System 1200 Newsletter – No. 41
Mixing GPS and TPS Data

Is There A Problem?

Sounds simple - complete half a survey with GPS, take the CF card from the GPS and put it into the TPS instrument and complete the survey. Easy?

It is easy, but all users of terrestrial (total station) or GPS instruments from any manufacturer should be aware of the potential "pitfalls" of mixing GPS and TPS data – grid, ground, projection scale factors, elevation scale factors... Or if a specific user is not (or does not need to be) aware of these pitfalls, then the instruments should be configured such that the instrument controls that the GPS and TPS survey "fit together".

Note, the problems that we will address in this newsletter existed before GPS was invented, but it is more useful now that GPS is a common surveying tool to consider the problem from the point of view of mixing GPS and TPS data.

This is a series of 3 newsletters - this first newsletter gives an overview of the "general problem" and explains the concept of grid and ground coordinates and so on. The following 2 newsletters build on this knowledge and look at use cases from both a total station and a GPS user's perspective.

After reading these 3 newsletters, it may then be apparent that perhaps the problem is not only in mixing GPS and TPS data, but rather a more general problem of fitting GPS and TPS measurements to existing control…

A Note On Terminology

For these 3 newsletters, the term "local grid" coordinates will not be used to describe coordinates given with an easting and northing - this is because we will later specifically distinguish between easting and northing "**true grid**" coordinates and easting and northing "**ground**" coordinates.

Is My TPS1200 Measuring Correctly?

Imagine the following:

Put two pegs in the ground at a distance of approximately 500m apart and measure the 2 points with your GPS1200 RTK rover. Ensure that you are using the appropriate coordinate system for that region (such as UTM32 or any other coordinate system). Compute the distance between the 2 points (using the COGO Inverse application program) and you should see that the horizontal distance between the 2 points is approximately 500m.

Now place your TPS1200 total station over one of the pegs and a target over the second peg. Turn on and measure a distance to the target over the second peg – look at the horizontal distance that has been measured.

Even allowing for a little error in setting up the total station and not holding the TPS prism or GPS rover vertically over the pegs – it is unlikely that the horizontal distance computed on the GPS instrument using COGO and the horizontal distance measured by the TPS instrument will be the same – they may be as much as 0.2m different. Why? What has happened?

Some background information may be useful to answer these questions.

TPS Measured Points

First, remember that it is a slope distance that is measured by the total station. (When computing the slope distance, the total station takes into account the atmospheric corrections - temperature, pressure and humidity, but we can ignore these corrections for this newsletter.)

The measured slope distance is then converted to a horizontal distance using the vertical angle (V).

It is the conversion of the slope distance to the horizontal distance which is most interesting for this newsletter because it is not only the vertical angle which is used to convert the slope distance to a horizontal distance, in addition the **geometric corrections** currently configured to be used on that TPS instrument are taken into account.

It is the **geometric corrections** which will determine if the horizontal distance is a **grid distance** or a **ground distance**.

If the **geometric corrections** are ignored, then **ground distances** are measured. If the correct **geometric corrections** are applied, then **grid distances** are measured (this can be thought of as the TPS measurements being "squeezed" (or stretched) to fit to the grid). Note, it is also possible that **geometric corrections** are applied, but not the "correct" corrections – this would mean **pseudo grid distances** are measured. This is also discussed later.

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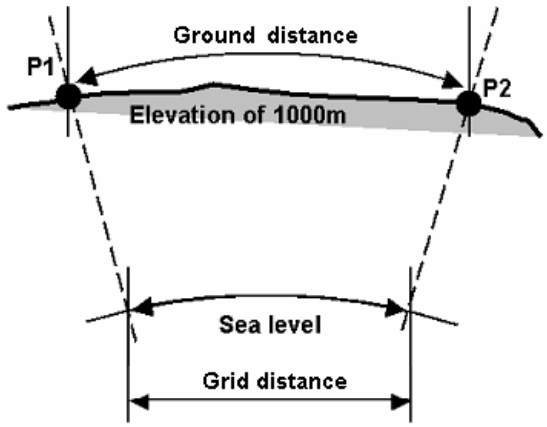
This is of course critical because this will then determine if the coordinates of the measured point are **true grid coordinates** (computed using the **grid distance**) or **ground coordinates** (computed using the **ground distance**). (If **pseudo grid distances** have been measured then this would result in **pseudo grid coordinates**).

Initially, it may be a little difficult to visualize a ground distance and a grid distance – surely, a distance is simply a distance? Well, yes and no…

The diagram below is typically used to explain the difference between a ground and grid distance.



The ground distance is shown as curved to indicate it is measured "over" the ground – this is simply the "convention" which is used. Of course, the actual distance is not curved, but straight. Imagine making a series of traverse legs – each individual distance measured for each traverse leg is "straight", but as the traverse progresses across the curved surface of the earth then the full traverse distance could be seen as a curve made up of many "smaller straight" legs.

GPS Measured Points

The coordinates of points measured with a GPS1200 instrument are stored in WGS84 geodetic coordinates.

However, most users require the coordinates to be converted to easting and northing coordinates (read newsletter 09-2004 for more information on coordinate types and coordinate conversions).

To do this a coordinate system suitable for that country or region is normally used. An example could be the UTM32 coordinate system – this is comprised of a "local" ellipsoid (the actual ellipsoid is not important for this newsletter) and a projection – in this case, the UTM32 projection could be used.

The conversion of the GPS measured points using the coordinate system will result in easting and northing coordinates based on the UTM32 coordinate system – in other words, **grid** coordinates.

It is also possible that the coordinate system being used can convert the WGS84 coordinates to **ground** coordinates – in this case, the GPS measurements are "squeezed" (or stretched) to fit to the ground.

Geometric Corrections

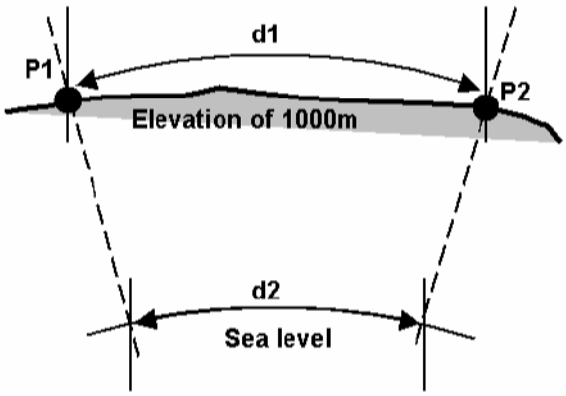
There are 2 separate parts to **geometric corrections** – the **height scale factor** and the **map projection scale factor**.

These 2 separate parts are first described and then shown how they are combined to compute the combined scale factor (or geometric corrections).

Height Scale Factor

Imagine the total station used earlier set up over the peg in the ground, measuring to the second peg in the ground. These pegs are both at an elevation of 0 (sea-level). We measure the distance between the 2 pegs and find that the distance is 500m.

Now imagine the 2 pegs at exactly the same location but now at an elevation of 1000m. Again measure the distance between the 2 pegs – but now the measured distance is shown as 500.078m.



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The diagram above clearly shows why this is – a distance measured between the same 2 points is greater when measured at a higher elevation.

It is the **height scale factor** that mathematically "describes" the difference between the two distances. So, if a distance is measured at an elevation of 1000m and it is necessary to know what the distance would be if measured at sea level, the **height scale factor** should be applied.

In summary, it can be said that the **height scale factor** allows the measured distance to be moved between the **ground distance** and the sea level distance – which is more commonly known as the **ellipsoidal distance**.

Map Projection Scale Factor

It was mentioned earlier that GPS measured coordinates (stored as geodetic WGS84) are converted to easting and northing **true grid** coordinates using the selected projection – but how is this done?

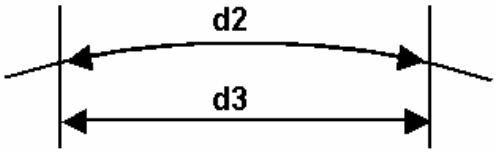
Mathematical formulas are used to convert the coordinates, with a unique formula being used for each projection type. The projections are defined by a set of parameters, which are used within the formulae.

Imagine you have taken the skin off an orange and now try to flatten the orange skin on a table. You cannot do this without "tearing" or at the very least "distorting" the orange skin. This is exactly what a projection does – it converts geodetic coordinates (the orange before we remove the skin) to grid coordinates (the flattened orange skin). The parameters describing the projection are defining how the orange is distorted.

One of the parameters describing the projection is the **Map Projection Scale Factor** (this scale factor actually changes as you "move within" the area covered by the map projection, but we can ignore that changing for now. It is the **Map Projection Scale Factor** that, for lack of a better term, defines "how" the orange is flattened.

Imagine again, the total station used earlier set up over the peg in the ground, measuring to the second peg in the ground. These pegs are both at sea-level (so we can ignore the **height scale factor**). We measure the distance between the 2 pegs and find that the distance is 500m, but if the mathematical straight line distance is calculated between the 2 points it is very unlikely this distance will be 500m. (You could be "lucky" if the **Map Projection Scale Factor** at this point is 1.000 and then the mathematical straight line distance would be the same as the measured distance, but it probably is not 1.000.)

The diagram below represents this difference created by the **Map Projection Scale Factor**. **d2** is the actual distance measured (shown by a curved line to indicate that it has not yet been flattened. **d3** is the mathematical distance, shown by a straight line to indicate that it has been flattened.

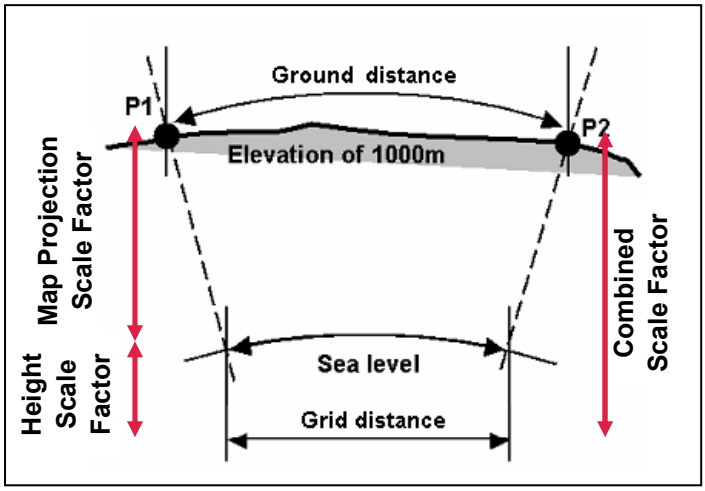


Geometric Corrections

We now know how to convert between grid and ground distances - using the **Height Scale Factor** to convert from a ground distance to an ellipsoidal (sea-level) distance and using the **Map Projection Scale Factor** to convert from an ellipsoidal (sea-level) distance to grid distance.

Combining the **Map Projection Scale Factor** and the **Height Scale Factor** (simply multiply them together) results in the **Combined Scale Factor** which allows to move directly between grid and ground distances.

This is shown in the diagram below.



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For the rest of this newsletter and the following 2 newsletters, the term **Geometric Corrections** will be used in the place of the term **Combined Scale Factor**.

SUMMARY

This newsletter was an overview of the "general problem" of mixing GPS and TPS data and the theory behind **Map Projection Scale Factors**, **Height Scale Factors** and **Geometric Corrections**. Also explained was the concept of grid and ground coordinates.

So far, this is all theory…

The next newsletter will apply this theory with use cases about how a total station user can use **Geometric Corrections** in the field and answer the questions about how they are actually computed and when should they be used.

Please contact your local Leica representative if there are specific topics you would like covered in these newsletters.

We welcome all suggestions for TPS1200, GPS1200, specific applications or LGO. We look forward to receiving your ideas.