Real time GPS Networks (RTN) and their Implications with Geographic Information Systems (GIS)

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SUMMARY

The installation of real time positioning networks (RTN) is rapidly growing throughout the world. These networks are eliminating the need for traditional control networks and changing the way survey data is collected. With the radio or cell phone link from the rover to the network, and the networks connection to the internet, precise positions can be logged consecutively both locally on the rover and to a GIS server in real time. Logging precise positions remotely in a GIS has vast implications on survey, construction, project management, archival and backup. This paper will discuss the technology used and implications on the surveying and GIS industries.

1. WHY REAL-TIME NETWORKS?

In surveying, GIS and mapping the goal of using GPS is to obtain the position of a point in some geodetic datum. The standard method of precise differential positioning requires a reference receiver at a station of known position, while the rover receiver's position is determined relative to the reference receiver. The so-called differential GPS or DGPS method relies on this principle and uses the GPS pseudorange observable. For high precision applications, carrier phase observables are required but increase the complexity of the solution mainly because ambiguity resolution algorithms must be used to determine the full range between satellite and receiver. The main objective of differential GPS, using pseudorange or carrier phase observables, is to eliminate or reduce error sources in the measurements. The last decade has delivered the high precision previously reserved for static GPS into the realm of real-time kinematic positioning (RTK). Data from the reference receiver is transmitted to the rover via some form of communication link and together with field observed data, the rover computes its position instantaneously. There are various options available for transmitting the data such as: cellular telephone, dedicated ground radio transmitters, communications satellites and the internet.

The main limitation of single-baseline RTK is its relatively short range of use from the base station because of distance-dependent ionospheric, tropospheric and orbit errors. Various GPS Augmentation Systems (WADGPS, WAAS, LAAS), use a network of reference stations spread over a wide geographic area and model the inherent GPS measurement errors so that position accuracy is nearly independent of baseline length. But because these are pseudorange systems, their accuracy remains at the meter level.

A natural extension to these pseudorange augmentation systems, real-time networks (RTN) or Network RTK have grown significantly in recent years. These systems deploy a network of reference stations and using both carrier phase and pseudorange observables, model the distance-dependent errors and transmit corrections for them to the rover, enabling it to compute precise single- or multiple-baseline solutions. RTN provides cm-accuracy in real-time at baseline lengths of up to 300 km making it a very economical survey technique.

Some DGPS systems, such as JPL's Global GPS Network (GGN) have shown that an Internet-based Global Differential GPS (IGDG) implementation, relying on near real-time IGS ephemeredes, can provide real-time positional accuracy of 0.l m horizontal and 0.2 m vertical to any stationary or mobile receiver anywhere, anytime [Kechine et al, 2003a,b]. Available over the open-internet, this level of precision is promising not only for precise navigation of vehicles but also certain GIS data collection, surveying and mapping applications.

The communication system connectivity required by these systems for collecting positions in real-time in the field can be used to simulateously log collected positions (in real-time, or near real-time) in the GIS that will eventually store and manage this data. The implications of the postitioning system (RTN) directly connected to the data management system (GIS) delivers efficiencies to existing tasks while adding new possible applications.

2. REAL-TIME NETWORKS: HOW THEY WORK

Real-time kinematic (RTK) positioning has been in production use by surveyors for over 20-years. RTK involves a reference receiver transmitting its received raw data or observation corrections to a rover receiver. Since RTK data-processing takes place at the rover, it has to resolve the integer ambiguities of the differenced carrier phase measurements in order to estimate its position. Rapid and reliable integer ambiguity resolution, however, suffers or even fails as the baseline length increases because of distance-dependent atmospheric and orbit errors. This effectively limits the conventional RTK range to about 10 – 20 km. However, distance-dependent errors can be accurately modeled by analyzing the measurements of an array of GNSS reference stations surrounding the rover site. In this way, the effective range of RTK positioning may be greatly extended, 50 – 100 km being typical [Wanninger, 2006].

In essence a type of GNSS augmentation system, RTN makes maximum use of the measurement stream from a network of reference stations to deliver cm-level accuracy positions in real-time for any number of remote rover users. Technological advancements in three key areas have made RTN viable: GPS signal-processing, digital communications and the ubiquitous Internet. An RTN comprises a regional network of GNSS continuously operating reference stations, some kind of central processing facility and communications media to transfer data from the network to the user. Presently, RTN networks provide users with either free data or fee for service use.

Traditionally, RTK is applied over short baselines involving one reference station and one roving receiver, using double-differencing of GNSS observables and employing some ambiguity fixing technique [Leick, 2004]. As mentioned, conventional RTK range is limited because atmospheric and orbit errors grow with baseline length. Herein lies the primary motivation for using a network of base stations: to model and correct for distance-dependent errors that reduce the accuracy of conventional RTK.

Two requirements lie at the heart of RTN. First, the positions of the reference stations must be precisely known, at the centimeter level at least. Long observation times at the reference stations and post-processing of their data easily provides this level of position accuracy. The second requirement is that the single- or double-difference integer ambiguities must be known for baselines between reference stations. With these, RTN models the errors, calculates correction information and transmits them to rovers which in turn use the data to derive their position [Leick, 2004].

2.1 Data processing

Data-processing for RTN comprises three fundamental steps: (1) computation of network corrections, (2) correction interpolation and (3) transmission of corrections to the rover [Chen et al, 2003]. In the first step, integer ambiguities are fixed for the reference station network. Only data with fixed ambiguities are used in modeling the distance-dependent errors. This critical step, while challenging because of the long baselines involved, is aided considerably since the precise coordinates of the reference stations are already known, atmospheric conditions are tracked continuously, multipath is minimized by analysis of past network data and predicted precise ephemeredes are available to reduce orbit errors. The challenging part stems from the fact that these ambiguities must be estimated in real-time whenever cycle-slips or long data gaps occur or new satellites come into view [Hu et al, 2002].

Step two involves modeling the distance-dependent errors and deriving the network corrections. These are generated from the residuals in carrier phase measurements on a satellite-by-satellite, epoch-by-epoch basis. The network corrections or correction model coefficients are transmitted to the rover for use in estimating its position.

In the third step, the RTN computes an optimum set of observations for a selected ”master” reference station, usually the one closest to the rover, from the reference station data and the previously derived network corrections. Alternatively, the master station observations can be virtually shifted to the rover site. This latter situation results in so-called Virtual Reference Station (VRS) observations which are used by the rover to process the short baseline to the VRS. Data outages at one or more reference receivers can degrade the network corrections or render them invalid. In some cases, the raw data from the master station alleviates this problem because the rover can generate a conventional RTK single-baseline solution, if the baseline length is not too long.

2.2 Geodetic issues

While GPS positions are defined with respect to the WGS84 reference frame, positions obtained from an RTN are in terms of the datum used for the reference station positions. If RTN derived positions are to be used in the context of GIS data referenced to a different datum, the positions must be transformed to the reference frame of the GIS. If this transformation is not done position differences up to many meters can be expected between the RTN and GIS data.

Regional real-time networks typically assume that the reference stations are stationary. This assumption does not hold in areas of active crustal deformation. RTN’s straddling plate boundaries may experience coordinate drifts of up to 50 mm/year (e.g. California, Japan and New Zealand). RTN users need to know the geodetic and geophysical characteristics of the RTN they are relying upon for their positioning.

GPS orbits are realized in the ITRF2000 global reference frame based on data from global tracking stations and with respect to an arbitrarily chosen time epoch. Thus, the GPS datum is global and time-variable, so that all RTN reference stations have changing coordinates with respect to the ITRF. In contrast, many national geodetic datums are static or semi-static and may differ significantly from the ITRF. Reference network operators may or may not track and maintain these datum differences and account for them in the published coordinates of the network stations. If not, this task falls to the users and it is imperative for users to know what flavor of data they are receiving when using RTN's and when integrating RTN derived data into their survey projects or GIS. A properly configured GIS can manage this and help eliminate associated data handling errors.

2.3 Accuracy

Accuracy improvements of RTN over conventional RTK depend on a number of factors, including: reference network configuration and extent, atmospheric activity and data processing techniques. Network characteristics such as the number of stations and their inter-station distances directly affects performance and accuracy of the RTN corrections and hence of rover positions. If the network extent is too large, difficulties arise in resolving integer ambiguities over long baselines and may result in unreliable network corrections.

Under normal atmospheric activity, the RTN approach may not bring much accuracy improvement over conventional RTK, the main advantages being unrestricted use of the network resource and extended range. Under active atmospheric conditions, the RTN approach not only extends the range but also brings significant improvements in positional accuracy over conventional RTK as well as reduced initialization time (Time-to-Fix). However, under extreme ionospheric conditions the rover may fail to initialize even using the enhanced capabilities of RTN. In most cases RTN initialization failure is due to the network's inability to correctly model the ionospheric errors [Chen et al, 2003]. Various methods are currently under study for monitoring the integrity of RTN with respect to the dispersive and non-dispersive network errors [e.g. Chen et al, 2003]. If this information is also transmitted to the rover, it can better assess the correction reliability and relate that to positional accuracy. This not only affects productivity in the field but also empowers the field personnel to decide those in-situ applications that current network conditions can support.

While competing manufacturers may claim to model errors more efficiently or more correctly (see for example Landau et al, 2003; Euler et al, 2001; Leica, 2005), all RTN methodologies essentially provide rover users with extended RTK range at conventional RTK accuracies or better. Published RTN accuracies range from 1-5 cm horizontal and 2-5 cm vertical based upon dual-frequency GNSS observations at maximum distance of about 50 km (e.g. Dixon, 2006; Grejner et al, 2005; Bock et al, 2003; Gao and Liu, 2002; Bock et al, 2000; Kechine et al, 2003a; Bray and Greenway, 2004).

As the baseline gets longer, the main limitation on RTK positioning accuracy is the spatial decorrelation of the ionospheric error. For dual-frequency receivers, this limitation is overcome by differencing observables between frequencies, a technique unavailable to single-frequency rover receivers. Recent improvements in ionospheric modeling using reference network receivers show that 0.1 m accuracy in horizontal and 0.2 m in vertical coordinates for single-frequency (L1) rovers is attainable over baselines between 100 – 300 km in middle geomagnetic latitudes (30 – 60 degrees) [Mohino et al, 2007].

GIS now supports double-precision databases and is capable of storing and managing precise survey data sets derived from real-time GPS networks.

3. REAL-TIME NETWORK IMPLEMENTATIONS

We can distinguish at least four unique implementations of RTN: Virtual Reference Station (VRS), broadcast-RTK (FKP), Master-Auxiliary Concept (MAC) and Epoch-by-Epoch™ Precise Instantaneous Network (PIN) positioning. Each of these RTN implementations, while fundamentally different in approach, provide cm-level accuracy positions in real-time using a network of permanent GNSS reference stations. The rover user obtains the relevant position information over one of a number of wireless communication media options.

The detail of these networks is beyond the scope of this paper, but are important to understand when implementing a RTN.

4. DATA FORMAT AND COMMUNICATION

When broadcasting network corrections and reference station observations data transmission bandwidth becomes an issue. Maximizing the data that can be transferred over limited bandwidth requires careful consideration of a suitable data format. A format should be size efficient yet flexible enough to accommodate various implementations of correction generation methods [Talbot et al, 2002]. These communication protocols can be utilized to communicate collected position and attribute data to the GIS.

4.1 Format protocols

Almost universally, the format for GNSS data transfer between different user equipment is the manufacturer independent RTCM SC-104 format, a standardized format as proposed by the Radio Technical Commission for Maritime Services, Special Committee 104. All manufacturers have the opportunity to participate in the format definition. RTCM SC-104 has defined at least 64 message types with formats nearly identical to that of the GPS navigation message [Hofmann-Wellenhoff et al, 1997]. Those message types used in the RTN context are Type 1, 2, 3, 9 18, 19, 20, 21 and 59.

The NMEA 0183 (NMEA for short) protocol is a means by which marine instruments and also most GPS receivers can communicate with each other. It has been defined and controlled by the US based National Marine Electronics Association. The NMEA 0183 standard uses a simple ASCII, serial communications protocol that defines how data is transmitted in a "sentence" from one "talker" to one or more "listeners". Most GPS software that provides real time position information can understand data in NMEA format. These data include the complete PVT (position, velocity, time) solution computed by the GPS receiver, the so called GGA (Global Positioning System Fix Data) sentence. Typically, NMEA GGA messages carry position information back and forth between rover and server, while RTCM 104 carries GNSS data and network corrections.

At present, except for PIN data, most RTN information reaches the rover units after proprietary algorithms generate either network corrections/coefficients or VRS data. But the RTCM 104 standard furnishes no format for network corrections. RTCM 104 reserves a message Type 59 within the standard for proprietary information, but the content is not specified in the standard. This Type 59 message carries the manufacturer derived network correction information.

For the most part, the various manufacturer specific network correction algorithms produce observations that should work with any user equipment, but these proprietary methods only achieve optimum performance when both rover and network hardware and software are from the same manufacturer. Without clearly defined data dissemination standards, multi-vendor operations are compromised or fail altogether because of rover firmware inability to deal with prevailing broadcast data streams. With the forthcoming RTCM SC-104 Version 3.1, to be released shortly, an interoperable definition for network RTK data protocols will become available for the first time. Using the new standard, network operators can serve up reliable, interoperable data streams without concern for the brand of reference network or rover equipment. The new data protocols are based on the Master-Auxiliary Concept (MAC) [Euler, 2005].

4.2 Data communications

Presently, the challenge for efficient RTN positioning lies in adapting wireless communication technologies for obtaining real-time information. The challenge includes defining compact data formats for compressing the data to be transmitted. Many factors affect the selection of a communication media including, ~~among others~~ technical aspects, economical aspects and administrative aspects. Technically, data format and content, network coverage area, bandwidth, data transfer protocol, reliability and error correction are all factors to consider. Moreover, the amount of data for transmission depends heavily on the data format used and the number of visible satellites. Cost of data transmission varies greatly with the method used. Radio transmission incurs a one-time cost to purchase the transmitters and antennas, but governmental regulations may severely restrict its use and reliability, not to mention its inherent range limitations. Other methods such as mobile telephone also have varying charges depending on, for example, data volume.

4.2.1 Radio-based communications

Conventional RTK uses an in-situ radio for communication between the base and rover. Radio communication poses several disadvantages in RTK applications. Firstly, UHF/VHF and higher frequencies are limited to line of sight range. Radio range may also suffer from attenuation due to atmospheric conditions, antenna response and RF interference from other users in the frequency band. Often these bands are crowded and external interference can deteriorate communication quality and cause data loss. This is especially true in urban environments where the airwaves are dense with a variety of RF transmissions. Finally, in most jurisdictions RTK radios must be licensed prior to use [Gao et al, 2002]. Radio communication is also regulated by federal and international bodies and available signal bandwidth continues to diminish because of the myriad demands for usable slots, many of these also shared by a large portion of the regional population.

4.2.2 Wireless communications

In modern societies, wireless communication relies on a dense network of transmission towers configured to maintain a constant signal power and avoid frequency collision by assigning different frequencies to neighboring towers [Gao et al, 2002]. Since network RTK is typically offered as a service covering a limited region, it makes sense to tap into existing communication services available in the same region for the transmission of RTN information. Mobile telephone networks based on the GSM and GPRS have been the most common for RTN data communications. More recent developments such as EDGE, CDMA2000 and UMTS will see more usage in future [Wegener and Wanninger, 2006].

In remote areas where terrestrial cellular service is unavailable, satellite communication provided by e.g. Iridium or Globalstar may be an alternative. These services, although expensive, allow subscribers to send and receive voice messages and data regardless of location. Other modes of data delivery include: FM sub-carrier broadcast using the Data Radio Channel (DARC) protocol, terrestrial television broadcasting with the data stream being modulated onto the audio sub-carrier and terrestrial digital audio broadcasting (DAB).

4.2.3 Internet communications

Internet data communication offers many advantages over other radio-based methods such as low-cost, accessibility, availability, flexibility and expandability. Ostensibly, the disadvantages of radio-based RTN are alleviated with Internet based RTN. The Internet is a global network and therefore does not suffer from range limitations. Ubiquitous as it has become, the Internet is accessible from almost any location in wired or wireless mode. Data transmission over the Internet is more reliable than over the radio waves because of much less interference, and more possibilities are available for data authentication. Internet access continues to advance daily. Technologies in common use for accessing the internet are LAN, wireless LAN (WLAN or Wi-Fi), wireless modem (CDMA), GSM, GPRS, EDGE, UMTS and various communications satellites such as Iridium or Globalstar. However, data outages can occur due to TCP/IP disconnects, dead or overloaded wireless periods. The low-cost of Internet communication though makes it easier to operate a very large network of reference stations whether the network is of regional or global extent.

Recently, a new method for streaming RTN data over the Internet has been developed called Networked Transport of RTCM via Internet Protocol or NTRIP. NTRIP is intended as an open, non-proprietary protocol for streaming real-time DGPS and RTK, and eventually GNSS, corrections and raw data to mobile users [Dammalage et al, 2006]. NTRIP is a generic, stateless protocol based on Hypertext Transfer Protocol (HTTP 1.1) and is enhanced to GNSS data streams [Lenz, 2004]. Developed as an alternative to radio and mobile communications network methods of GNSS data streaming, NTRIP enables data streams from network reference stations to be accessed by clients through a single well-defined communication method. It allows simultaneous computer or receiver connections to a broadcasting host. NTRIP supports wireless Internet access through mobile IP networks like GSM, GPRS, EDGE, UMTS and it is part of the RTCM 104 Version 2.3 and 3.1 standards [Wegener and Wanninger, 2006]. One over-riding advantage of NTRIP for users who can gain wireless Internet access is its potential to service unlimited users, unlike server based RTN's with a limited number of dedicated access points. NTRIP, via unrestricted GNSS data sharing, promises many new GNSS applications such as the concept of a global real-time network of GNSS reference stations, providing access to GNSS data from any station in the network from anywhere in the world.

These same internet protocols can be used to log positions and attributes into GIS. Generally, interruptions in communications can be managed by storing positions locally until connections are restored. This "sometimes connected" scenario relieves the need for sophicated two-way GIS-rover communications with one-way rover-to-GIS communications accomplished over less reliable, but simple TCP/IP with above referenced wireless modem technology.

5. CONCLUSIONS

Advances in communication technology have enabled the development and implementation of precise real-time GPS networks (RTN). Although there are many considerations when implementing an RTN, the achievable survey-grade accuracies provide new possibilities to GIS data collection and applications. Advances in GIS technology enable the management of precise data sets such as those collected with RTN in large, centralized GIS databases. The same advances in communication technology that enable RTN's, enable the real-time posting of data in GIS from field collection devices. These complimentary technological advances provide the platform for new and exciting applications.

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