Network RTK: same look and feel... only better

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Easier, more accurate and more reliable Global Navigation Satellite System (GNSS) positioning is increasingly becoming available to Continuously Operating Reference Station (CORS) users in Australia. Generally at no extra effort or cost to the user, thanks to the growing availability of Network Real Time Kinematic (NRTK).

Until recently, NRTK services were only available in major urban areas but are now rapidly becoming accessible in regional areas. This transition to the next level of GNSS positioning is made possible by many factors, including GNSS modernisation and the rapid densification of nationwide CORS infrastructure. NRTK will flourish even further as the commitment to interoperability and the sharing of CORS infrastructure between private and government sectors continues to gain pace.

Many professionals currently enjoy the high precision and increased productivity offered by single-base RTK systems. For the user in the field,

NRTK has the same 'look and feel' as traditional RTK... only it's better. Users can select an NRTK option instead of a specific CORS or the 'nearest base' in their mount point list. It's that simple.

In this article we quickly review the core difference between conventional, single-base RTK and NRTK. Using CORSnet-NSW, 5 million observations and 1750 station occupations in several test areas across NSW, we then show that NRTK consistently outperforms single-base RTK in both precision and accuracy.

Single-base RTK vs. Network RTK

Conventional, single-base RTK uses GNSS data from a single CORS (or temporary reference station) to determine the differences between expected and actual observations. These differences are constantly changing over time and from location to location.

Single-base RTK corrections are determined by a reference station at a single location. Positioning quality (accuracy,

repeatability, reliability, and initialisation time) therefore deteriorates as the user moves away from the CORS. This is caused mainly by the atmospheric conditions differing more and more between the CORS and user locations. Two-centimetre, single-base RTK solutions are therefore generally limited to a distance of about 20 kilometres. Long-range RTK is possible over up to about 50 kilometres, but positioning quality can vary.

The NRTK solution, on the other hand, is based on several CORS (between three and six) that are closest to the user. NRTK can be generated in a number of different ways (see Position 41, June 2009). In a nutshell, it uses all the surrounding CORS to determine, model and optimise the corrections for each user, instead of selecting only one CORS and ignoring all its neighbours as in single-base RTK (Figure 1). This delivers 'near' constant positioning quality.

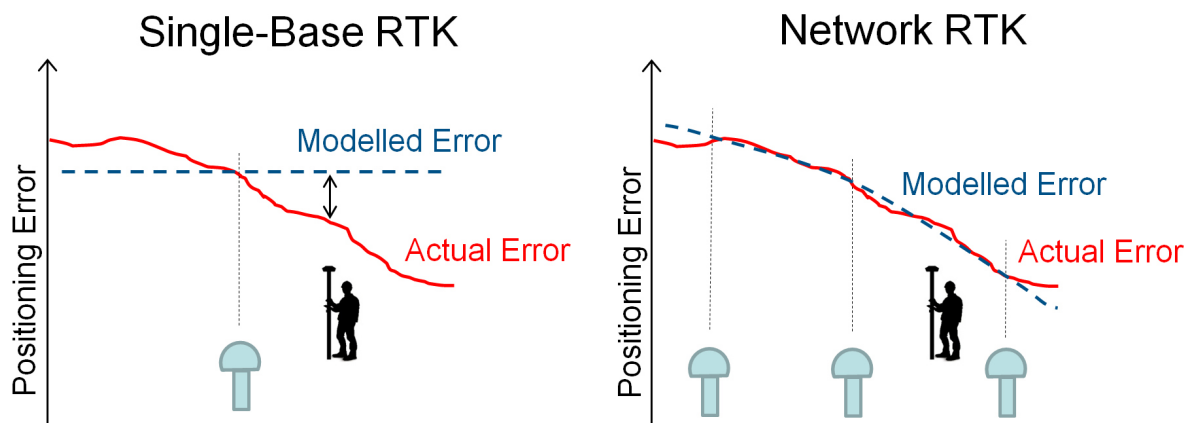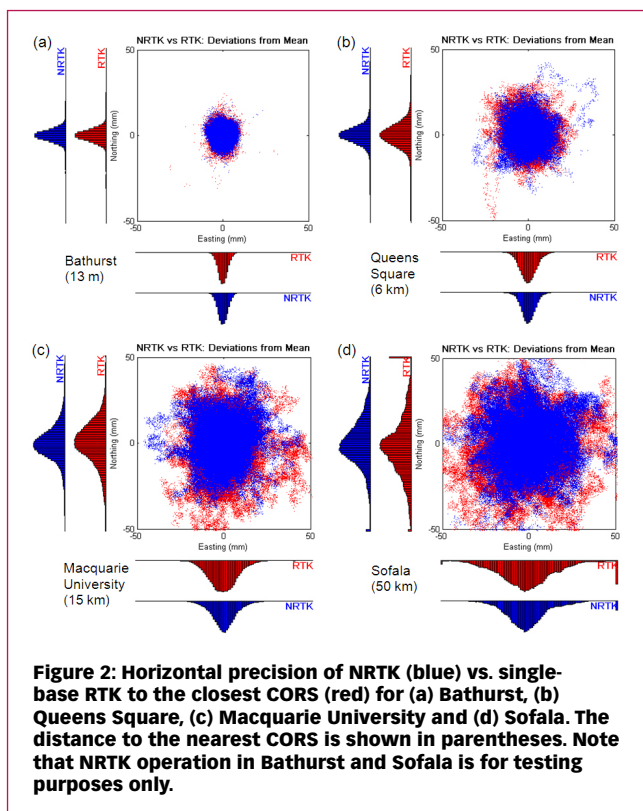NRTK corrections are obtained and used in much the same way as single-base RTK corrections. But NRTK auto-

Figure 1: Modelling of the atmospheric and orbit errors for single-base RTK and NRTK.

Figure 2: Horizontal precision of NRTK (blue) vs. single-base RTK to the closest CORS (red) for (a) Bathurst, (b) Queens Square, (c) Macquarie University and (d) Sofala. The distance to the nearest CORS is shown in parentheses. Note that NRTK operation in Bathurst and Sofala is for testing purposes only.

matically changes the CORS used in its calculations as the user moves around the network. Any CORS outages (maintenance periods or faults) are dealt with automatically and invisibly behind the scenes. The user can therefore concentrate on getting the job done, without the hassle of switching CORS.

NRTK precision

Precision describes the repeatability or spread of the observed positioning results. It is determined by comparing a large number of observations against their mean value and indicates how close repeated observations are to each other.

We investigated the precision of both NRTK and single-base RTK by collecting three consecutive days of real-time GNSS data at four different locations around NSW. The test sites were designed to include NRTK cells (the areas encompassed by the surrounding CORS) of different size, i.e. those in urban and regional areas.

At each test site, up to six GNSS receivers operated simultaneously side-by-side. Either in NRTK mode or in single-base

RTK mode connected to a CORS at distances between 13 metres (simulating users who prefer to set up and use their own base at each job) and 70 kilometres away. Determining the position of each receiver every second resulted in 260,000 positions per instrument at each test site and a dataset of 5 million observations overall.

Figure 2 illustrates the higher precision of NRTK in regards to horizontal position compared to single-base RTK using the closest CORS over increasing distances of 13 metres and 6, 15 and 50 kilometres. The histograms along the coordinate axes indicate the distribution of observed positions around the mean, organised in groups separated by one millimetre.

If any observed positions differed by more than 50 millimetres from the mean, they were put into the most extreme histogram groups. This is visible for the Sofala

test site (Figure 2d), which uses a NRTK cell of larger than recommended size that has not been released to the standard user. The closest CORS is 50 kilometres away. As expected, NRTK precision decreases with growing NRTK cell size, but it still outperforms single-base RTK in all cases.
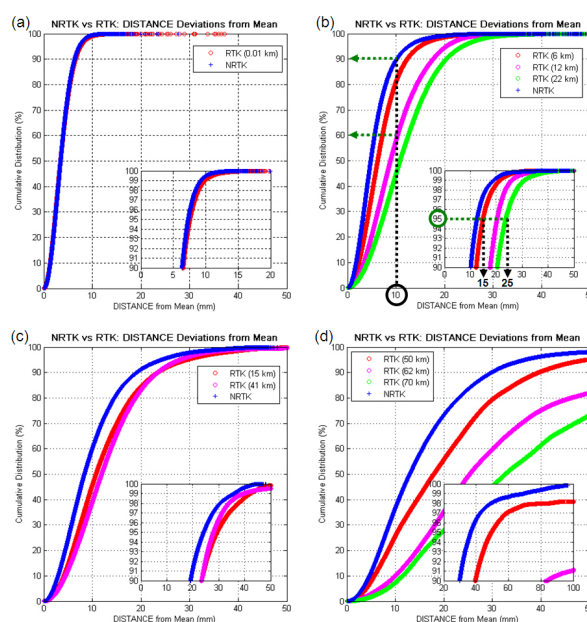
Precision and reliability

It is useful to investigate the relationship between precision and reliability. This enables us to quantify the possible risk of obtaining a position too far from the mean, for a single RTK/NRTK position. We can determine the percentage of positions equal to or better than a specified distance from the mean. Plotting this information illustrates the distribution of the data and the typical probability of achieving a particular quality from a single position (no averaging applied).

Figure 3 visualises the distribution of the horizontal position (distance from mean) for NRTK and single-base RTK over various distances. Figures 3b and 3c, while site specific, are a rough guide to help users get a feel for the precision and reliability achievable with NRTK and single-base RTK using CORS. They can be used as a tool to balance precision and risk as you use NRTK or as you decide at what range you can use single-base RTK. Let us explain how to use these graphs.

Let's take the Queens Square dataset (Figure 3b) as an example. Using NRTK, 90% of the horizontal positions have a precision of 10 millimetres or better. This may or may not be good enough for your job... your decision. When using single-base RTK over 12 kilometres at the same location, only 60% of the positions fall within this precision. Now ask yourself about your alternatives. Can you use RTK connected to a CORS, should you use NRTK, or should you set up your own base closer to the job for the day?

Similarly, if we inspect the insert of Figure 3b, 95% of the horizontal positions using NRTK have a precision of 13 millimetres or better. This translates into a 5% risk of obtaining a position worse than 13 millimetres. For single-base RTK, 95% of the positions have a precision of

Figure 3: Precision vs. reliability of horizontal position for NRTK and single-base RTK over increasing distances for (a) Bathurst, (b) Queens Square, (c) Macquarie University and (d) Sofala. Note that NRTK operation in Bathurst and Sofala is for testing purposes only.

15-25 millimetres for baselines ranging from 6 to 22 kilometres. You decide which technique is best for your job.

NRTK consistently outperformed single-base RTK at all test sites, even when compared to single-base RTK over a very short baseline of 13 metres. While the distribution of positioning quality was very similar, NRTK produced a smaller number and magnitude of outliers (most notably those greater than 20 millimetres, see Figure 3a). This illustrates the benefit of using NRTK even for surveys very close to a single reference station.

As expected, NRTK performance decreases from high-density urban to low-density regional NRTK solutions (Figures 3b-d). This is why NRTK is currently available only in some regions and will not be extended to cover areas like Sofala until additional CORS are available. We also confirm that most of the time you can expect to achieve manufacturer's specifications of 10 mm + 1 ppm for single-base RTK over up to about 50 kilometres under good conditions (Figure 3d).

It is well known that the quality of GNSS-derived heights is generally up to 2-3 times less precise than for horizontal positions. This is caused by the geometry of the GNSS satellite constellation (no satellites are visible below the horizon).
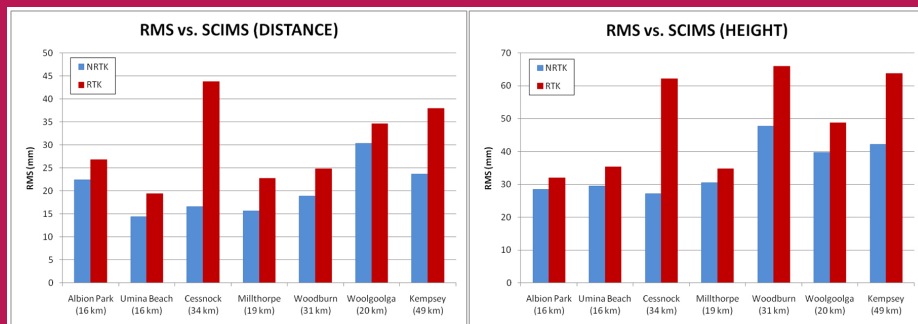
Figure 4: Accuracy of NRTK (blue) and single-base RTK (red) positioning vs. SCIMS for each test area, indicated by the root mean square (RMS). The distance to the nearest CORS is stated in parentheses. Note that NRTK operation in the Woodburn, Woolgoolga and Kempsey test areas is for testing purposes only.

Our investigation into the height component (data not shown) confirms this fact and that it also applies to NRTK. Again, taking the Queens Square dataset as an example, 95% of the NRTK heights have a precision of 23 millimetres or better. This still outperforms single-base RTK over baselines from 6 to 22 kilometres, where 95% of the heights have a precision of 30-60 millimetres.

In summary, NRTK and single-base RTK have the same 'look and feel', but NRTK consistently provides a higher precision and reliability for GNSS positioning using CORS.

NRTK accuracy

Let's now turn our attention to accuracy. Precision is fine, but if you're off the mark, you've got a problem. Accuracy describes how close an observed value is to its 'true' value. It indicates how well a derived position agrees with the known (published) coordinates of a survey control mark.

We determined the accuracy by comparing both NRTK and single-base RTK solutions on established ground control marks to their official Survey Control Information Management System (SCIMS) coordinates. Using seven test areas spread across eastern NSW, we investigated a range of NRTK scenarios and cell sizes routinely encountered in practice. The regional NRTK cells were generally of recommended size (maximum distances of 70-90 kilometres between CORS) but significantly larger than those found in the Sydney metropolitan area.

It is important to note that CORSnet-NSW operates in the GDA94(2010) realisation of the national datum. Therefore, a site transformation is necessary. This is also known as site calibration, localisation, or a 'nudge' in precision agriculture. The site transformation relates surveys using CORSnet-NSW to the local survey control network, which reports coordinates in the GDA94(1997) realisation (see Position 50, Dec 2010).

We performed one site transformation using NRTK, and, separately, another using single-base RTK to the closest CORS as a comparison. Following GNSS best practice, absolute antenna modelling (see Position 51, Feb 2011) was applied to all GNSS rovers involved.

Within each test area, we selected up to 15 high-quality established survey marks (displaying accepted real-world GNSS conditions) as test points. We observed these test points for 1 minute using NRTK, applying the NRTK-derived site transformation. After re-initialisation, this was followed by a 1-minute observation using single-base RTK to the closest CORS, applying the site transformation derived by single-base RTK.

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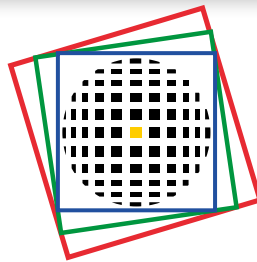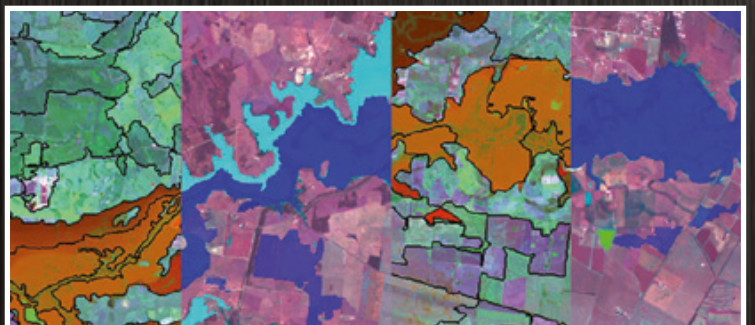
*Conditions apply

After occupying all test points once, we repeated the procedure to obtain 10 rounds of observations on each test point at different times of day over several days. This resulted in 1750 separate occupations across the seven test areas, thanks to the input from all Land and Property Information (LPI) survey offices in NSW.

In all seven test areas, NRTK always produced a smaller spread among re-occupations and a better agreement with the official SCIMS coordinates. The achievable NRTK accuracy is generally about 20 millimetres (or better) in horizontal position and 30 millimetres in height at the 68% confidence level (Figure 4).

NRTK positioning quality diminishes considerably when larger than recommended distances between CORS are used. This is visible in the Woodburn, Woolgoolga and Kempsey test areas. NRTK will only be available to CORSnet-NSW users in these areas once further expansion of the network has taken place to improve the quality of these solutions.

NRTK, again, provides a substantial improvement over single-base RTK, boosting accuracy by generally at least 5 millimetres, in both horizontal position and height. The largest improvement is achieved in Cessnock. Here, NRTK accuracy improves on single-base RTK over 34 kilometres by a factor of about 2.5, in both horizontal position and height.

Conclusion

NRTK has the same 'look and feel' as single-base RTK, and is just as easy to use, but provides better GNSS positioning results. The NRTK correction data provided by CORS networks is optimised based on the user's (changing) location within the network, rather than being reliant on a single reference station. This allows better error modelling, which results in improved positioning quality at the user end.

Our extensive tests have compared the performance of NRTK to single-base RTK using CORSnet-NSW. We have found that NRTK consistently produces superior coordinate results in regards to both precision and accuracy. In addition, NRTK is more reliable, and reduces the risk of outlier observations, even when compared to single-base RTK over a very short baseline.

LPI recommends the use of NRTK within regions of the State where it has been declared operational (see www.corsnet.com.au) and where it satisfies the user's needs. The graphs presented should be used as a guide only, as GNSS performance depends on many factors. Users should always use professional care and diligence when adopting any new technology.

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