Field/Lab Exercise 2 – Surveying Offsets and Handheld Survey Tools *Field*

<u>*Data Goal of this Exercise*</u>*: to explore surveying methods as offsets from GPS points.*

Background: Cartesian and Polar Coordinates, Absolute and Relative

- **Cartesian** coordinates are positions related to orthogonal XYZ axes. *Relative* coordinates are relative to an arbitrary origin, like a stake hammered in the ground and "east-west" and "north-south" axes, also defined arbitrarily. *Absolute* coordinates are relative to a universally defined horizontal global datum, like spheroidal geographic coordinates, or projected coordinates tied to those spheroidal coordinates.
- **Polar** coordinates are vectors of **distance**, **direction**, and **vertical angle**, and are almost always relative.

Land surveying has a similar purpose to GPS, in fact GPS is sometimes considered a technology that can be used to *replace* traditional surveying methods. This is only partially true, and it's best to think of their relationship is as a mutually beneficial one, with each having its benefits:

	GPS	Surveying
Positioning	Absolute, using trilateration from satellites.	Relative. Instruments measure polar coordinate angles and distances from other features, and can compute relative Cartesian coordinates.
Advantages	Doesn't require known ground features. Points don't need to be close to other points.	Works everywhere you can see. For local surveys, can measure with very fine accuracy.
Disadvantages	Doesn't work everywhere. To get to submeter or especially decimeter accuracy, may require a lot of time per point feature.	To derive absolute locations, needs known locations to survey from, and at least one known and accurate direction or known second location. Absolute accuracy is limited by known locations.

GPS is an absolute positioning system, so determines position on the planet based on trilateration from satellites of known locations. Note that *absolute* does not mean absolutely accurate; it just means that it doesn't need to reference ground features. Total station surveys are relative surveys, but can be used for absolute locations if control points are needed.

Two ways in which surveying and GPS come together nicely are:

1. **Offsets**. There are always situations where you cannot get a GPS position. There are also situations where the GPS position you apparently get is problematic – especially in multipath situations such as near buildings or rock outcrops – and you should not use the positions you are collecting. To capture a point in a problematic location, like in a canyon or forest, you may need to determine it as an offset from a GPS point.
2. **Benchmarking**. To determine absolute coordinates for a GIS, a surveying instrument needs known locations to work from. Traditionally this was done by using fixed benchmarks, and this is still done in urban areas where benchmarks are common. Using a GPS to establish benchmarks can greatly aid a surveying project.

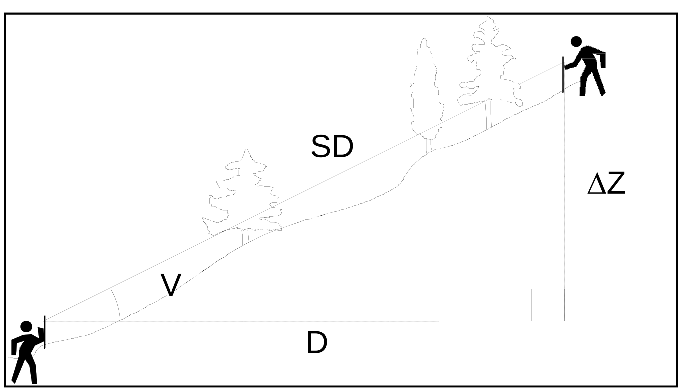
Accuracy and Appropriate Technology

Of course, accuracy considerations are crucial here, and here we should consider our purpose and appropriate technology. For benchmarking a total station survey, for a purpose that requires something approximating centimeter accuracy, a handheld GPS with an accuracy of 3-5 m just isn't going to cut it. Your total station may be able to survey relative positions to centimeter accuracy, but its absolute positions are limited by the accuracy of its benchmarks. At the same time, if the purpose only requires 3-5 m accuracy, where a handheld GPS instrument will do the trick, it may be overkill to use a total station; handheld survey instruments like compasses and clinometers may work. This table is a rough guide of the current situations

Accuracy needs	Appropriate GPS Technology	Appropriate Survey Technology
3-5 m	handheld GPS like Garmin or Juno	Handheld Brunton or Suunto compass and clinometer accurate to 1°, tape or laser rangefinder distances. Pacing also may suffice.
~ 1 m	submeter GPS like GeoXT	laser rangefinder, with compass for relatively short shots (< 50 m). ~ 2 m accuracy at 100 m.
0.1-0.3 m	GeoXH with Zephyr	total station (5" accuracy)

In this exercise, we'll look at the use of handheld survey instruments (high-quality compasses and clinometers) and distance devices to record vector *offsets* from points. We'll be able to use these offsets to (a) make it possible to determine positions where we can't use a GPS; and, by extension, to (b) continue along a traverse to collect a sequence of new positions.

We're shifting focus here from absolute to relative position, and using polar coordinates to derive those relative positions. As a general rule, if you're working in a small area, relative position is more accurate than absolute. However, relative position depends on both (1) the accuracy of both the position you're relative to, and (2) the accuracy of its ability to measure the vector offset. Most surveying equipment use highly accurate means of measuring vector offset, but may be starting from a GPS point to get an absolute position.



Measuring relative position with vector offsets

Vector offset uses *polar coordinates* instead of *Cartesian coordinates.*

Polar coordinates are vectors of distance and direction. Direction is divided into horizontal (azimuth) direction and vertical angle.

- Azimuth is as measured on a compass 0-360°, with 0° or 360° being north, 90° east, 180° south, 270° being west.
- Vertical angle is measured from horizontal 0° up to vertical, 90°. Vertical angle can also be measured in percent, or rise/run from 0% to very high numbers, where vertical would be infinite (so can't be used for such); 100% corresponds to 45°.

SD = slope distance (direct)

D = horizontal distance (on a map) = SD * cos(V°)

V = vertical angle (° or %)

tan V° = ΔZ/D

V(%) = ΔZ/D * 100%

ΔZ = SD * sin(V°)

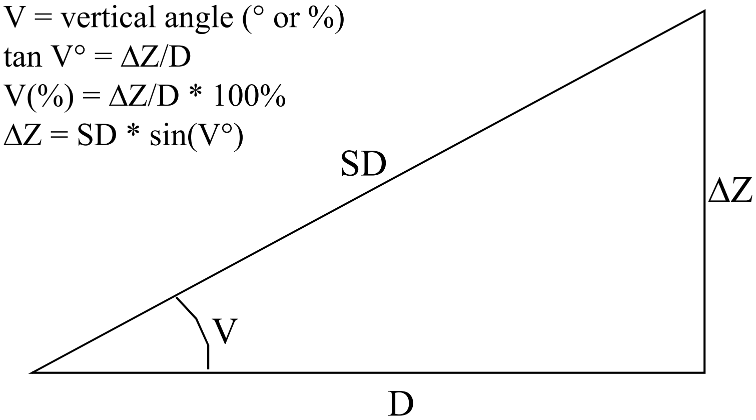
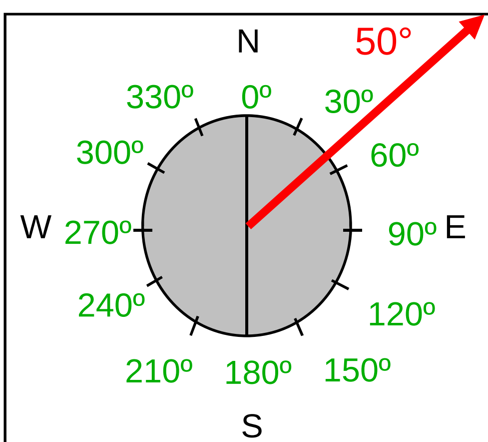


Fig. 4. Vertical angle relationships and equations.



Az = 50° sighting to some object

ΔX = D * sin(Az)

ΔY = D * cos(Az)

Fig. 5. Horizontal angle (azimuth) & equations

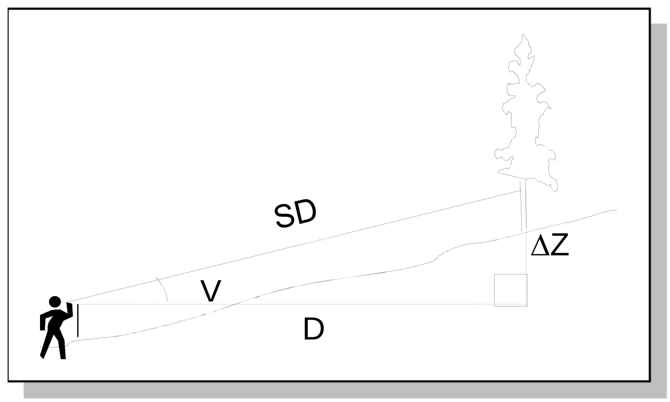
Manual Offsets

As before, we'll start with a manual process, which will always work, even with a GPS receiver that doesn't know how to do it the fancy way (we'll see that next).

- Find a location where you cannot get GPS reception, preferably somewhere in your previously sketched area. The instructor may have some ideas, but typical locations are in densely forested areas, in canyons, or both. Find a nearby spot where you can get reception and record a position, using averaging for the best accuracy. Using UTM coordinates, make note of this location and its ID:

ID: __________ X: ____________ Y: __________________ Z: _______________

Note: you can also store this waypoint in the GPS to download later. You should make a careful note in your notebook about what the point represents, that it's not the actual location but will need the vector offset.



- Measure the offset with handheld instruments, pacing, survey tape, and laser rangefinder. Measure all distances directly as "slope distances" in metres. If measuring to a tree, measure this distance from a given height above the ground (e.g. chest height) to the same height on the tree. Hold the tape tightly directly between the GPS point and the target location. Read vertical angles in degrees with + or – indicating if the reading is upslope or downslope. Read compass azimuths in degrees (0 to 360°). Read foresights and backsights. If the backsight differs by more than 1° from the foresight (for azimuth, add or subtract 180°; for V, change the sign), shoot again until you are within that tolerance (for shorter distances, you can opt to go for 2°). Note that magnetic interference may affect compass readings, so you may need to ignore one or the other reading; cross out the one you don't trust.

Feature	ID_{GPS}	SD_T	SD_L	V	V_B	D_T	D_P	D_L	AZ_{mag}	AZ_B

T= taped, L = laser, B = backsight

- Use the calculator (set to 'degrees') to derive the following:
  $D = SD * \cos(V)$
  $AZ = AZ_{mag} + 14.1 =$ ____________
  $\Delta X = X + \sin(AZ)*D =$ ______________ $X_{tree} = X + \Delta X =$ _______________
  $\Delta Y = Y + \cos(AZ)*D =$ ______________ $Y_{tree} = Y + \Delta Y =$ _______________

Using TerraSync to do Offsets

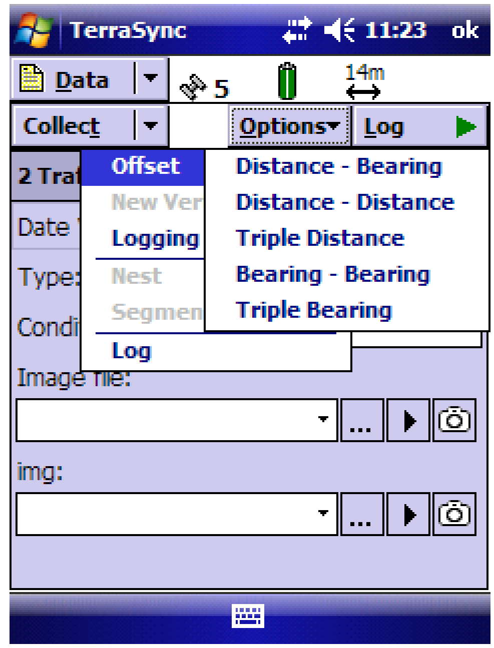
TerraSync and Pathfinder know all about offsets, and make this process pretty easy. An offset can be recorded with a collected point or vertex, and this is retained with the data. The actual GPS point might get real-time differentially processed or post-processed, and then the saved offset is applied to the feature you are after. As with the manual method, the offset is always *from the GPS* toward the feature. This convention makes it easy to use solo methods where the user is holding the GPS and might be using a laser rangefinder to shoot distances to a desired feature.

- First we need to set up the GPS to use the offset format we are going to provide. In **Setup ... Units** set the **Offset Format** to **Slope/Inclination** (instead of Horizontal/Vertical where we would need both of those distances); and set the **North Reference** to **Magnetic** (since our compasses read magnetic directions) and the magnetic declination correctly set (to 14.1 for SFSU in 2012). Also make sure the Distance Units are set to **Meters**.
- Open your **Quadfeatures** data file, and go to **Collect Features** mode, and survey a tree that you can't stand next to and get a decent point. Measure the slope distance, vertical angle and compass direction (for best accuracy, do a backsight of the compass direction), and while (or before, if log later is set,) collecting your GPS point, use the **Options** button to go to **Offset**, set to Distance-Bearing, and enter the compass bearing in degrees, the slope distance and the inclination (make sure to enter negative or positive as appropriate).
- Collect some more. Try staying at one GPS point, and "spraying out" to multiple tree features. Each point needs to be collected as a GPS point, since only one offset is saved with each point, but this will illustrate a process we will use with submeter GPS.

UTM Coordinates of GPS Point to spray from: __________________ __________________

Tree Description	SD	Foresight	Backsight	Vertical

Complex Offsets



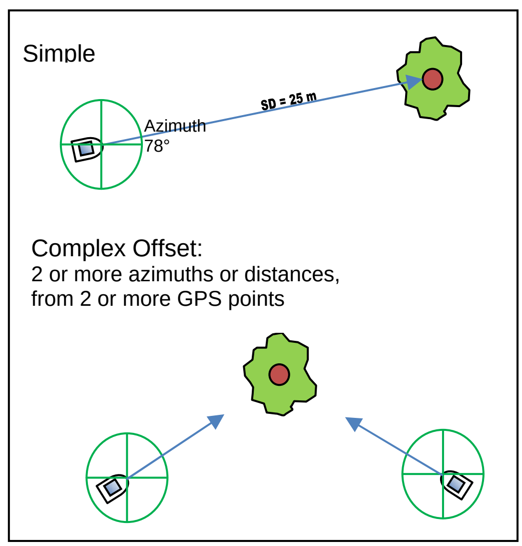
TerraSync also has the capability of doing "complex offsets" where you use two or three GPS positions together with *either* distances or compass bearings. These are handy in two situations:

1. You don't have a compass or clinometer with you, but you either (a) have a distance device like a tape or a rangefinder; or (b) you know how to pace your distance. You can use **trilateration** with 2 or 3 distances

2. You can't physically get to the point you need to locate, but you have a compass and can see the point from three surrounding GPS points, using **triangulation** with 2 or 3 compass readings.

Offset Options	GPS pts	Requires
Distance - Bearing	1	1 Slope distance and 1 compass bearing *(simple offset)*
Distance - Distance	2	2 Distances and left vs. right setting
Triple Distance	3	3 Distances
Bearing – Bearing	2	2 Compass bearings
Triple Bearing	3	3 Compass bearings – must have an error check

Considerations for complex offsets
Using more than one GPS points to find a desired feature point employs triangle, either using triangulation or trilateration methods. Triangles work best when they are not too skinny, with the ideal shape being equilateral with each corner at 60°. So, in creating either a single triangle with two GPS points and a feature, or creating multiple triangles, you should try to spread your points out. With three points, you should try to surround your feature on all sides. This is the same issue as with GPS where we minimize the PDOP by collecting when satellites are spread apart.



- **Setup: Pacing Distances.** We'll do both, starting with pacing distances. For the 3-5 m accuracy of the handheld GPS, pacing accuracy is sufficiently accurate. First, we need our pace distance.

  - Count your extended paces over the 100-m course that the instructor specifies. Note that a pace is two steps, so starting with your left foot it's each time you put your right foot down. Extended paces are stretched out, more consistent than normal walking. Do this four times, back and forth twice, and record the number of paces here:

____________ ____________ ____________ ____________ sum = __________

- Go to the calculator program on the Juno, add them up and divide 400 by this number to get the length of your pace in meters, and write this down, to two decimal places: _____

We'll do various kinds of complex offsets for the field assignment. Refer to the *Juno_Terrasync* guide for instructions on each of the methods. There is further information in the Terrasync Getting Started manual. On-screen instructions also guide you through the process, which works pretty well as long as you take the time to read and understand what it's telling you.

- Check the **Units** settings to make sure they are correct for your methods and equipment, most likely:
  Distance Units Meters
  Offset Format Slope/Inclination
  North Reference Magnetic (since we're using a compass)
  Magnetic Declination 14.1 which I got by using:
  http://www.ngdc.noaa.gov/geomagmodels/struts/calcDeclination

- Collect at least one tree location using each of the following methods. For each, create a point with the Log Later setting in force, and go to Options to set the Offset method. As with other points, you'll use the data dictionary so you can record data on the type of tree, etc. You should try to record the same tree with different offset methods, to compare how they work, but feel free to record some other ones.

  1. **Distance – Distance**
     Pay careful attention to the instructions, and you'll need to note which side – left or right – the (tree) feature is in relation to a line from your first to second GPS point.

  2. **Triple Distance**
     Notes: This will require three GPS points. It actually derives three intersections, and will average these to give the best estimate.

  3. **Bearing – Bearing**
     Be careful reading the compass. Remember it reads from right to left – move it left and right to see how the numbers go. Some compass show a backsight reading as well, but you should use the bolder foresight reading. Also the Quad has a lot of places with magnetic interference from buried cables, so you might confirm its readings by backing up several meters and shooting through your GPS point (leave a partner holding a rod on the point) to the feature to see if it matches.

  4. **Triple Bearing**
     Note: as with the Triple Distance, it averages three intersections to derive a resulting location.

Control Points with Submeter GPS

At the end of the first day, we need to capture some control points for controlling a sketch. We haven't talked about this in class yet, but we need to get enough GPS points to accurately control our map. We'll try to leave some survey pins behind to use the next day.

As part of this exercise, we will use higher accuracy carrier-phase GPS, at the submeter or possibly subfoot level. Carrier-phase collection can be much more complex and there are various methods we can use suitable for different situations. Learn more about these in the *Terrasync Software Getting Software Guide* section on **High Accuracy Data Collection**. We'll be using the ProXH and GeoXH GPS units to capture features using H-Star technology, but it's useful to see how this compares with other methods. Each high-accuracy method uses a different part of the GPS signal called **carrier phase**. The three modes of using carrier phase are:

1. H-Star technology
    - down to 10-30 cm (1-3 dm, "subfoot") accuracy in real-time or after postprocessing.
    - usable soon after collection to 30-cm or so accuracy.
    - moderately priced equipment
    - can use public base station data
    - Requires a period of uninterrupted carrier phase logging of ~2 minutes to achieve 10-20 cm accuracy.
2. Carrier Phase Post-processing
    - 1-30 cm accuracy after post-processing
    - can use public base station data
    - Requires a period of uninterrupted carrier phase logging of 10-45 minutes to achieve 1-30 cm accuracy
    - Positions are not usable until the minimum continuous carrier lock time has elapsed.
    - Accuracy degrades rapidly with distance from base station.
3. Real-time Kinematic
    - cm accuracy in real-time, with no need for post-processing
    - not able to operate in difficult GPS situations
    - needs short distance to base station, usually employed nearby.

- ➢ As a group, we'll capture high-accuracy points at points that we'll use to survey offsets later. Label these with their ids on the trail map provided in the first exercise.
- ➢ We'll download and post-process the data in the morning.

Note: Carrier Lock must be maintained to get high accuracies. Must maintain lock with at least 5 satellites. In difficult situations, code may be used instead, but with less accuracy.

If you consider the above properties, there really are two purposes for this type of GPS:

1. **Submeter feature collection**. It's reasonably easy to capture ~1 m accuracy features using these units, though still more difficult (and much more expensive) than using the

handheld units. The units are larger and require a range pole setup to really get the accuracy we're after.

2. **Benchmarking**. As you can see, it takes more time per point and ideal conditions to approach a decimeter accuracy level, and a lot of time per point and perfect conditions to get to centimeter accuracy. So this is really in the realm of ***benchmarking***, where we establish a control point to survey from with a total station.

Compass Traverse (optional)

An extension of a vector offset is to continue from a known point through a *traverse* of points. This is similar to the field sketch with GPS points we did earlier, but we'll get the points from processing the traverse. You're provided with an example of a field notebook page, with a data recording area on the left, and a sketch area to the right. Assuming ID 201 is a known location, we record a series of offsets as shown here. Note that data are stored on the line with the ID of the target location. Refer to Fig. 2 for a corresponding sketch.

Id	SD	Az	Back Az	V	Back V
201					
202	10.0	170.5	250.0	-5	+5
203	1.5	270.0	91.0	0	0
204	12.2	130.0	311.0	-2	+2
205	2.2	189.5	9.0	+3	-2.5

- Survey a traverse assigned by the instructor, starting at a known point. Record features such as larger trees, etc., in the sketch. Hold the tape tight and directly between the two points (or at a constant height above both points). *Make sure to check all backsights* that they fit within 1° of your foresights, and record both foresights and backsights (don't convert the backsights to foresights, just record them as you have them, but re-measure them and change them as necessary.) *Finish the survey by closing back to the first point*.

In the previous field exercise, you collected:

1. Survey readings from handheld instruments
2. TerraSync features with built-in offsets
3. Possibly, a compass/clinometer traverse from a known point

1. Vector offset (optional)

For our manual offset, we could also do the computations in Excel before importing into ArcMap. You'll need the GPS coordinates you're surveying from and the various offset readings. You could either put the formulas in or use one I've provided.

➢ Open **travclose.xls** copied from the class data folder, and go to the **Simple Offset** worksheet.

Cells in green should be set

								mag decl	D factor						
								14.5	1				-------------uncorrected------------		
sta	sd	az (fs)	bs	vert	bsRev	err	ddtoaz	corr Az	hd	dx	dy	dz	x'	y'	z'
209													546094	4175190	134
2091	21.8	176	348	0	168.00	-8.00	-4.00	186.50	21.80	-2.47	-21.66	0.00	546091.53	4175168.34	134.00

There are several things to set:

a. Magnetic Declination: 14.1 is currently accurate for this area; change if necessary.
b. D factor: if your horizontal distances are in feet and you want to convert to meters (e.g. to match UTM), put 0.3048 in this cell, currently set to 1 (in green).
c. Enter your X (easting), Y (northing), Z XYZ coordinates (UTM or other) for your known point, the first line in the table, row 9: cells N9, O9, P9.
d. Your slope distance (SD, direct tape measurement), azimuth foresight, azimuth backsight, and vertical angle.

➢ Now copy the resulting XYZ coordinates in row 10, into your spreadsheet you're going to bring into ArcGIS, after the corresponding source GPS point (e.g. put 2091 after 209). You may need to insert a row, and Edit/Paste Special (Values) to make this work well. Then continue to export this worksheet into dbf, and bring it into ArcMap. Display both your normal waypoints, your source waypoint, and your offset point.

? Despite that fact that your target point is likely to hidden by trees, does it seem to make sense?

? Are there any serious blunders in your survey (like being obviously off by 180°)?

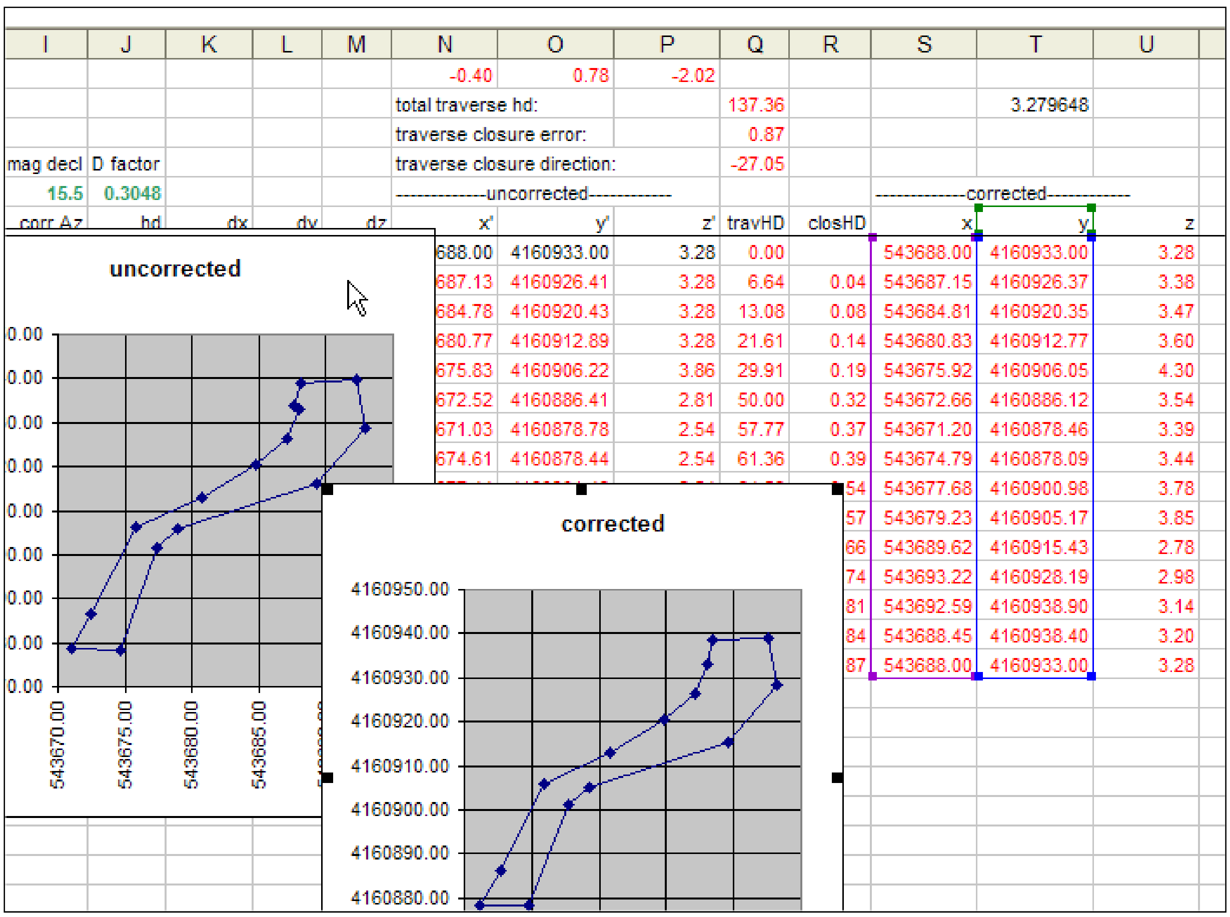
2. TerraSync Offsets

Download your saved GPS features with offsets using Pathfinder, and refer to the *Guide*. See how it deals with each of the types of offsets saved with the features.

3. Traverse (optional)

This is really just an extension of the previous process. The difference is that your data is a full traverse, and in fact a *closed* traverse in that you finish on the first point. Use the same **travclos** spreadsheet, but use the **ClosedTraverseDataEntry** worksheet to enter your data. The same data entry needs exist as the simple data entry above (magnetic declination, D factor, starting known point), but you'll have more lines of survey data.

One difference with the closed traverse is that the last point is automatically assumed to be the same as the first point, so an automatic closure is performed. Have a look at the two "maps" created (Excel doesn't really make decent maps unless you force X and Y spacing to be the same, but you can get a rough view) to see how much alteration is created, and check the traverse closure error shown in red in cell Q3. It should be less than a meter for a reasonably good survey, and I've usually gotten to a half meter.



- ➢ Enter your data, check the closure error, and if it's ok, save the document, and then bring the output worksheet into ArcMap as before. Compare the location of points to the aerial orthophoto – though your ability to do so will be limited by tree cover – the reason you had to use survey methods in the first place.

Id	SD	Az	Back Az	V	