GNSS Solutions:

Real-Time Kinematic with Multiple Reference Stations

"GNSS Solutions" is a regular column featuring questions and answers about technical aspects of GNSS. Readers are invited to send their questions to the columnist, **Dr. Mark Petovello**, Department of Geomatics Engineering, University of Calgary, who will find experts to answer them. His e-mail address can be found with his biography at the conclusion of the column.

What is multiple reference station RTK and what are its advantages and disadvantages?

Multiple reference station RTK (real-time kinematic) is a complex, yet natural extension of single reference station RTK. Single reference station RTK actively and dynamically measures GNSS measurement errors, most notably satellite orbit, troposphere, and ionosphere errors.

These measurement errors are characterized by their spatial correlation. To this end, in single reference station RTK, the errors are assumed to be constant everywhere around the reference station. In reality however, because the errors are not constant, the quality of these error estimates degrade as a function of distance and can reach an unacceptable level for ambiguity resolution after tens of kilometers.

One approach to ensure an acceptable level of measurement error over a wide geographic region is to deploy many reference stations, each operating independently. Once this infrastructure is in place, users select the reference station that will provide them with the greatest reduction of measurement errors and apply the corresponding corrections in the traditional single reference station RTK approach.

Unfortunately, the decision of which reference station to use can be problematic especially when the user is located between reference stations with nearly equally spacing. The estimated measurement errors at each of the reference stations may be different but the user is forced to discretely choose one or the other.

The solution to this problem is multiple reference station RTK. Instead of choosing the solution from one reference station or another, the multiple reference station solution allows users to combine the estimated measurement errors at each of the reference stations and smoothly transition from the errors at one reference station to another.

The multiple reference station solution is not only better because of the ease of use when transitioning between reference stations but also because the smooth combined solution is more likely to represent the user-observed measurement errors. This provides an even further reduction of user measurement errors, relative to the single reference station case.

An example of multiple reference station processing is illustrated in **Figure 1**. The red line represents the changing errors as a function of receiver location. There are two reference stations in this example. A blue reference station is located at –2 and a green reference station is located at +2, while the user in this example is located at 0 in the middle of the network.

If a user were to use only the measurement errors recorded at the green reference station, then the residual error experienced by the user is represented by the vertical green line. Alternatively, if the user were to incorporate only the measurement errors of the blue reference station, then the error experienced by the user is represented by the blue line. When both reference stations are used, then a combined interpolated solution results, as indicated by the black sloping line, and the corresponding residual error is shown as the vertical black segment inside the black arrows.

Although there may be times when a single reference station's solution is better than the network solution, the network solution is generally more likely to accurately represent the errors over the region because of the additional information gained from combining the data from all reference stations.

Figures 2 and 3 show comparisons of the residual dispersive and non-dispersive errors experienced by a user for both the single reference station and network reference station methods employing real data. In all cases, being close to a reference station provides the best solution.

The advantage of the multiple reference station model is seen in the region between reference stations outside of the areas in which typical single reference station RTK processing would be acceptable (i.e., less than 15 kilometers to the nearest reference station).

In practice, combining the data from multiple reference stations to provide an integrated solution is more complex than the image shown in Figure 1. The following steps must be taken to create the network error model and apply it effectively in the user receiver:

1. Accurately measure the relative measurement errors between the reference stations. The most accurate GNSS measurements are phase measurements; however, to use these measurements the carrier phase ambiguities must be precisely estimated and fixed to their correct integer values. To use the integer ambiguities, one must employ the double-differenced form of the measurements. The double-differenced measurement estimates must then be undifferenced for the later steps. This adds significant complexity to the multiple reference station processing.

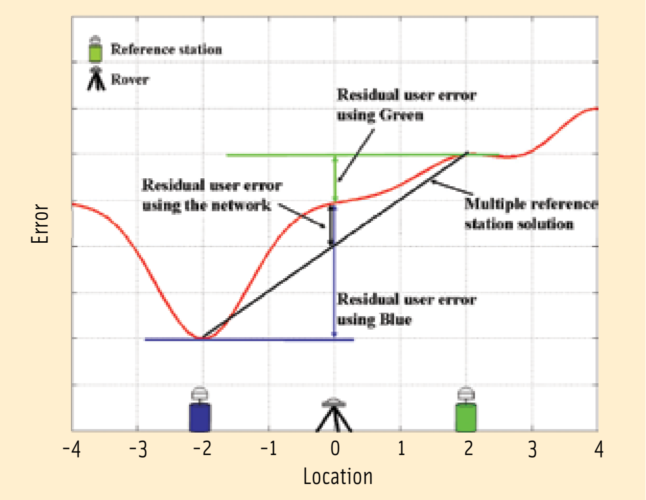

FIGURE 1 Example of the measurement error of one satellite across a region (red line). This error is measured at two locations indicated by the green and blue reference stations.

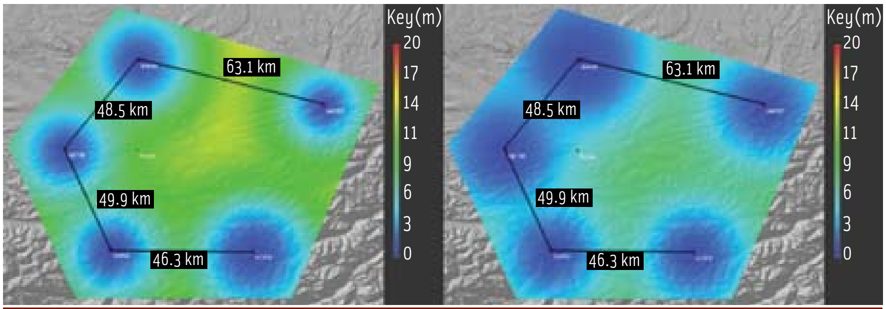

FIGURE 2 The estimated residual dispersive (ionosphere) error for a single reference station user (left) and a network reference station user (right)

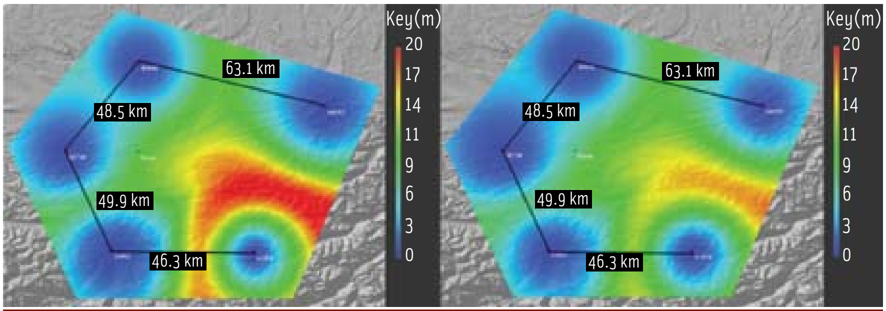

FIGURE 3 The estimated residual non-dispersive (troposphere/geometry) error for a single reference station user (left) and a network reference station user (right).

2. Interpolate the relative measurement errors between the stations to the location of the user.
3. Convert this information into a receiver-acceptable format. Four acceptable options currently are used for transmitting network corrections:
   a. Master-auxiliary corrections. These corrections contain the absolute errors for one master reference station and the relative errors for all other auxiliary reference stations. For this format, interpolation from step 2 is performed by the user.
   b. FKP (Flächen Korrektur Parameter), which are area correction parameters. These corrections contain the absolute errors for one master station and the parameters of a regional plane model. In this case

interpolation from step 2 is performed by the user.

c. Single reference station corrections. These are the absolute corrections for one station combined with the relative predicted errors between that master station and the user. This format option allows for users whose receivers are older and do not support the recently developed network correction formats.

The performance improvement depends on many factors, including the variability of the measurement errors in the region and the ability to successfully resolve network ambiguities.

d. Virtual reference station (VRS)*. VRS corrections are the single reference station corrections (described earlier) that have been mathematically translated to a virtual geographic location that is closer to the user's location. This location change moves the reference station to a distance that is more representative for the new level of measurement error after applying the network error model.

4. Use the received corrections to calculate the position of the network user.

The main advantage of multiple reference station RTK stems from the improved user performance. However, the improvement in performance can also be analyzed in an opposite manner, namely, as a way to increase the spacing between reference stations while still achieving the same level of performance. The performance improvement depends on many factors, including the variability of the measurement errors in the region and the ability to successfully resolve network ambiguities.

Multiple reference station RTK is more robust against station outages because a network solution can still be calculated even if individual reference station data is missing. However, due to the current trend of sparse network station spacing, the absence of any individual reference station would likely cause pockets within the network with less than desirable performance. Even under these conditions, the network solution is still more likely to provide a solution better than that from a single reference station.

This improvement comes at a cost of increased complexity and infrastructure. The data from all of the network reference stations must be collected in a central location for processing and then redistributed to network users. The cost of maintaining a processing center and data communication links for each reference station may be significant, depending on the number of reference stations and the country and region in which the network is located.

** The term "VRS" is widely used to describe real-time correction networks. The term "VRS" and the technology originated with and are trademarked by Trimble.*

Manufacturer

The figures in this article were produced using Leica GNSS QC Software, **Leica Geosystems AG**, Heerbrugg, Switzerland. IG

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