Real-time GNSS field procedures: maximising gain and minimising pain

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Real Time Kinematic (RTK) is an established, proven and extremely popular Global Navigation Satellite System (GNSS) technique. Users may employ either a conventional radio link between base and rover, or its modern equivalent, a wireless internet connection to a Continuously Operating Reference Station (CORS). In any case, RTK is the norm in many spatial applications.

Users revel in the high precision, increased productivity and hassle-free positioning offered by this 'real-world digitising' technique. Today's modern user also benefits from the additional rewards provided by Network RTK (NRTK).

In this article, we revisit two of the original GNSS best-practice field procedures for non-mobile (static) RTK/NRTK applications. Using CORSnet-NSW and some 5 million observations in four test areas, we confirm these procedures are still valid, and continue to improve precision (or repeatability), accuracy and reliability when coupled with modern techniques.

We present updated guidelines regarding occupation times and the time span between double occupations. We also show that coordinate quality (CQ) indicators provided by the GNSS rover equipment should continue to be used with caution.

Occupation times and averaging observations

Occupying a location for more than one measurement, observation or epoch and averaging (or windowing) the results has been best practice for static applications since satellite-based positioning first began. It is regularly applied by hand-held recreational, GIS/mapping and survey-accuracy users. Most importantly, averaging reduces the effect of extreme, short-lived outlier observations, thereby increasing reliability, precision and accuracy.

In other words, averaging mitigates the risk of obtaining a rogue result that disagrees with the actual position by a large amount. You may recall that the

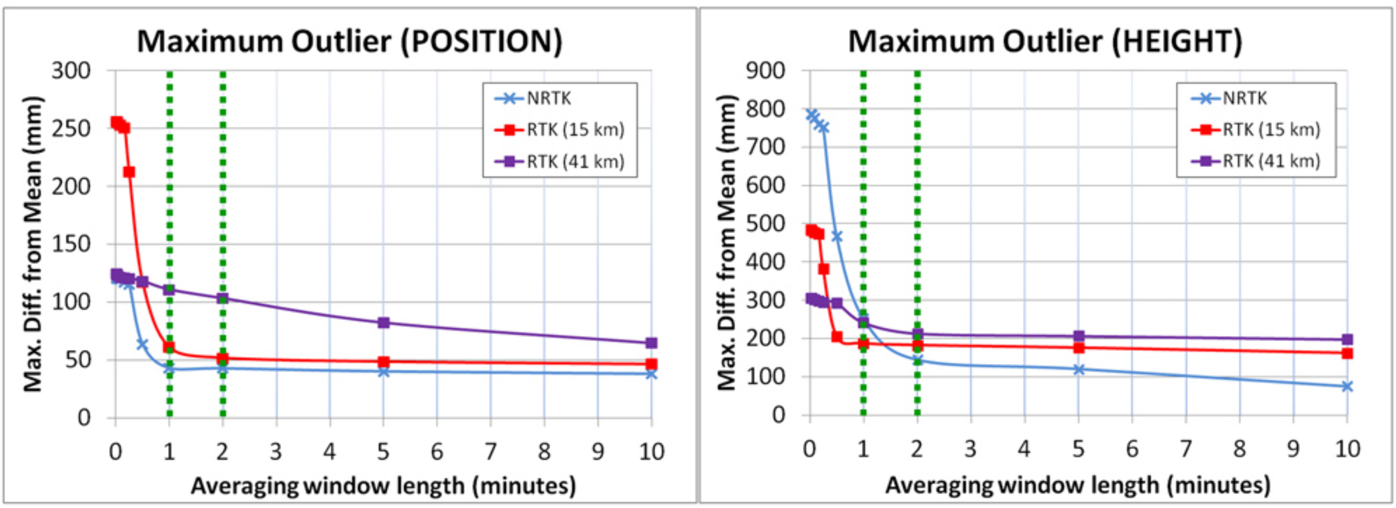

Figure 1. Maximum outliers in horizontal position and ellipsoidal height for observation windows of up to 10 minutes at Macquarie University.

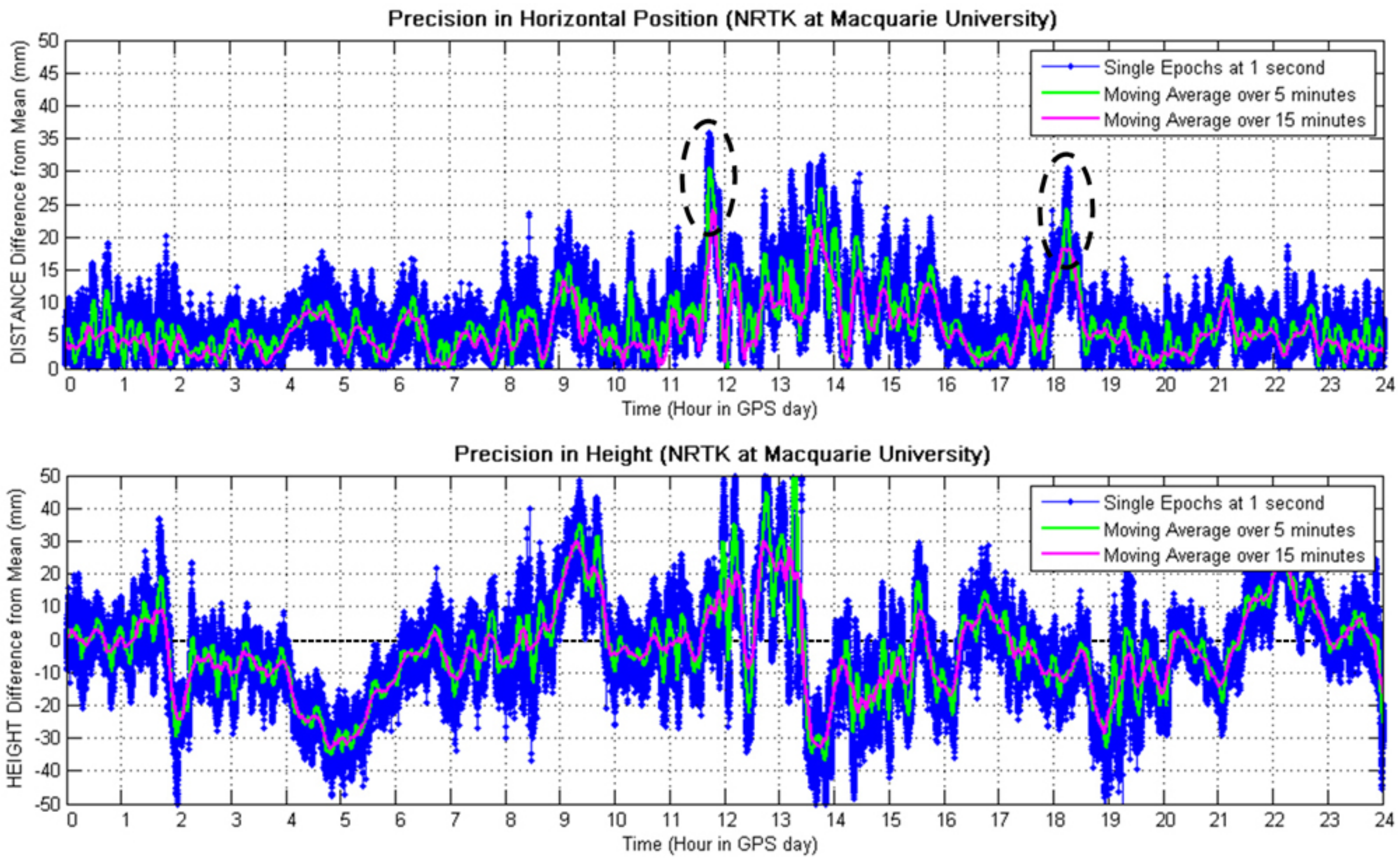

Figure 2. Typical time series of horizontal position (top) and ellipsoidal height (bottom), showing individual 1-second observations and the effect of averaging.

benefit of averaging follows the principles of the Law of Diminishing Returns – that is, a little helps a lot. But how long should a modern real-time user spend on a mark to benefit from averaging without sacrificing productivity?

We found that an observation window of 1-2 minutes reduces the effects of extreme outliers as much as possible in the shortest time frame. If the application requires high quality heights, or the user is located at some distance from the nearest GNSS reference station, a 2-minute observation window should be used. Investigating some 5 million observations across four test areas, and employing up to six rovers, simultaneously revealed that this applies to both RTK and NRTK.

While 1-2 minutes may seem like an eternity for some real-time users in the field, it is still far quicker than the alternative option of using rapid or fast static GNSS techniques. The time can be spent completing other tasks, such as filling out metadata in the instrument or field book, taking site photos, examining plans, and looking up the next mark to be occupied.

Let's take the results from one test area as an example. Figure 1. shows the largest outliers obtained in horizontal position and ellipsoidal height for NRTK and RTK over two different distances. Based on a 3-day dataset (260,000 positions per technique), this figure illustrates the benefit of averaging for various observation windows of up to ten minutes.

We can see that a large improvement is generally achieved between observing for 1 second versus averaging for 30 seconds and 60 seconds. Averaging for longer than 1-2 minutes does not appear to provide any significant further improvement, except for longer single-base RTK baselines.

But it is important to note that averaging doesn't fix everything. Averaging can still produce results that are significantly offset from the actual position (Figure 2). In particular, note the peaks evident at about 12 and 18 hours in the horizontal position. This type of disagreement from the mean is mainly caused by changing atmospheric conditions and/or bad satellite geometry (DOP factors).

Time between double occupations

Double occupations are well established, best practice for many surveying applications, including GNSS observations. They can detect blunders, like observing on the wrong mark, poor centring or a wrong instrument height. For GNSS, double occupations are also useful to detect the effects caused by incorrect ambiguity resolution or bad multipath conditions.

Some may argue that the need for double occupations has decreased due to improved multipath minimisation techniques, the greater use of fixed-height antenna poles, improved reliability of ambiguity resolution, and modern instruments automatically reinitialising and checking their ambiguities every few seconds. Nevertheless, double occupations are still one of the best methods to prove the correctness of positioning results.

As mentioned earlier, the averaging technique can still produce a result significantly offset from the actual position. For high-accuracy applications, double occupations can therefore improve the precision, accuracy and reliability of GNSS positioning.

The old rules still apply. If possible, the second occupation should be at a different time of day and use a different antenna height. GNSS rover poles offering a choice between two fixed antenna heights (for example 1.800 and 2.000 metres) are very useful. Care should be taken with extendable poles that may slide and cause the antenna height to change during the survey.

Connecting to a different reference station is also advisable (and sometimes required). Another option is to use a different NRTK method. For example, a user can switch between the Virtual Reference Station (VRS) approach and the Master-Auxiliary Concept (MAC) (see *Position* 41, June 2009).

But how long should a user wait until re-observing a mark? Our analysis of the same data indicates that two occupations can be assumed sufficiently independent from each other if they are taken 10-30 minutes apart. Waiting any longer to re-observe is generally not likely to improve positioning results any further. This applies to both RTK and NRTK.

Coordinate quality indicators

In practice, a coordinate quality indicator (sometimes called CQ, RMS or position quality by manufacturers) is often computed by the GNSS rover. It can give a rough estimate of the precision of the determined position and help filter out poor observations. The CQ indicates how much the computed position is likely to deviate from the actual position. The lower the reported value, the better the estimated quality of the coordinates. But it must be remembered that the calculation of CQ values does not take into account external factors such as multipath, centring or pole-wobble errors.

Our extensive testing has clearly demonstrated that a specified CQ value does not necessarily represent the actual precision of the coordinate solution. In fact, the actual precision is often a lot worse than indicated by the CQ (by up to a factor of 5-7). This occurs for both RTK and NRTK, even under the favourable satellite and multipath conditions encountered during our tests. It is worth noting that NRTK shows consistently smaller CQ values when compared to RTK. As expected, this suggests a better quality of the NRTK solutions.

All our datasets show that CQ values have a minimum threshold value of about 5 millimetres in horizontal position and about 8 millimetres in height. This conservative estimate of quality in perfect conditions quickly becomes overly optimistic as the CQ algorithm fails to account for real-world variations.

As an example, Figure 3. illustrates the relationship between reported precision (CQ value) and actual precision (compared to the mean over a 3-day observation window). Each circle represents one of 260,000 horizontal positions observed at this site using NRTK.

It quickly becomes clear that the reported CQ value is often too optimistic. For example, as highlighted in the figure, the reported CQ value may indicate a precision of 10 millimetres, although it is actually much closer to 50 millimetres.

We also found that misleadingly low CQ values reported by the GNSS rover allow a small number of large outliers to slip through undetected. For example, consider the cluster of outliers at nearly 120 millimetres distance from the mean shown in Figure 3. The CQ incorrectly reports the expected precision of these positions as 15 millimetres.

These large outliers are most likely caused by incorrect ambiguity resolution and can be detected and mitigated by observation techniques such as averaging and double occupations. Obviously, this is of more concern to the user than the reverse scenario, where a poor CQ value is reported for a positioning result with good agreement to the actual position, effectively resulting in throwing away good data.

These findings show that CQ values are still prone to be overly optimistic and should therefore continue to be used with caution. Testing the GNSS rover equipment is advisable to get a more realistic indication of the actual positioning quality obtained in typical user situations.

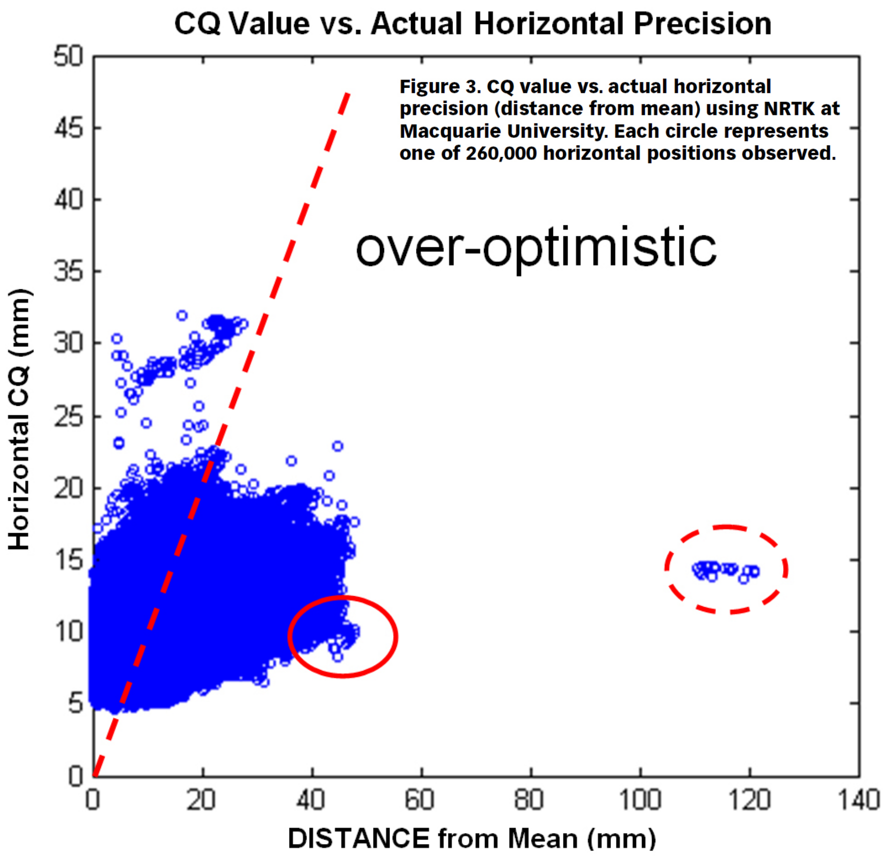

Figure 3. CQ value vs. actual horizontal precision (distance from mean) using NRTK at Macquarie University. Each circle represents one of 260,000 horizontal positions observed.

Conclusion

We have revisited two well established, best practice field procedures that can improve the precision, accuracy and reliability of static, real-time GNSS surveys. Our tests confirm that these procedures are still valid and apply to both RTK and NRTK.

To maximise gain, with the least amount of pain, in the field, RTK/NRTK observations should be averaged over a window of 1 minute. Averaging over 2 minutes should be applied at longer ranges and/or when better height results are sought. Double occupations should be taken at least 10-30 minutes apart.

It is helpful to use coordinate quality indicators provided by the GNSS rover equipment to get a feel for the expected precision of the derived position and to help filter out outliers. But users need to be aware that these indicators are often very optimistic and should therefore be used with caution.

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