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Multiple Reference Station Approach: Overview and Current Research

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Biography

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Introduction

The availability of high precision reliable three-dimensional positioning tools has opened the door for many applications. GPS is being used by many industries to provide positioning and location-based services, many of which require a high level of precision. These applications include 3-D marine navigation in constricted waterways, aircraft positioning and guidance, land navigation, and water vapour estimation to name a few. Inland marine transportation, for example, is limited by the height positioning accuracy. If the accuracy is increased, then more cargo can be carried while ensuring clearance under the keel. GPS technological advances will assist these industries to be more competitive and cost effective, as well as well as creating innovative location-based services.

The accuracy of the system dictates the range of its use; in other words, the more accurately users can determine their positions, the more applications that will utilize that accuracy level. The highest accuracy positions are obtained only after the estimation of the carrier phase ambiguities. The ability to resolve these biases is limited primarily by the correlated errors due to the troposphere, the ionosphere, and satellite orbits. The use of differential techniques, whereby a station with known coordinates is used as a reference station, has proven successful in the removal or reduction of these errors. The largest drawback of this approach, however, is the relatively short distance that must be maintained between the two receivers.

In an attempt to overcome these shortcomings, methods based on the use of networks of GPS reference stations are being developed to further reduce the effect of correlated errors and thus improve positioning accuracy. These networks of reference station can be used to measure the correlated errors for a region and predict their effects (through advanced interpolation methods) spatially and temporally within the network. This process (Network RTK) can reduce the effects of the correlated errors much more than the single reference station approach allowing for reference stations to be spaced much further apart to cover a larger service area than the traditional approach and still maintain the same level of performance.

Network RTK is comprised of three main processes: network correction computation, correction interpolation, and correction transmission. The network correction computation uses the network reference stations to precisely estimate the differential correlated errors for the region. This is usually accomplished using carrier phase observations with fixed ambiguities between the network stations. Thus ambiguity fixing between these stations is a major part of this process. The second process interpolates these network corrections to determine the effects of the correlated errors at the user's position. The third is the generation of virtual reference station (VRS) measurements to relay the corrections to the rover receiver for use with standard RTK software.

Measured Network ErrorS

The first step of Network RTK is to measure the errors at the reference stations. In most cases, the errors are measured as the difference between the carrier phase observations (with fixed ambiguities) and the range, which is calculated using the known reference station coordinates. These errors can be measured in terms of the raw L1 and L2 carrier phase observations or a linear combination of the L1 and L2 observations. Linear combinations are used to isolate the various error sources to take advantage of their unique characteristics.

Interpolation of the Measured Network ErrorS

The interpolation of the correlated errors to the location of the user receiver assumes a stochastic and physical relationship between the errors. For example, all interpolation methods result in the closest reference stations having the most influence over the predicted value because a close reference station is more likely to experience the same error conditions as the rover receiver than one which is further away.

Raquet [1998] proposed a method of interpolating the observed errors between the reference stations to a user's position anywhere in the network. In this method an exterior process determines the carrier-phase integer ambiguities between the reference stations. These ambiguities are then used to estimate the differential errors between the reference stations. The measured errors are interpolated to a user in the network using a linear least-squares prediction method. Covariance functions that represent the stochastic behavior of the errors must be determined at the outset. This method has been implemented in a functional real-time system and provides good improvement in post-mission and real-time [Cannon et al 2001a, 2001b; Fortes et al 2000a, 2000b, 2001; Alves et al 2001; Raquet et al 1998; Raquet 1998; Zhang1999a,Zhang & Lachapelle 2001].

Wanninger [1999], Vollath et al [2000a] and Wübbena et al [2001a] discuss a slightly different interpolation scheme where only the surrounding three stations are used to predict the corrections at the user. In this simpler model, a plane is fit to the error estimates at the three surrounding stations. This plane represents the two-dimensional differential errors within the three-station triangle. This method has also proven to provide good positioning results under a quiet ionosphere and with a relatively high reference station density [Wanninger 1999; Wübbena et al 2001a, 2001b; Vollath et al 2000a, 2000b, 2001, 2002].

Virtual Reference Station Calculation

Once the corrections for the rover are determined, they still need to be transmitted to the user receiver in a suitable format. The traditional single baseline approach has a large impact on this process because most off-the-shelf receivers do not yet have a method of accepting network corrections. To compensate, many network RTK systems create virtual reference stations. A virtual reference station is a collection of corrected data from one reference receiver (in the network) that has been corrected for a local area within the network. This data is usually geometrically translated to be close to the region for which it is corrected. The rover receiver can then accept the virtual reference station data as a single reference station. This process is described in Fotopoulos [2000].

In general, the virtual reference station approach creates a "reference station" for use with standard off-the-shelf receivers that do not have the capability of accepting network corrections. There are many downfalls to this approach: The rover receiver will interpret the virtual reference station as a single reference station, which may cause the rover to use a processing scheme that is not optimal [Townsend et al 2000]. In most cases, the rover receiver will optimize the processing scheme based on the distance between its position and that of the reference station. In the case of a virtual reference station the position of the reference station is arbitrary because it is based on a network of stations. A solution would be to have the service provider ensure that the VRS is an appropriate distance away from the user to optimize the processing scheme but this is not always possible with multiple users. This requires the service provider to know the approximate position of the user. In this case, the rover would be required to send its position, via NMEA messages, to the processing control center to insure that the interpolation is calculated for the correct position and to position the VRS appropriately. The complex two-way communications network required is another drawback [Euler et al 2001]. A final downfall of this method is that it does not comply with the RTCM standard because the standard does not allow for the reference station data to be corrected for atmospheric or orbit errors [Townsend et al 2000].

Future of Multiple Reference Station Approaches

Current recommendations for the future of the virtual reference station approach deals mainly with standardization of network RTK messages. Once standard RTCM network corrections are selected then network corrections can be feed directly into the rover receiver without the need for a virtual reference station. Townsend [2000] proposes a grid based correction scheme where the corrections for various points on an irregular grid are passed to the rover receiver. The rover receiver can then use any interpolation scheme to calculate and apply the corrections. The grid points could contain only reference stations or reference stations and predicted errors, which were determine through interpolation.

Euler et al. [2001] proposes a similar scheme where the corrections for a master reference station and the coordinates for a master reference station are given along with correction and coordinate differences relative to the master station. In this scheme the rover receiver has the option of interpolating the corrections for its location or simply reconstructing the observations for a single reference station. This gives receiver manufacturers the liberty to implement any interpolation scheme they feel is best.

Although multiple reference station RTK methods have proven to be effective in test networks, operational deployment remains complex and high ionospheric activity levels have limited their advantages during the past few years during which the methods have been tested. Serious reliability issues remain. However the introduction of a 2nd and 3rd authorized civilian frequency, as well as the combined use of GPS and Galileo is expected to have a dramatic impact on the effectiveness and large scale deployment of these methods in the decade ahead.

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