FieldGenius Technical Notes
GPS – Local Transformation

Local Transformation

Due to a variety of reasons, it may be necessary to adjust position coordinates for distortions which can include scale, rotation, translation in northing and translation in easting. The flexibility of FieldGenius' local transformation utility allows it to be used for a variety of applications and applied to positions derived from GPS or terrestrial observations. For GPS applications there are two possible reasons for the need of a transformation:

1. Translating from Local System to Plan System
   GPS receivers by default generate geodetic coordinates (latitude, longitude and ellipsoidal height) and the process of converting to cartesian coordinates (northing, easting and orthometric height) or *local system* is done with existing well defined map projection systems such as Universal Transverse Mercator (UTM) or the State Plane Coordinate System (SPCS). Selection of the map projection in FieldGenius is done within the Datum page of the GPS Configuration and a local zone is selected to minimize scale and meridian convergence distortion. Most land, boundary or property surveys are unique with regards to their generalized plane and coordinate origin for each project. The coordinate system for these surveys is often referred to as a *plan system* with coordinate magnitudes being kept small for ease of recording and calculations. The majority of projects can suffice with a simple translation in northing and easting to produce plan system coordinates from GPS determined local system coordinates. The translation is easily determined by comparing a plan system coordinate and a local system coordinated for a single point.

2. Consideration for Scale and Rotation
   Projects with larger extents need to take into consideration the curvature of the earth's surface which can be handled by the application of scale and rotation transformations plus the previously mentioned translations. In the case of mixing GPS observations and terrestrial observations it does become important to apply a transformation, especially in scale, due to the fact that there is a difference in distance between positions measured on the ellipsoid and the terrain surface. As seen in Figure 1, coordinates derived from GPS are always referenced to the surface of the ellipsoid as per the application of map projections. When the two points on the ellipsoid are projected upwards along the ellipsoid normals onto the earth's surface, they diverge, and a terrestrial distance observed between the points will be greater than the computed distance of the same two points on the ellipsoid. The effects of this zenith divergence becomes more evident as distance between the two points becomes greater and for larger terrain heights above the ellipsoidal surface.

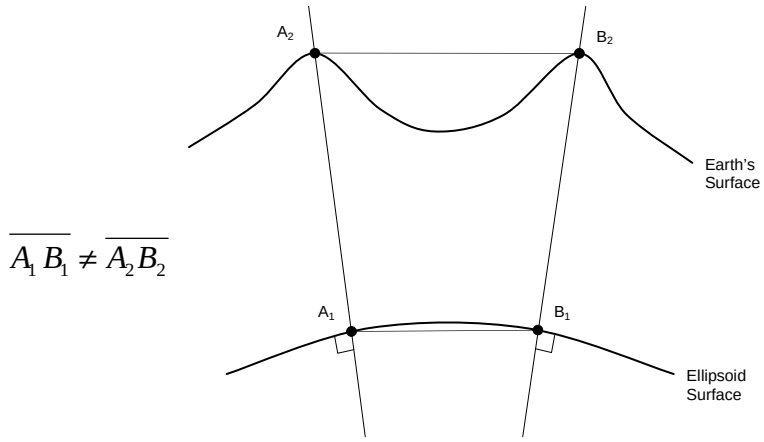
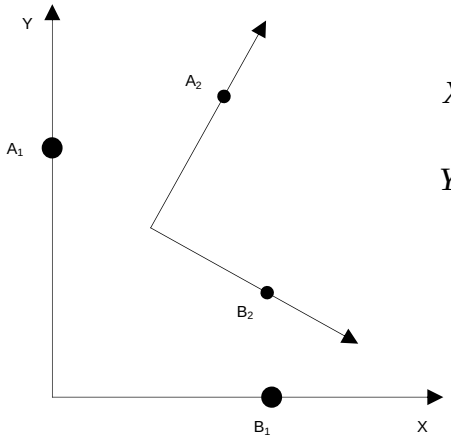


Figure 1. Divergence of Ellipsoid Normals.

Transformation Concepts

In order for the transformation parameters to be resolved, a sufficient number of control points are required with coordinates in both the plan system and local system. The determination of a four parameter transformation (two translations, scale and rotation) on a horizontal plane requires at minimum two physical points with each having two sets of corresponding coordinates as illustrated in Figure 2. Points A_1 and B_1 exist in what is termed the local system and are transformed into the plan system points of A_2 and B_2. The use of more coordinate observations will provide redundancy and the means to identify outliers for elimination. Solving for over constrained parameters is done with the application of least squares to provide the most rigorous minimization of residuals. Once transformation parameters have been resolved, newly observed or existing coordinates can easily be converted to the plan coordinate system.



$$X_2 = S\left(X_1 \cos\theta - Y_1 \sin\theta\right) + \Delta X$$

$$Y_2 = S\left(X_1 \sin\theta + Y_1 \cos\theta\right) + \Delta Y$$

WHERE:

S	Scale
Θ	Rotation
ΔX	Translation in X
ΔY	Translation in Y

Figure 2. Horizontal Four Parameter Transformation.

The selection control points for determining the transformation parameters are critical in reducing a colinearity condition along a particular axis. Colinearity will present itself if

the control points are concentrated in a linear fashion as shown in Figure 3 (Poor Design) and thus weaken the parameters in a perpendicular direction. Control points should extend to the corners of the project boundary and be extended with equal distances in both horizontal directions.

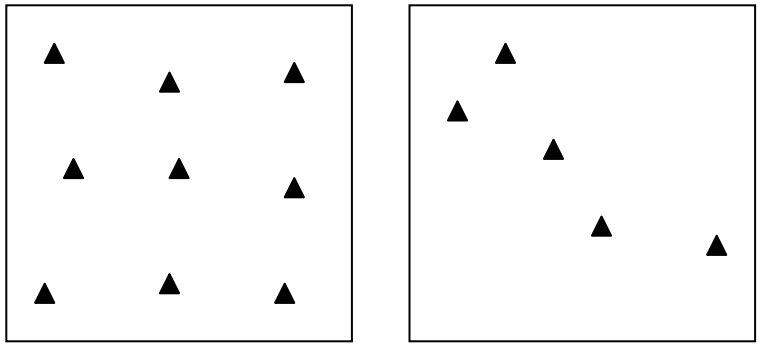


Figure 3. Transformation Control Design.

Vertical Transformation

The vertical transformation function of FieldGenius operates independently of the horizontal transformation. A sloped plane is calculated from the residuals of the constrained point pairs to determine a vertical bias, slope in X and slope in Y. To determine a vertical bias at least one point pair must be constrained and for all three parameters to be determined at least three point pairs must be constrained.

The use of the vertical transformation function should be restricted to cases where a geoid model is not available or there is a know problem with an existing geoid model. The vertical transformation is a first order function and should therefore be limited to small areas due to the geoid in reality being considered a function of high order spherical harmonics.

Local Transformation Example A

For this example the simple case of translating the GPS derived local coordinates to the desire plan coordinates will be used. The example will demonstrate how FieldGenius can be used to determine and apply the transformation parameters. A project is created consisting of four points in the plan system as denoted in Figure 4 and the corresponding coordinate listing shown in Table 1.

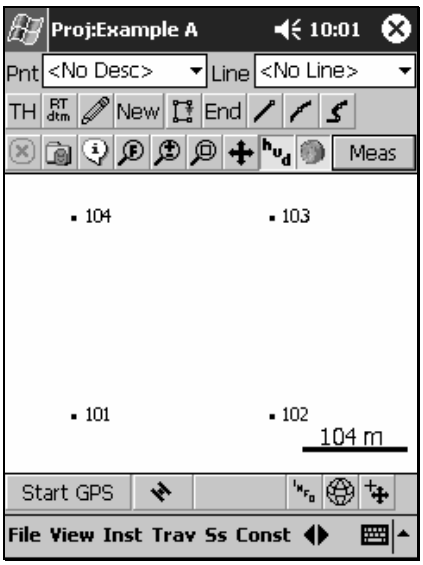


Figure 4. FieldGenius Project with Points in the Plan System.

Point	Northing	Easting
101	1000.000 m	1000.000 m
102	1000.000 m	1200.000 m
103	1200.000 m	1200.000 m
104	1200.000 m	1000.000 m

Table 1. Plan System Points.

The GPS reference station will need to occupy a point within the project area which can be an existing plan system point (101-104) or a new point set for the project. For either setup of the reference station, the GPS antenna should have an unobstructed view to the satellite constellation to ensure that the rover station operates at its full potential. If the reference station is unable to occupy a plan system point, the rover station can instead measure an existing plan system point with local system coordinates and for this example that case will be assumed. Using FieldGenius to configure the GPS reference station, a suitable map projection is selected and the reference station position will be determined autonomously as shown in the two diagrams of Figure 5.

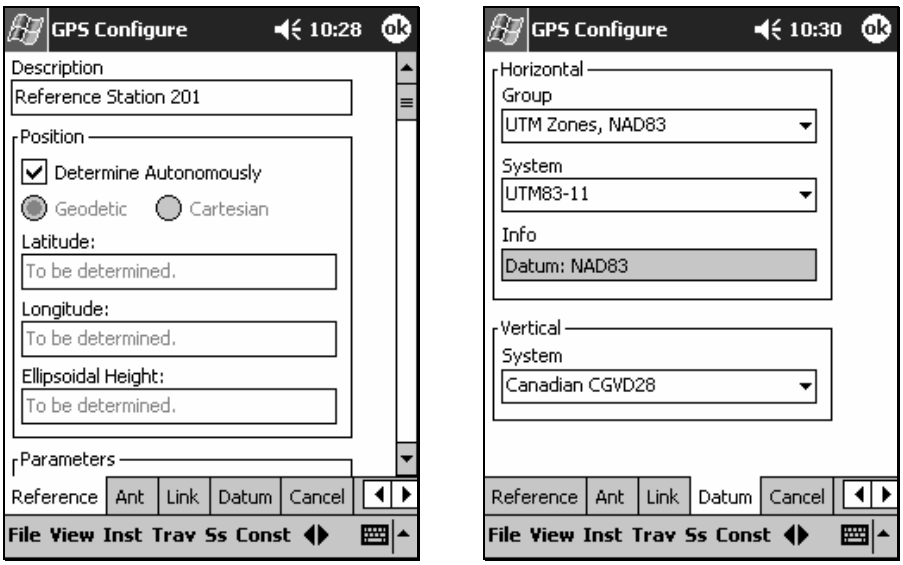


Figure 5. FieldGenius Reference Station Configuration.

Upon initializing the reference station GPS receiver, FieldGenius at the user's discretion will set the GPS with an averaged autonomous position and store the local system position. Once the reference station is operating and transmitting corrections, the rover station is used to measure plan system point 103 and the new local system point is assigned point number 203. Table 2 indicates the measured coordinates of point 203 in the local system which corresponds to point number 103 in the plan system. Figure 6 illustrates that FieldGenius now has points in two different coordinate systems as indicated by the large separation.

Point	**Northing**	**Easting**
203	5523295.939 m	311585.808 m

Table 2. Local System Point.

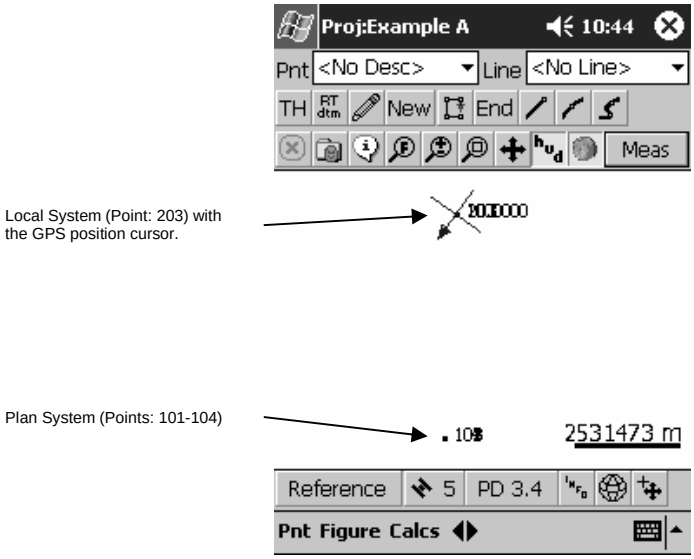


Figure 6. FieldGenius with Two Coordinate Systems.

Now that points exist in each of the coordinate systems the local transformation parameters can be determined and applied. Transformation Settings can be accessed from the Points menu of FieldGenius. Initially the transformation parameters of translation in northing, translation in easting, scale and rotation will be null and any transformation will not be applied to GPS positions as indicated in Figure 7.

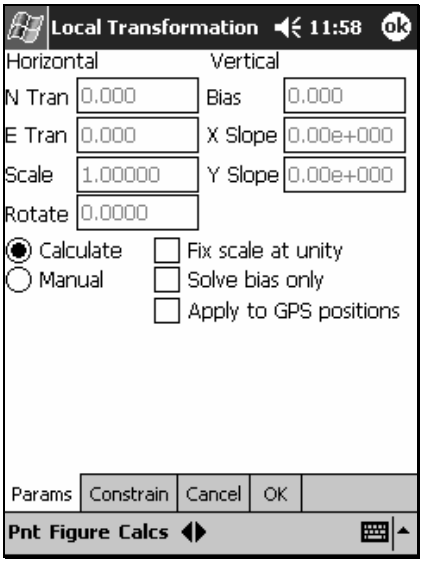


Figure 7. FieldGenius Default Transformation Parameters.

From the Local Transformation Setup select the Constrain tab for the entry of local and plan point pairs to be used in the determination of the transformation parameters. As seen in Figure 8 point 203 is entered as a local system point and corresponding point 103 is entered as a plan system point. The check boxes for constraining to horizontal and

vertical are left enabled. The following tabular columns denote residuals in northing, easting and height and for this case are all zero due to the transformation being minimally constrained.

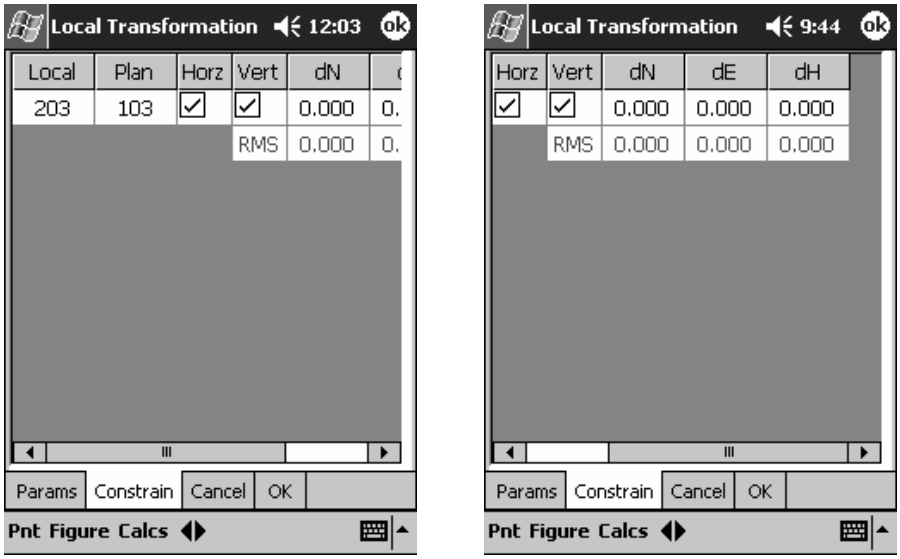


Figure 8. FieldGenius Constrained Points for Transformation.

The calculated transformation parameters can be viewed by returning to the Parameters page. Since only one point pair being is being constrained, the utility has only determined a translation in northing, translation in easting and vertical bias. The addition of more point pairs would allow for scale, rotation and slopes in X and Y to be determined. The check box for the field “Apply to GPS positions” must be selected to transform the GPS positions from the local system to the plan system.

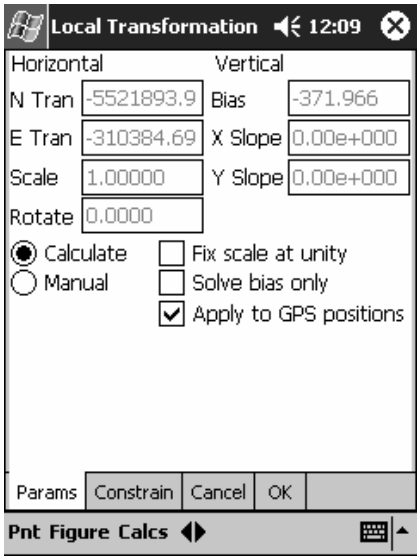


Figure 9. FieldGenius Calculated Transformation Parameters.

The map view of FieldGenius will now show the effect of the transformation by showing the new position of the GPS position cursor and denoting new coordinate values.

Returning to point 103 with the rover station will verify the transformation process. New points measured with GPS will reflect the applied transformation parameters.

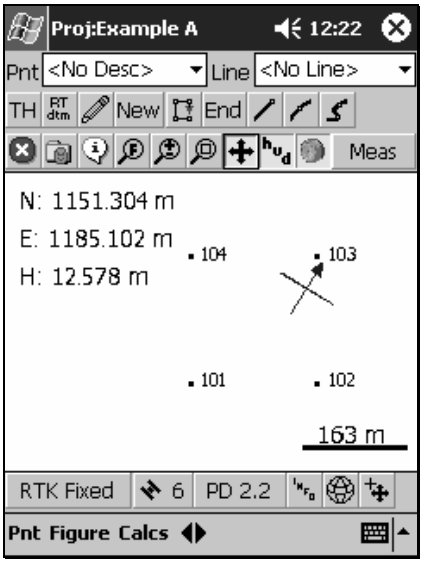


Figure 10. FieldGenius Transformation in Effect.

Local Transformation Example B

This example will investigate the process of transforming a set of existing terrestrially derived positions so that they are constrained to a set of GPS derived positions. The process of transforming points is reversed from previous discussions and will therefore imply that the GPS derived coordinates are in the plan system and the terrestrially derived positions are in the local system. Another consideration for this example is that the project area is relatively large and more than one point pair will require to be constrained to determine all four parameters and for redundancy. Determination of the transformation parameters will account for the geodetic implications of the earth's curvature and meridian convergence. The existing FieldGenius project is illustrated in Figure 11 with the 100's series points having been established with a total station.

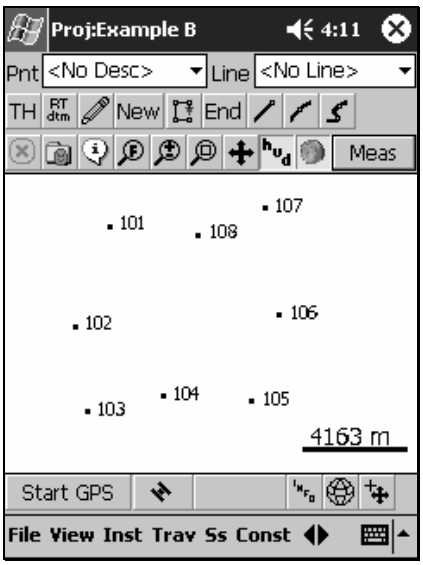


Figure 11. FieldGenius Project with Points in the Local System.

The GPS reference station occupies a national geodetic control point and has been configured with the corresponding published coordinates. The GPS rover station is used to measure points 102, 104, 106 and 108 to establish coordinates in the plan system and these new points are respectively name 202, 204, 206 and 208 (Table 3).

Local System (Conventional Points)				**Plan System (GPS Points)**			
Point	**Northing**	**Easting**	**Height**	**Point**	**Northing**	**Easting**	**Height**
101	10820.603	3060.696	383.133				
102	6765.098	1674.638	384.936	202	5516443.987	311551.600	384.946
103	3325.620	2136.657	384.589				
104	3941.646	5216.788	383.543	204	5513620.403	315093.864	383.557
105	3736.304	8810.273	383.299				
106	6227.118	9939.654	382.980	206	5516905.954	319816.969	382.983
107	11539.300	9323.628	381.795				
108	10461.255	6654.182	384.380	208	5520140.241	316531.321	384.376

Table 3. Coordinate Listing.

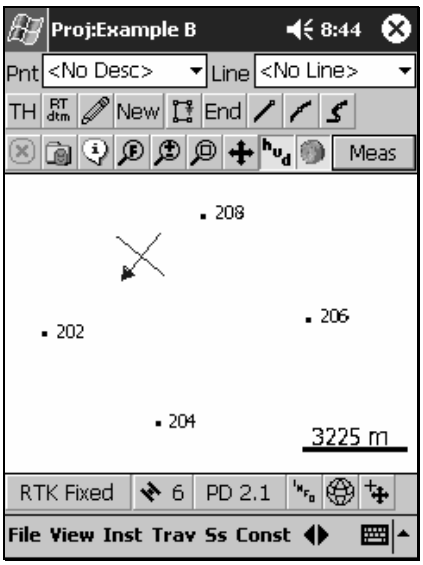


Figure 12. FieldGenius Project with Points in the Plan System.

Now that coordinates have been established in both the plan system and local system, the Transformation Setup is started from the Point menu of FieldGenius. Figure 13 shows the Constrain page after the point pairs have been entered and their corresponding computed residuals. With four point pairs being used the horizontal transformation has a redundancy of two point pairs and the vertical transformation has a redundancy of one point pair. The residuals are within acceptable limits and do not necessitate the removal are addition of point pairs.

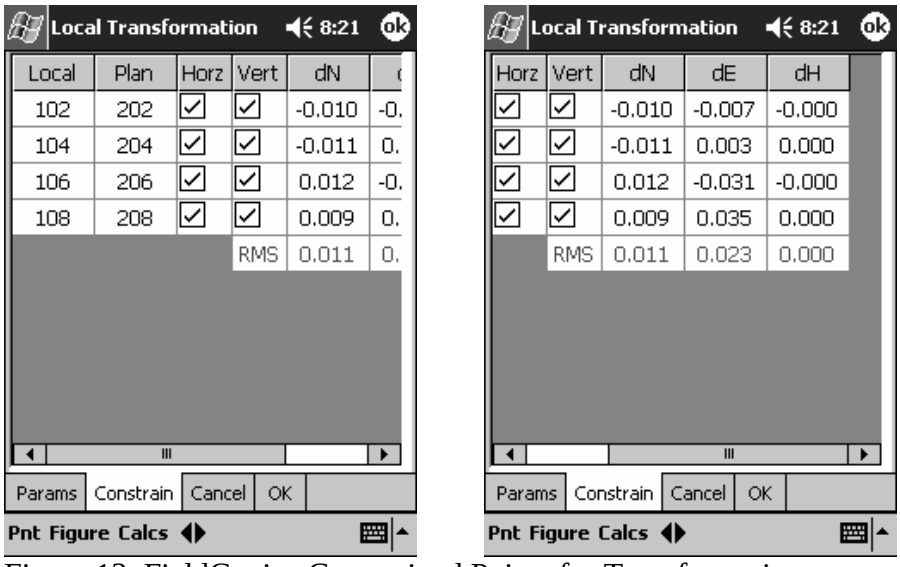


Figure 13. FieldGenius Constrained Points for Transformation.

Viewing the Parameters page, as indicated in Figure 14, will provide feedback of the calculated horizontal and vertical transformation parameters.

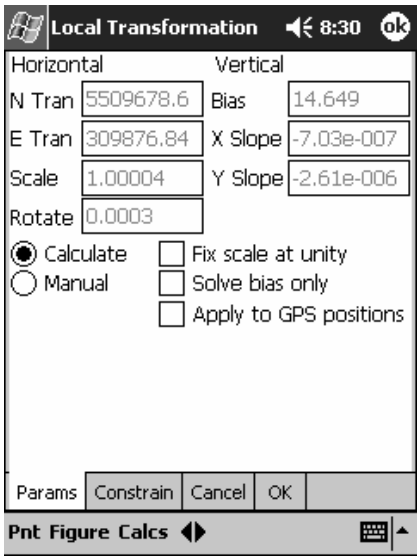


Figure 14. FieldGenius Calculated Parameters.

Using the calculated transformation parameters the local system points (101–108) can be transformed in the Transform Points dialog accessed from the Points menu of FieldGenius. The list of terrestrially derived points is entered as shown in Figure 15.

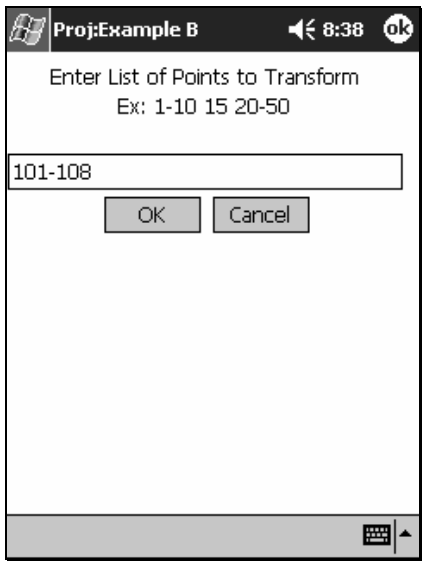


Figure 15 Transforming Existing Points to the Plan System.

After successfully transforming the points 101 through 108 from the local system to the plan system which was constrained to the GPS point 202 through 208 the results can be seen in Figure 16. The diagram illustrates the matching of points 102, 104, 106 and 108 with corresponding points 202, 204, 206 and 208 respectively.

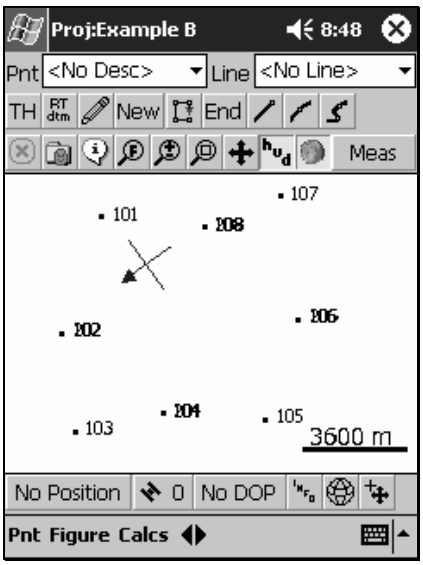


Figure 16. Results of the Transformation.