Using RTK GNSS to Measure Cadastral Distances

Peter Gibbings and Michael Zahl

Faculty of Health, Engineering and Sciences, University of Southern Queensland

Corresponding Author Email: Peter.Gibbings@usq.edu.au

Abstract

This paper reports findings of an empirical study into the accuracy and precision of 'measuring' (more correctly calculating or deriving) lines on a cadastral survey from RTK GNSS observations at each end of the line. Unlike earlier publications on this topic that relied on zero-baselines for data analysis, this research uses a range of physical baselines selected to represent typical conditions that may be encountered on a cadastral survey. The research also privileges observations at each end of the line that are taken in quick succession rather than the more generalizable notion of observations taken at any particular time. Results indicate that, provided appropriate corrections are applied, RTK GNSS can provide accurate distances and the accuracy is not expected to degenerate substantially as a function of the length of the line being measured (derived). Preliminary analysis indicates that if observations are taken in quick succession, the distance above which distances may adequately be derived by RTK, and below which distances ought to be measured with a conventional total station could be shortened, but a cautious approach to this is recommended with great emphasises on the need to build redundancy and independent checks into surveys. Further focussed research will be undertaken to test this hypothesis and results will be published in the near future.

Keywords: RTK, GNSS, cadastral distances

Introduction and Problem Statement

In late 2012 a guideline was released by the Surveyors Board of Queensland (SBQ) regarding the use of RTK GNSS on Cadastral Surveys. The section in the SBQ guideline on short distances essentially seeks to outline what distances ought to be measured with a conventional total station, and what distances may adequately be measured (actually calculated or derived from two points) by RTK, with due regard to compliance with relevant cadastral surveying Regulations and surveying standards. The associated cautionary note in the Guideline made it clear that no definitive distance was recommended and this decision was essentially left to professional judgement. However, the example using data from SP#1 (Inter-Governmental Committee on Surveying and Mapping (ICSM), 2012 - Note that this version is now superceded) indicated that given those conditions 640 metres may be appropriate, but it was also acknowledged that this may be shortened if improved observation techniques were used.

This was somewhat unsatisfying, and as a result Gibbings and Zahl (2014, in press) set out to discover a more decisive answer to this question. Subsequently, empirical tests were carried out using a series of zero baselines for analysis, from which additional details were published (Gibbings & Zahl, 2014, in press).

Gibbings and Zahl (2014, in press) pointed out that the use of zero baselines is quite common for this type of testing (for recent examples see Odijk, Teunissen, and Huisman (2012), and Janssen and McElroy (2013)), however, to extrapolate this to physical lines, the assumption has to be made that the errors associated with RTK positions would be the same at each end of the measured (derived) line. But we know there may be site-specific errors, such as multipath and interference, that will vary. So the question that arises is whether or not these results can also be expected with physical distances rather than zero baselines. Therefore testing physical distances, as opposed to zero baselines, would represent a useful addition to existing knowledge. An associated question relates to the accuracy of measurements and how well they compare to ‘true’ distances.

Most earlier testing used data collected over long periods of time, often so that satellite geometry has time to change and to allow findings to be considered representative of the general case. A secondary question then is whether taking observations at each end of the line in close succession might have any impact on the precision.

Aim

This paper aims to further elaborate on the distance above which distances may adequately be measured (derived) by RTK, and below which distances ought to be measured with a conventional total station. But, unlike earlier publications that relied on zero-baselines for data analysis, the research reported in this paper uses a range of physical distances selected to represent conditions that may be encountered on a cadastral survey. In this case the standard of comparison is a series of distances measured with a standardised (calibrated) total station. The end points of the physical distances were also derived from two RTK observations taken in close succession to determine if this may have any impact on the precision of the derived distances.

Background

Standards

The accuracy requirement for distances measured on cadastral surveys in Queensland is stated in the Cadastral Survey Requirements (commonly known as Survey Standards) - this document is actually a series of standards and guidelines under the Survey and

Mapping Infrastructure Act 2003. Section 3.4.2 (Measurement Accuracy) states that, 'All surveyed lines (e.g. boundary lines, connections) must have a vector accuracy of 10 millimetres + 50 ppm' (Spatial Policy of Department of Natural Resources and Mines, 2010 - Version 6.0, Reprint 2, p. 13). For the purposes of this paper it is assumed that 'vector' refers to a distance derived from two RTK positions, one at each end of a line. This 'vector accuracy' is used when analysing results in this research paper to determine the desired precision of the measured lines. Note that this 50 ppm is not stated at any confidence level, though pragmatically we assume 95%.

It is also worth mentioning that in the current paper we are making a clear distinction between accuracy and precision. We link accuracy to how close a measured distance is to the true value. In this case we use distance measured by a suitably standardised (calibrated on a current certified EDM range) total station as the standard of comparison. The precision refers to the repeatability of the measurement at a certain confidence level. To allow comparison of results with recent publications, we quote precisions in terms of both 99% and 95% confidence.

Previous Research

Gibbings and Zahl (2014, in press) analysed several thousand zero-baselines calculated from 10 different sites with 60 observations (combination of three second and 30 seconds of data) taken at each site. They found the 95th percentile with 30 second observations to be 23.7mm, and 99th percentile was reported as 28.9mm, with a maximum deviation of 120.8 mm. It was noted that the 95th percentile for the three second data was consistent with the 30 mm at 95% identified by Ong Kim Sun and Gibbings (2005); and the 95th percentile for the 30 second data was similar to the 15 to 24 mm at 95% identified by Janssen and Haasdyk (2011).

On the proviso that sufficient checks and redundant observations are taken to eliminate outliers and other conditions are met, two key interpretations of the analysis by Gibbings and Zahl (2014, in press) were:

- If you take 30 second observations (and check them to eliminate outliers) and you were looking for 99% confidence, then you should not use RTK to derive distances less than 378 metres; and
- If you take 30 second observations (and check them to eliminate outliers) and you were only looking for 95% confidence, then you should not use RTK to derive distances less than 274 metres.

It is noted that these were simply interpretations of the data and not recommendations though. We will refer to these findings during the conclusion and recommendation section of this paper.

Research Method

Test Sites

For this research we used the same ten test sites as Gibbings and Zahl (2014, in press). The sites were generally in a line: the first site was selected as the master with the other nine stations positioned at various distances from the master ranging from two metres to 200 metres. The ten test sites were located in a generally open area bounded by West Street and the main entrance into the University of Southern Queensland (USQ) Toowoomba campus (refer to Figure 1). This area provides over a hectare of open space and, although the area has some scattered trees surrounding it, the ten sites were chosen so they did not have any significant obstructions above the 15° elevation mask. It is acknowledged that the test sites were selected to minimise site specific errors. Some Cadastral surveys may be conducted in less ideal conditions and therefore the final test results need to be interpreted accordingly.

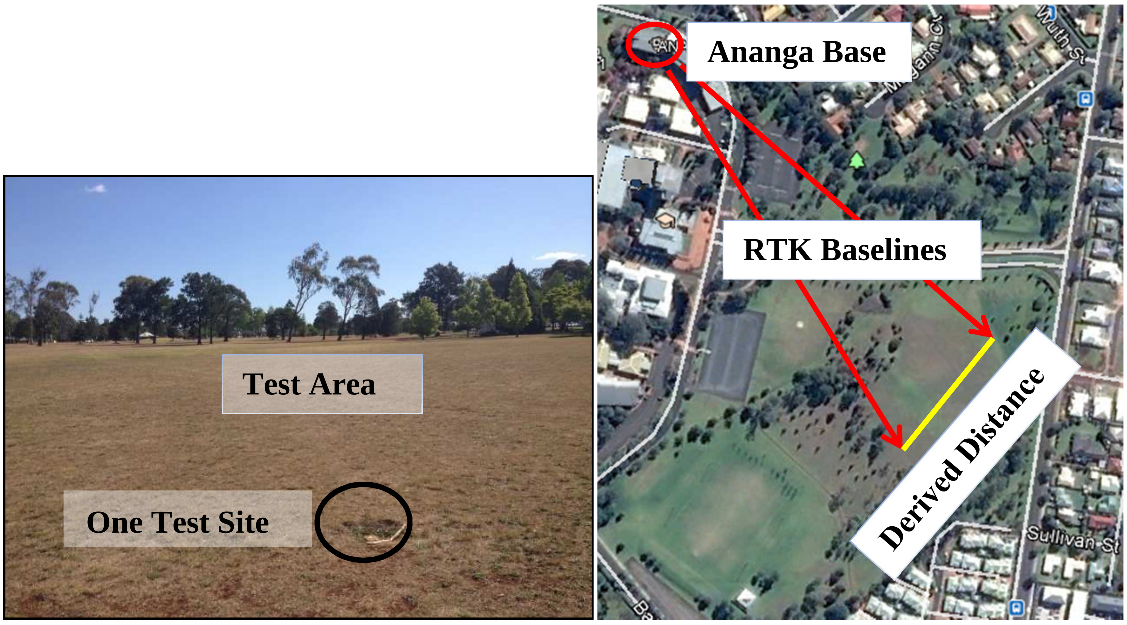

Figure 1 – Test area showing one test site in the foreground (Gibbings & Zahl, 2014, in press)

Each of the 10 test sites were a similar distance (approximately 450 metres) from the USQ base station (refer to Figure 1) and, except for minor individual site irregularities, it is expected that RTK observations at each site would yield comparable precisions.

The USQ continuously operating base station ‘Ananga’ was used to derive the real time corrections for the RTK observations. Corrections were received through the CMR+ format via a radio link. The base station is a stable mark, has a clear sky view (refer to Figure 2) and as far as we are aware is free of multipath, electromagnetic radiation, and other site specific errors. The base receiver is a Trimble Net R5, which is controlled by Trimble GPS Base software version 2.5.

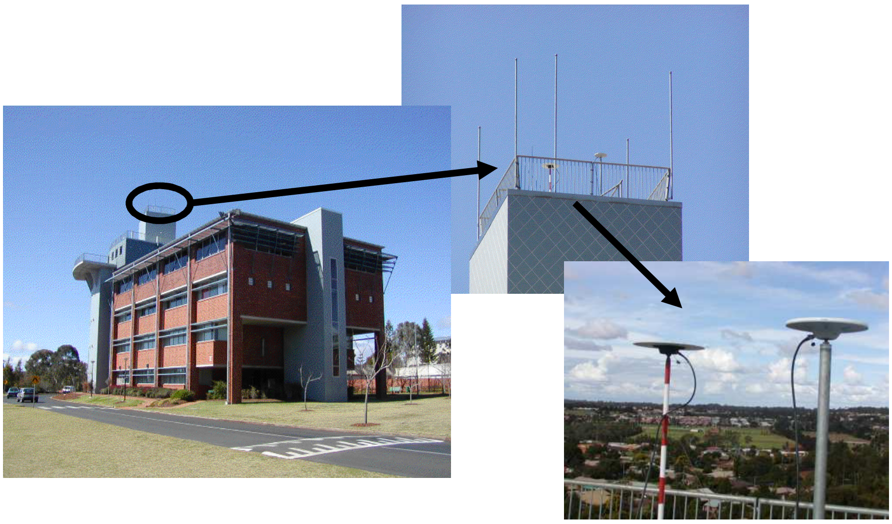

Figure 2 – USQ CORS Base Station ‘Ananga’ (Gibbings & Zahl, 2014, in press)

Data Collection

Each set of observations involved ten RTK GNSS observations (one at each site). Ground distances (actually grid converted to ground) were calculated from the master to each of the other nine stations providing nine distances for comparison. To replicate a real-world cadastral surveying situation as much as possible, each of these ten observations were taken as close together as possible (with respect to time) and the rover was not in general reinitialised before each observation. Though it is recognised that neither of these criteria (observations close together and not reinitialised) would always be the case on a cadastral survey, they are the criteria chosen for the purposes of this testing to be representative of a general cadastral survey. Thirty such sets of observations were taken with observation times of three second duration (without a bi-pod), and a further thirty sets of observations of thirty second duration (with a bi-pod). The sets of observations were taken at different times of the day over different days and each set began with a reinitialisation. One and two minute data were also collected and will be analysed at a later time. Three second data was taken to allow comparisons to earlier research, and because that represents minimum effort to achieve a derived distance. Thirty second data was selected for analysis in this paper to allow comparisons with earlier tests, and as a compromise between what has been recommended by other researchers (normally between one and three minutes) on the one hand, and what may be practiced by field surveyors on the other (based solely on anecdotal evidence). In no way is this designed to infer that we recommend thirty second observation times though, it simply allow us to provide some test results and comparisons that may be more relevant to the realities of work for contemporary practitioners.

Each of the nine distances were also measured with a standardised total station and short distances were further checked with a standardised tape to eliminate possible errors due to these short distances. The total station was standardised by comparison against a certified baseline and appropriate corrections (constant and scale factor) were derived and applied to subsequent measured distances. The distances were each measured thirty times and an average was taken as the standard of comparison for distance accuracy.

Data Analysis

Distances are not physically measured with RTK, rather they are calculated or derived from RTK positions, one at each end of a line. From the RTK coordinates, ground distances were calculated from the master to each of the other nine stations providing nine distances for comparison for each set of observations. There were thirty such sets of observations meaning each of the nine distances was ‘derived’ thirty times. A combined line and elevation scale factor (commonly known as CFS or combined scale factor) was applied to the distances as calculated from the delta coordinates to achieve ground distances. The three second data were processed and analysed for precision separately from the 30 second data at each site. Only the 30 second data was analysed for accuracy since the precision of the three second data was not good enough to warrant further investigation, and it is not recommended to simply take three second observations for this type of work. The results of the three second data do facilitate comparisons to earlier research, and therefore provide some confidence in the reliability of the test system.

This experimental design provided 30 RTK 'derived' distances for each of the nine test distances (ranging from two to 200 metres). Of course it would be possible to form many more distances from any combination of points. For example, instead of choosing the first station as the master, we could have calculated all possible distances between the ten stations. We chose not to do this so we could keep the data as independent as possible and to relate the distances to those directly measured with the total station. We could have also chosen to calculate distance from observations between the thirty sets (for example, the first point from set one, and the second point at the other end of the line from set two). This was discarded because the sets were measured at different times and over different days and, for this testing, we wanted to keep the two RTK observations used to calculate the distance as close as possible together. We will revisit this decision in the discussions later in this paper.

Results and Discussion

Three Second Data

To allow comparisons with earlier research, we selected percentiles derived from spreadsheets rather than theoretical confidence intervals (that means we didn't just apply a scalar to the one sigma to get 95% and 99%). For example, the 95th percentile represents that number below which 95% of our observations fall, which is intuitively quite similar to what you would expect from the 95% confidence interval. Three second data was analysed to calculate a range, 99th percentile, 95th percentile, and one sigma. We added the one sigma to emphasise the folly of using this as a reliable statistic for survey observations (this is one reason that most standards and research use 95% or 99%). Results are summarised in Figure 3.

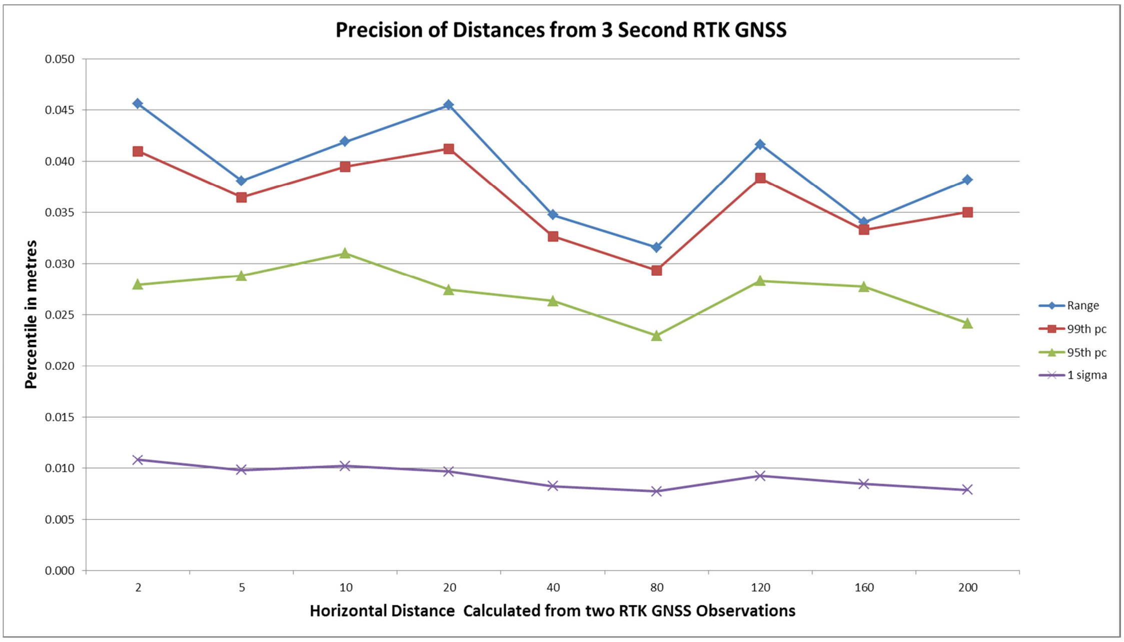

Figure 3 – Distance Precision for 3 second RTK GNSS

Although there are no large outliers as is often reported in much larger data sets, the 99th percentile is around 36 mm and the 95th percentile is around 27 mm. The 95th percentile is similar to the 30 mm at 95% noted by Ong Kim Sun and Gibbings (2005), and the 30.5 mm found by Gibbings and Zahl (2014, in press). This confirms recommendations from many other research publications that three second data observations are not acceptable for this type of survey.

Thirty Second Data

A similar graph is now produced for the thirty second data – refer to Figure 4.

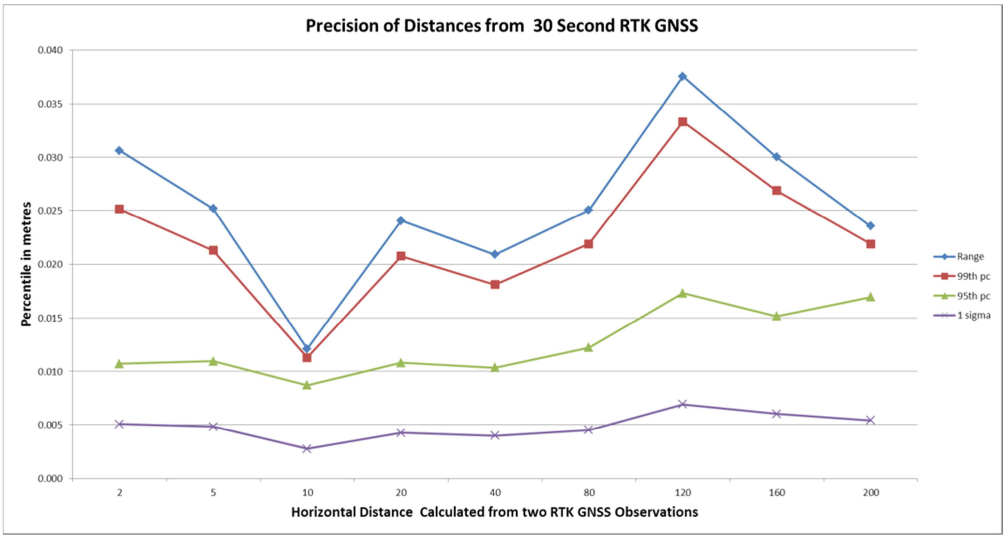

Figure 4 – Distance Precision for 30 second RTK GNSS

Two obvious irregularities can be seen in Figure 4. The statistics for the 10 metre distance seem far superior to the others, and the statistics for the 120 metre distance seem considerably worse. We do not offer any logical explanation for this except for the small sample size and the possibility of some site-specific irregularities.

Again there are no large outliers in this data set. The 99th percentile is around 22 mm and is slightly better than the 28.9 noted by Gibbings and Zahl (2014, in press). The 95th percentile for this data set is around 13 mm and again is better than the 23.7 mm at 95% noted by Gibbings and Zahl (2014, in press) and the 15 to 24 mm at 95% noted by Janssen and Haasdyk (2011) recognising of course the different conditions and observation times.

These results, and particularly the two irregularities, highlight the fact that it is very difficult to arrive at definitive precisions that are completely generalizable, and the results on any particular survey may vary quite a lot due to the many internal and external variables in the measurement system. During any analysis we make some assumptions and the results represent what was discovered at those particular times, with those satellite constellations, at those sites, on those dates, with that equipment and operators. Clearly sometimes you may get better results, and sometimes you can get substantially worse results than expected.

Of prime importance here is the fact that we took care to ensure that the observations at each end of the line were taken as close as possible together (within a few minutes). It is recognised that the experimental design may lead to some bias here, for example, the time difference between the observations for 0m to 2m distance will be less than for 0m to 200m. The closeness of the observations was not originally our main focus and therefore we recognise that our experimental design is not ideal to isolate this aspect. Nevertheless, it is most likely that this has meant that the satellite constellations are consistent between the two observations and no satellite has risen above or dropped below the observation mask during that time. This short time interval would also have the effect of minimising changes in the ionosphere and troposphere between the observations. To demonstrate this, the data was processed with all possible combinations of points as described earlier - the 95th percentile was 24 mm compared to 13 mm at 95% stated earlier using only the points in close succession. Due to the nature of errors associated with RTK GNSS (non-random behaviour over short periods of time), taking observations in close succession may have a positive effect on the apparent precisions. Whether or not these conditions can be consistently simulated on a typical cadastral survey is debatable, however, it does suggest that further research is needed in this regard, particularly with a more robust experimental design to isolate that time-correlation aspect.

We now turn our attention to main focus of the testing, the accuracy of the derived distances. For this analysis we compared the ‘derived’ RTK distances with the average of 30 standardised total station observations as the ‘known’ standard of comparison or ‘truth’. Of course, this ‘truth’ directly relates to the distance that might appear on a cadastral survey plan as a result of conventional total station measurements. For each of the nine lines the mean of the 30 observations is plotted in Figure 5. To provide a quick visual representation of the precision of these, the 95% confidence intervals, have also been depicted at each point by the length of the vertical lines (whiskers). The deltas on the left hand axis are calculated as RTK 'derived' distance minus the total station 'truth'.

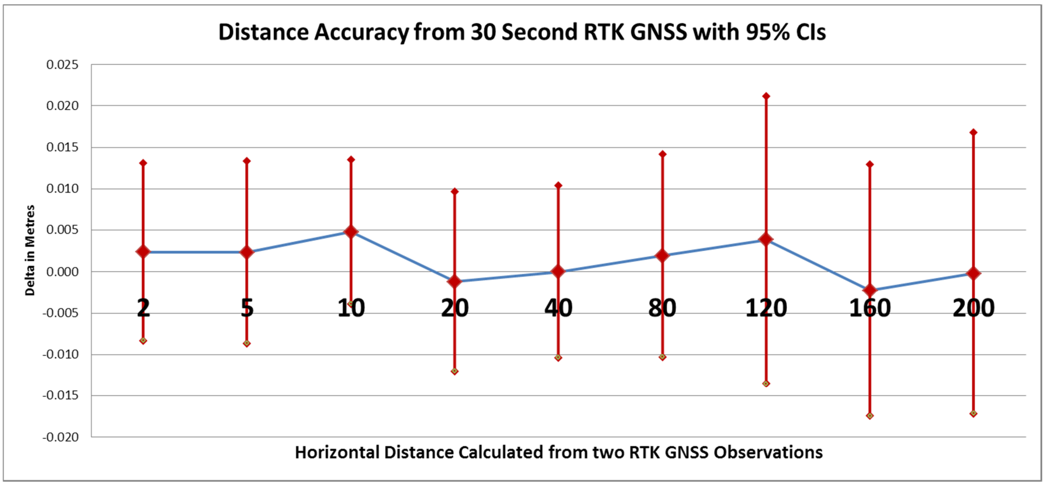

Figure 5 – Distance Accuracy from 30 second RTK GNSS with 95% CIs.

There is only a 1.3 mm positive bias (the RTK distances being longer than the total station distances) and this is well within the measuring precision of the system at 95% confidence. As a cautionary note, it is critical to correctly calculate and apply the combined scale factor to each RTK distance in order to compare them against ground distances measured with the total station.

As expected, the accuracy does not in general degrade significantly as a function of the length of line being measured (though some vary, the 95th percentile at both 2 metres and 160 metres is 13mm). Total station distance precision will vary as a function of the length of the line, for example 3mm ± 3ppm. This is an advantage of RTK GNSS over total stations, and the inference is that over longer lines it may be more accurate and precise to use RTK than to radiate with a total station. This is something that warrants further investigation if/when survey standards are under review.

Conclusion and Recommendations

The aim of this paper was to further elaborate on the short distance aspect – the distance above which distances may adequately be derived by RTK.

The first conclusion is that observations of three seconds should not be used for cadastral surveying work.

The second conclusion is that, provided appropriate corrections are applied, RTK GNSS can provide accurate distances, and this accuracy is not expected to degenerate substantially as a function of the length of the line being measured (derived). This degradation would be a function of other elements such as distance from RTK base station if using a single base though.

One interpretation from earlier research was that if you take 30 second observations (and check them to eliminate outliers) and you were looking for 99% confidence, then you should not use RTK to derive distances less than 378 metres (Gibbings & Zahl, 2014, in press). This was based on achieving the standard of 10 millimetres + 50 ppm. Data presented in this paper from the 120m distance suggests that this could be closer to 470 metres whereas the average of all distances indicates a distance in the order of 245 metres. Therefore, we cannot recommend any change to current thinking based on these results if you are looking for 99% confidence.

A further interpretation from earlier research was that if you take 30 second observations (and check them to eliminate outliers) and you were looking for 95% confidence, then you should not use RTK to derive distances less than 274 metres (Gibbings & Zahl, 2014, in press). Data from the current research suggests that this may be reduced to something like 150 meters if you take the observations at each end of the line in quick succession, which is closer to the 120 metres suggested by some other jurisdictions. However, we need to be careful with this because the results were achieved from a small sample and critically relied on the two RTK observations at each end of the line being taken with as little time difference as possible (and remember this was for 30 second observations and being prepared to accept 95% confidence).

Based on the small amount of data provided here, the authors cannot recommend adopting 150 metres (this is left to professional judgement), even if the RTK observations at each end of the line are taken in quick succession. But we plan to test this rigorously and report findings in the future. We also need to consider what happens if satellites do enter and leave the solution, or if the satellite geometry changes significantly, in the time between measuring the two points. We do not have enough data to estimate, in general, what effect this might have on the precision of the derived distance. Nevertheless, it is something worth investigating in more detail and the authors plan on pursuing this further.

This testing was conducted in very specific conditions and the way equipment and observation techniques behave across conditions, days, systems etc. will inherently change any conclusions. Interested parties are encouraged to conduct their own tests and draw their own conclusions that may be more relevant to their specific measurement systems. It is prudent to use professional judgement in any instance of utilising RTK GNSS: consider whether it is appropriate for the job at hand, the observation methods employed and how the raw observations will be reduced to form 'derived' distances that may be shown as measured on a plan.

One final conclusion to be drawn from this research is that the results reinforce the need to build redundancy and independent checks into surveys, particularly cadastral surveys, and not just rely on single observations (even of 30 seconds or several minutes). This multiple observation of sites is important to allow a surveyor the opportunity to identify any possible outliers, as there is of course a chance that some major anomaly may arise even at the 99th percentile.

As always with research of this nature it is appropriate to finish with some caveats. These tests cannot be considered definitive (although results do agree with previous research). During the analysis we have made some assumptions as explained; the results represent what was discovered at those particular times, at those sites, on those dates, with that equipment and operators, and with observations taken in quick succession. We leave it to the reader to decide if the results are generalizable and for how long the results may remain valid. Further, we have only tested a small number of possible combinations of variables that may be experienced on a cadastral survey. Finally it is worth once again remembering the 'outliers' in observations, whether you use 99% or 95% confidence … don't forget about the other 1-5%!

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