares and solving for the point currently occupied by the center of the instrument circles allows us to eliminate the pocket tape measure up and use an instrument height of zero. This allows us to combine the resection routines aboard the data collector with the Precise Trigonometric Leveling techniques developed by Charlie Glover and popularized by Jesse Kozlowski.[Kozlowski] Using these techniques, topographic data can be collected simultaneously with the development of the control network, but with greater precision and confidence than with traditional trigonometric traverse.[4]

Reflectorless EDM

Although the method works well without it, reflectorless EDM technology adds even more speed, accuracy, and flexibility. Using targets such as tacks in poles or other vertical surfaces saves repeated walking and setup time. Accuracy is enhanced as target centering error is eliminated for most observations by the using reflectorless EDM measurements to a target point in a vertical surface rather than to a prism on a rod over a target. This eliminates prism aiming error, the possibility of prism offset error, and rod plumb and bubble errors.

How to derive defensible standard errors on your in-house equipment

When you reduce this data in the office, how do you know if your NLSA is “correctly weighted”? You could use your equipment's vendor-published standard errors as a starting point, but in some cases that could be a blind assumption. For example, our equipment is a Leica 1203. When we consider that such a rating means “no worse than 3 seconds”, and that the next better instrument is a 1” unit, we conclude that our 1203 is probably somewhere between a 1” and a 3” instrument.[5]

In house test results vs. manufacturer's published specs

4 Traditional traverse with pocket tape measure-ups and zenith angles.

5 Note that all the instruments are made on the same assembly line and then tested for tolerances.

Field data in conjunction with the chi-square test can determine a realistic standard error to use for our weighting. This gives a starting place at the beginning of analysis and can be tuned to the field data for a given job. For example, on a recent job with over 4000 observations, using 3” as the weight for H & V directions in Star*Net gave results that are far under the lower bound of the chi square test. Experimentation showed that a horizontal std. error assumption of 1.4” passed the chi-square test at just above the lower bounds, indicating a realistic assumption.

The measurements from which these weights were determined were gathered with the Precise 3D method, so other factors that might have influenced the weights, such as instrument and target centering error, were mostly eliminated.

Star*Net has several different standard error definitions. For distance measurements there are EDM constant and PPM, where we thus far have not diverged from the manufacturer's published values. For horizontal value there are “direction” and “angle”, which merit some discussion. The DIN specification for “direction” is for two pointings, one in each face. An “angle”, then, is the difference of two directions, or some combination of BSD-FSD-FSR-BSR. If for a “direction” in our Star*Net input data we use individual circle readings rather than the mean of two faces, we will need to change the weight to match our definition. Likewise for an “angle” -- Let's say we have what is nominally a 3” direction instrument, and we measure an angle in one face only. We are calling this an “angle”, but it is composed of half the precision of the DIN specification. Our weights should be altered to reflect this. An angle composed of two 3” directions (both faces) would be 3” * sqrt(2) = 4.24” But our angle composed of two 4.24” half-directions (one face) would be 4.24” * sqrt(2) = 6”.

All this may seem like splitting hairs, but there is a point: you want your work to be defensible. If your work is ever challenged in a legal action, the opposition does not need to prove you wrong, they only need to create doubt. [Petersen] If you do not know the field-proven standard errors of your in-house equipment, you are vulnerable in two ways: you won't know when something is out of adjustment, and you won't be able to defend your work if questioned.

Practical Considerations and Field Test Wisdom

Leica ATR – Automatic Target Recognition works extremely well when kept calibrated. When we separate the data we collect using the Precise 3D Method into categories of reflectorless shots (HI and HR = 0) and prism shots, we find that the standard errors for horizontal direction readings are slightly better for the ATR (1.3” for machine-aimed ATR shots as compared to 1.8” for human-aimed reflectorless shots). This is interesting because the ATR shots have additional target centering, prism aiming, and rod bubble errors

Measuring rod height is key for good elevations, since the method mixes rod shots with reflectorless shots.

We have not yet tried true nodal prisms, which would eliminate some prism aiming error. This is on our list for future research.

We are using a rod with a pair of 8' bubbles, and we adjust the bubbles whenever they disagree by any noticeable amount. The logic is that if the rod is dropped or if the bubbles are bumped, they won't be knocked out of adjustment in the same direction.

Combining this method with GPS in general and Leica Smart Station in particular

This method combines extremely well with the Leica Smart Station option, where an ATX1230 GPS antenna is mounted on top of the total station. Static GPS data can be collected while performing total station measurements. When the data is processed, the antenna height is always a consistent 0.146m, and the GPS positional data can be combined with the total station data in the NLSA. In this way we scale and rotate the total station's assumed coordinate system data onto geodetic data and the state plane grid. Again, verticals are more precise due to avoiding the pocket tape measure up.

Conclusion

We continue to develop this Precise 3D Method and welcome your questions and comments. We would like to hear from surveyors and their loyal crews who try the method with other brands of equipment, data collectors, and desktop least squares packages.

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