Analysis of free station errors

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Free station setups are becoming increasingly more common in surveying for coordinating positions, especially within engineering surveying. In spite of this there has been little research that has analysed the effects of different factors on the errors and accuracy of the resulting coordinates from free stations. The effect of different instrument precisions, numbers of targets observed, target geometries and observing with single or both instrument faces were investigated. SNAP, a least-squares adjustment programme available from Land Information New Zealand was used to trial these scenarios. The use of free stations for surveying the construction of Wellington hospital provides an example of a typical situation where these findings could be applied.

Free station setups

The free station procedure determines the co-ordinates of an unknown point using both distance and direction observations to stations that have known co-ordinates. Typically, a minimum of two fixed stations must be observed, although three is better survey practice. It is essentially a combination of a distance and angular re-section. While these separate processes are generally well understood there has been limited information on errors resulting from free station solutions. Nearly all modern total stations have in-built software for the free station process that calculates the resulting coordinates and displays the error information for the observed lines and coordinates. An advantage of a free station is that the instrument can be set up in the most convenient location, rather than being forced to use a known point. This may therefore save time and improve safety for the surveyors and equipment.

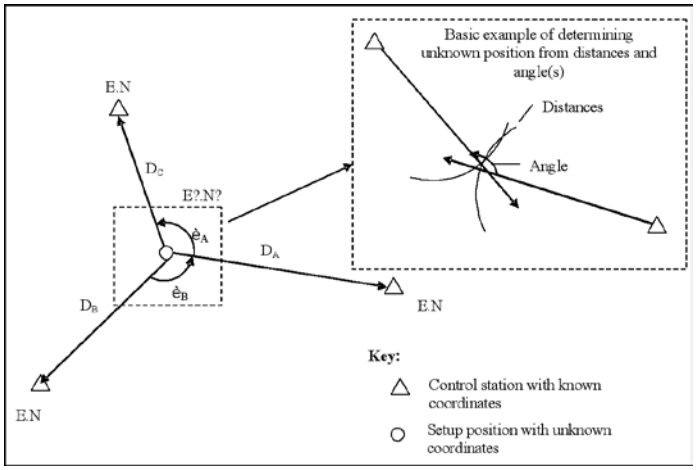
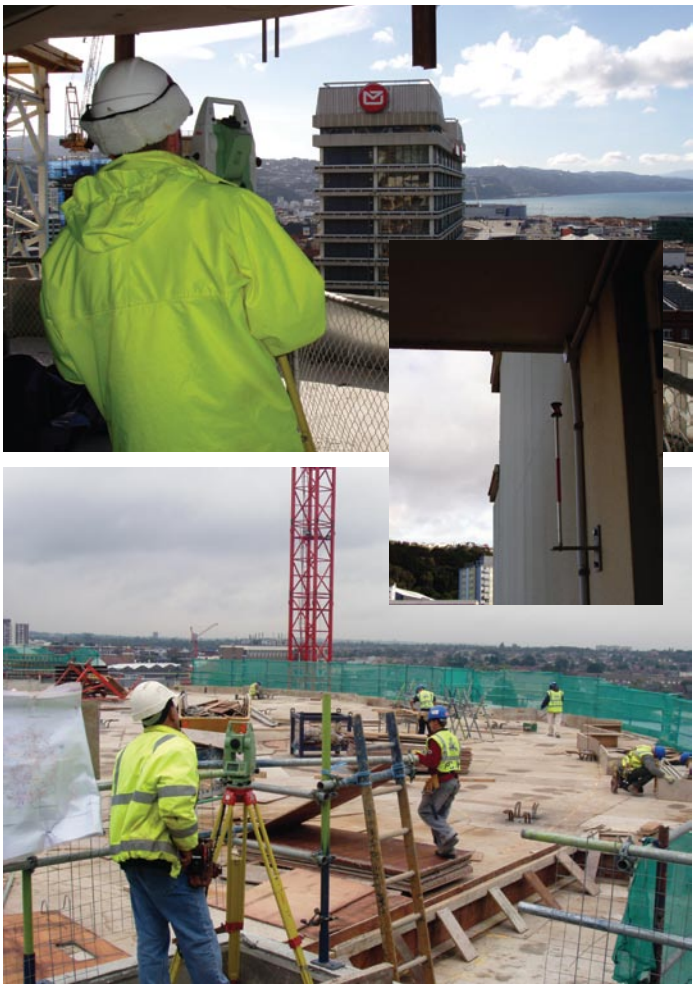


Figure 1: Free station procedure and processes

Use of free stations

Free station setups were used extensively by Cardno TCB Ltd for the setting out of a new high-rise building to be used by Wellington regional hospital. Observations were made to five permanently



Figures 2, 3 and 4: Surveying part of the Wellington Regional Hospital building, with observations to prisms on surrounding buildings similar to that demonstrated

mounted prisms on surrounding buildings, with accuracy tolerances required to the millimetre level. Setout work included establishing grid-line offsets, vertical datums, as-built surveys and vertically controlling the building between floors.

In situations such as this it is important for the surveyor to understand the different effects of errors on these free station setups. Choices that need to be made may include –

- What instruments will be used depending on their different precisions
- How many targets should be used, given site location constraints
- What geometry of these targets is best
- What improvement can be gained by observing with two faces, rather than only one

The effects of these factors on the resulting accuracy of the setup point were investigated. For all observations, unless stated otherwise, the precision specifications for a Leica TC308 total station used were 5" in angle and 3 mm+3 ppm in distance. A standard site layout was used for all but the geometry test, which had a fixed number of pre-specified positions where targets could be placed. The intention was to simulate a real life situation such as was found at Wellington Hospital. To compare different scenarios, a standard baseline configuration of four stations was used.

The error ellipses from SNAP show the size and shape of the errors in the resultant coordinates and observations at a 95% level of confidence. These were examined in this analysis and indicated the greatest sources of error and therefore what could be changed to decrease them.

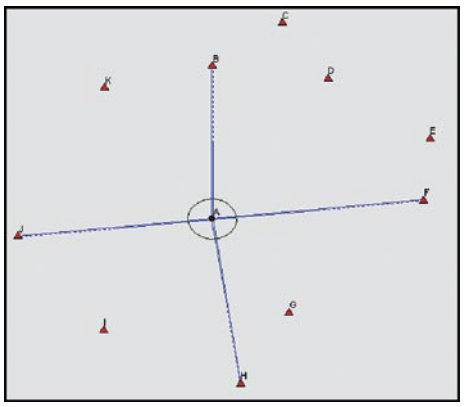


Figure 4: Standard configuration of four stations

Analysis of free station errors

Effect of instrument's precision

Assuming a Leica TC308 instrument was used there are three possible levels of precision that can be tested. Using the baseline layout of four targets the horizontal accuracies ranged between 4 mm (with the 5" and 3 mm+2 ppm instrument) and 1 mm (1" and 2 mm+2 ppm instrument). These results indicate that the instrument used is definitely an important consideration, particularly if millimetre accuracy is required.

Number of targets

Using the constrained layout of possible target positions there is an exponential relationship between the number of targets observed and accuracy of the free station setup position. For example, between two and five targets the errors decreased quite significantly as the number of targets were increased (Figures 7 and 8). Between two and ten targets were trialled, and to ensure the results were not

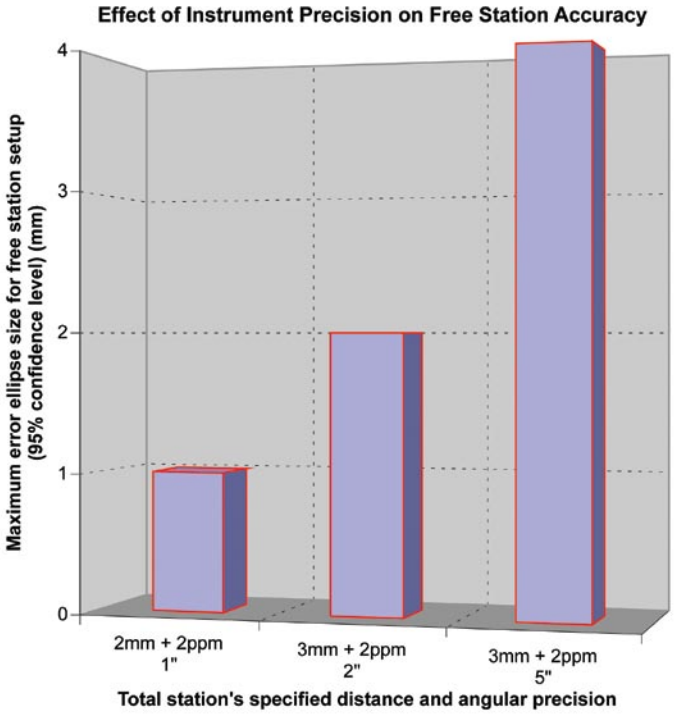


Figure 5: Effect of instrument precision on free station accuracy

biased the angles between these were reasonably constant.

An accuracy of 4 mm was calculated for the baseline configuration of four targets, with this decreasing to 5.3 mm with two targets and conversely increasing to 2.5 mm if 10 targets were observed. Therefore, if it was possible to observe additional targets the greatest gains in accuracy for each additional target observed occurs up to an approximate total of six where the accuracy gains decrease to 0.5mm.

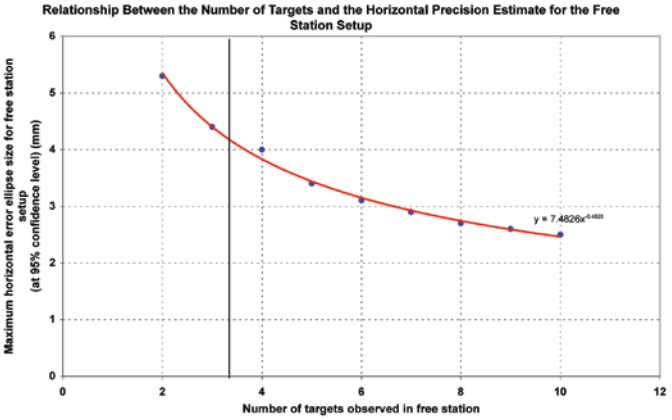


Figure 6: Relationship between the number of targets and the horizontal accuracy estimate for the free station setup

Geometry test

The influence of target geometry on the resulting accuracy was analysed using two observed lines to known positions. These observed lines and positions were of varying angular separation and distance. As expected the errors increased significantly when there was a small angular separation between the targets. While the error size was at the ~10mm level for larger separations of 90° and 160°, it increased to 50 mm when they were only separated by 20°.

Secondly, as the distance to the targets increased the shape of the error ellipse became more circular, with the semi-minor axis

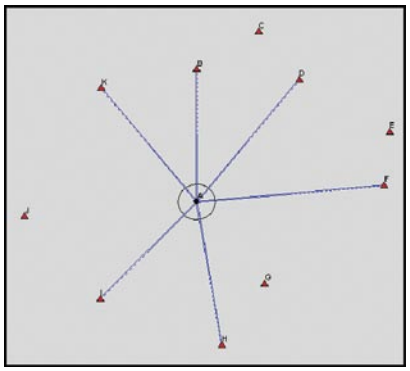


Figure 7: Sample layout and error ellipse for number of targets test

increasing from one to eight millimetres as the distance increased from 150 metres to 1000 metres. This is a reflection of the angular accuracy weakening as the distance to the targets increased, while the distance accuracy weakened by a much lesser degree.

Thirdly, there was a small decrease in the errors of the calculated position as the target separation grew closer to 180° – from 90° to 160°. However, further investigation is required to ascertain why this occurred, as only a preliminary analysis was undertaken. Therefore, the geometry of the targets and balance between the errors from distances and angles observed clearly influences the accuracy of the calculated position.

Relationship of horizontal accuracies to geometry combinations

Station angular separation	Distance to targets	Horizontal error ellipses		
		95% (mm)		1σ (68%) (mm)
		Semi-major axis	Semi-minor axis	Semi-major axis
20°	150	50	6	20
160°	150	9	1	4
160°	1000	9	8	4
90°	150	12	2	5

One or both faces test

The effect of observing with only one or both instrument faces was investigated by repeating the number of observations made to each target. When both faces were used the estimated errors of the free station coordinates decreased by 1 mm (from 4 to 3 mm) Three targets were also trialled, with the errors decreasing by 1 mm (from 5 to 4 mm).

Conclusion

Four different tests were undertaken to demonstrate the effect of a range of factors on the size of the errors for a free station setup. Using the standard configuration of four targets, it was found that observing two faces instead of one increased the accuracy of the result by 1 mm.

More important, however, was the impact of the quality of the total station. It was found that a change in horizontal angle precision from 2" to 5" changed the accuracy by 2 mm. It was also found that there is an exponential relationship between the number of targets and the accuracy, with the changes in the accuracy steadily decreasing to the 0.5 mm level when up to five targets are observed.

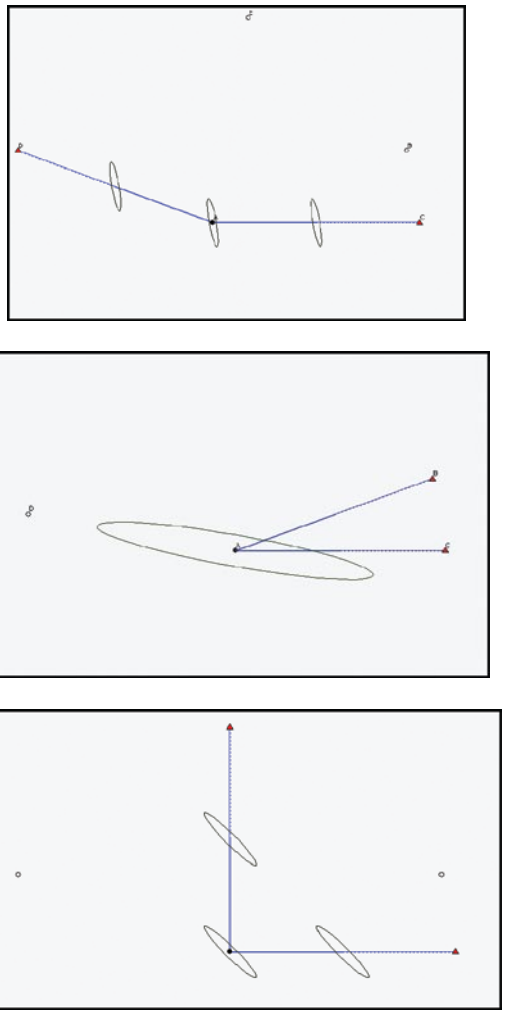


Figure 8: Layout and error ellipses for the free station geometry test observations and positions.

Both the geometry of the targets and the different proportions of errors from the angle and distance observations were shown to have a clear influence on the resulting accuracy. In designing surveys using free station setups, such as Wellington hospital, it is important that the effects of these factors on the accuracies and errors are understood.

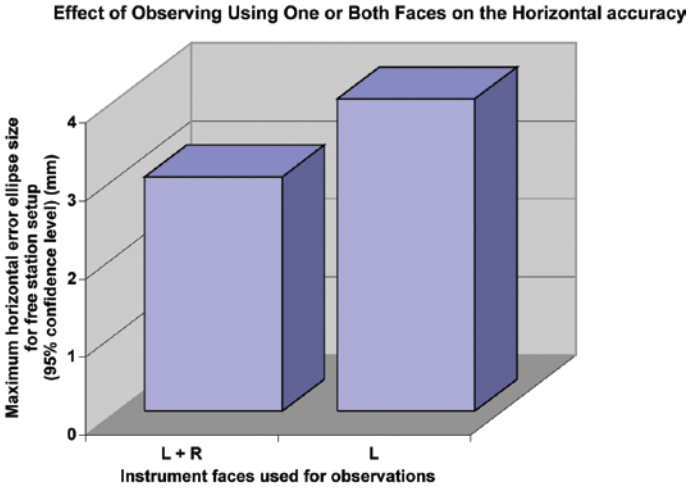


Figure 9: Effect of observing using one or both faces on the horizontal accuracy