Differential GPS Positioning over Internet

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Abstract

A differential GPS positioning system is able to provide more precise position solutions than a stand-alone system through the application of corrections calculated at a reference station or a network of reference stations with known surveyed coordinates. Differential corrections are usually transmitted to the users via radio, beacon or communication satellite. In this paper, the concept of differential GPS positioning based on wireless Internet has been be described. To assess the feasibility of the proposed method, a prototype system has been developed and tested in the field using CDPD-based wireless Internet access. The field results have shown satisfactory positioning accuracy and differential data latency over the Internet. In addition to Internet advantages for wireless communication, the use of the Internet to develop new positioning methods has also been discussed.

1 Introduction

Measurements made from the Global Positioning System (GPS) are affected by a number of error sources including satellite orbit error, satellite clock error and atmospheric effects. Autonomous GPS positioning is therefore subject to the effects of all the above error sources and can only provide positioning accuracy at the level of about 15 meters. This stand-alone positioning accuracy could be further degraded to a level of 100 meters before the Selective Availability (SA) was turned off in May 2000. In order to achieve higher positioning accuracy to the level of several meters to a few centimeters, differential GPS (DGPS) techniques must be applied.

The major objective of DGPS is to cancel/reduce the error sources in the GPS measurements due to inaccurate GPS satellite clock and orbit data, atmosphere effects as well as GPS satellite and receiver related biases. Using DGPS method, however, at least two GPS receivers must be used with one serving as a reference receiver station with precise known coordinates and the other as the rover station for which positioning is required. The reference station is used to generate differential corrections to be applied by the rover station to cancel/reduce the above- mentioned error sources and subsequently to derive an improved position solution. Due to the requirement of a reference station, the method is effective only for short reference-rover separations because the error sources between the reference and the rover stations would be less spatially correlated as the increase of their separation distance. DGPS positioning using a single reference station therefore is often referred as Local Area DGPS (LADGPS).

To increase the effective range of the generated differential corrections, multiple permanent reference receiver stations are often used to form a reference network. Dependent on the size of the network, there are two different types of reference networks, namely,

a) Wide Area DGPS (WADGPS) network;
b) Regional Area DGPS (RADGPS) network.

A WADGPS network focuses on providing differential corrections from a continental-wide to a global scale while a RADGPS network on a regional scale (Gao et al., 1997). A number of WADGPS and RADGPS networks have been implemented to date and there are many currently under development. The US Wide Area Augmentation System (WAAS) is a typical example of WADGPS networks whose reference station separations are typically a few thousand kilometers

Journal of Geospatial Engineering, Vol.3, No. 1, pp. 1-7.

apart (Loh, 1995). The WAAS differential corrections are currently available with obtainable position accuracy at the meter-level although the network is not yet fully operational. On the other hand, a RADGPS network consist of multiple reference stations separated in the range of several hundred kilometers and the Swedish SWEPOS network is a typical example of such networks (Hedling, et al., 1996).

For real-time positioning applications, no matter what type of DGPS networks you may use, a continuous data link must be established between the reference network and the rover stations in order for the DGPS users to receive the differential corrections generated from the reference network. For local and regional area differential positioning, radios and local communication systems are typically used while for wide area differential positioning satellite communication is appropriate although it is much more expensive to use. As the advance of Internet technology along with its fast expansion in coverage and accessibility, it has been widely demonstrated that the Internet could become a cost-effective and efficient alternative for a wide range of applications including differential satellite positioning that we will discuss in this paper.

This paper describes recent research results in the use of Internet as the communication link for differential positioning and navigation applications. The paper will show that Internet-based differential positioning systems are advantageous when compared to the DGPS systems that are currently in use. The technology will not only improve the flexibility in the use of DGPS technology but also open doors for many innovative GPS applications.

The paper is organized as follows. The paper will first provide a brief description of the Internet and its characteristics as a communication tool. The concept of differential satellite positioning using Internet and an Internet-based Real-Time Kinematic (RTK) prototype system are then described. After that, an Internet-based mobile-to-mobile approach is also described as a possible solution for DGPS positioning using multiple moving reference stations (Luo, 2001). The field test results are finally provided to assess the obtainable differential positioning accuracy of the prototype system and its feasibility in operational environments.

2 Wireless Internet Advantages

Internet is characterized by its low cost, easy accessibility, availability, flexibility, and expandability. Currently the cost to connect to the Internet is very reasonable and it is no doubt that the cost will further be reduced in the future. In the past several years, the Internet has been evolved into one of the most important communication methods. Many applications are in fact increasingly required to be Internet-based due to its fast and worldwide accessibility. The Internet can also offer many advantages over the conventional radio data transmission method when it is used for differential satellite positioning. Some of them are described in the following.

First, Internet is not limited by an effective data transmission range, which implies that the rover station can be away from the base station as far as the user needs. In fact, the Internet theoretically can reach any corner of the world and its communication range is not constrained by factors such as the horizon requirement.

Secondly, the Internet can be accessed in any place where there is an Internet access either in the office or field. This also makes it affordable to operate many additional reference sites for large WADGPS network to improve the network redundancy. Subsequently, an improved redundancy can offer higher level of continuous service even if some reference stations are out of service unexpectedly. Since the Internet keeps expansion daily now, its accessibility will be further enhanced in the future while with reduced cost.

In addition, an Internet-based approach is particularly advantageous for differential positioning in regions with severe signal interference such as urban areas and for applications with a large number of rover users such as fleet and mobile asset management systems. The Internet has also been considered as the communication standard for the development of a rapidly emerging application area known as location-based service such as location-aware billing and advertising.

3 An Internet-Based DGPS Prototype System

An Internet-based WADGPS network implementation has been described in Muellerschon et al (2001) where the focus was placed on the network development using the Internet to transmit reference site data to the processing center. In this section, we focus on the development of an Internet-based differential positioning prototype system where the rover users access the differential correction data via the Internet.

The prototype system consists of a reference station and multiple rover stations. The system configuration is depicted in Figure 1. The reference station consists of a navigation receiver capable of generating RTCM differential correction data and a server computer. The server computer at the reference station can be either directly connected to the Internet via a local area network or wirelessly connected to the Internet via a wireless modem. On the other hand, each rover station consists of a rover navigation receiver, a client PC computer and a wireless modem. The client PC computer wirelessly links to the Internet using the installed wireless modem via a communication network to receive differential data from the reference station.

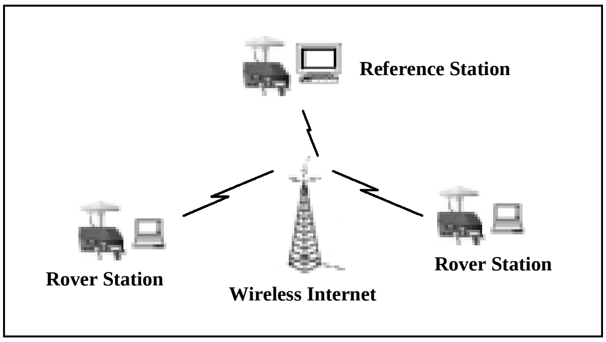

Figure 1: Internet-based DGPS Positioning

The transmission time taken for the user to retrieve the differential correction data from the reference receiver station determines the differential data latency for the positioning. Less than a few seconds of data latency is typically required for most DGPS applications. To minimize the data transmission latency and its subsequent influence on the DGPS positioning accuracy, the Internet protocols should be carefully selected which defines how the data are transmitted through the Internet. Internet currently uses a Transmission Control Protocol/Internet Protocol (TCP/IP) suite to connect all the networks, organizations and users across the world. The Transmission Control Protocol (TCP) and the User Datagram Protocol (UDP) are two important transport protocols that have been widely used for Internet applications.

TCP provides a stream delivery and virtual connection service to applications through the use of sequenced acknowledgment with retransmission of packets when necessary while UDP provides a simple message delivery for transaction-oriented services. TCP is able to provide highly reliable data transmission since it takes extra time to ensure reliability, flow control and connection maintenance. As a price for the superior reliability, the TCP protocol may not suitable for high precision real-time applications such as Real-Time-Kinematic (RTK) positioning because it requires an acknowledgement of the data arrival and the retransmission of any lost data [Hada et al., 1999]. Compared to TCP, UDP is able to provide faster data transmission although the reliability is not as high as TCP with a possibility of data losses. Since fast differential data transmission is essential for the success of a real-time positioning system to derive accurate positions, UDP protocol has been utilized in this research to test the performance of the developed Internet-based DGPS system.

4 Internet Beyond Wireless Communication

Although the previous focus has been on the use of the Internet as a communication tool for differential satellite positioning applications. The Internet advantages, however, don’t stop there which could help create new methods to the use of satellite navigation systems. In the following, the concept of mobile-to-mobile differential satellite positioning is described as an example. It is no doubt that high precision location information will be no longer a luxury but basic commodity of daily lives in the near future.

Although the establishment of a reference network of multiple reference stations is able to extend the differential correction coverage to larger areas, the distance between the users to any of the reference stations is often still too long for high precision positioning. This is particularly true for RTK applications. The deployment of highly dense reference stations on a permanent basis seems too costly and difficult to implement. To tackle the problem without adding new permanent reference stations, mobile reference stations can be used as a bridge to tie the rover users to the permanent reference stations. The concept is depicted in Figure 2.

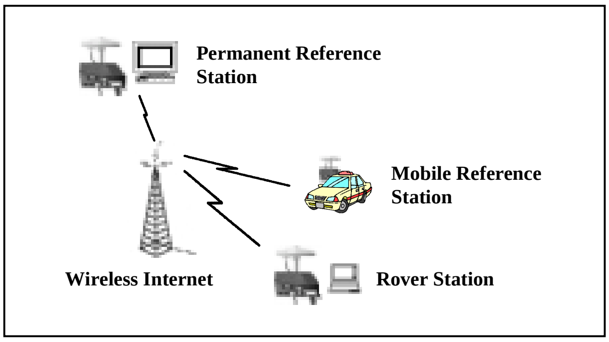

Figure 2: Concept of Mobile Reference Station

From Figure 2, we see that the proposed mobile-to-mobile solution employs a mobile reference station whose separation to either the permanent station or the rover user is less than the separation between the rover user and the permanent reference station. Because the shorter baseline length between the permanent reference station and the mobile reference station, the latter's position can be precisely determined using RTK technology where integer ambiguity resolution becomes feasible. The difference between the mobile reference station and the permanent reference station is that the mobile reference station is usually mounted in a vehicle so the mobile reference station must wirelessly access the Internet. Once the precise position of the mobile reference station is known in real-time, it can be applied to serve as a reference station for the rover users. Since the baseline length between the mobile reference station and the rover user is shorter than the distance when the rover user is directly differencing with respect to the permanent reference station, it allows the rover user to conduct high precision RTK positioning because the integer ambiguity resolution becomes feasible now.

The above concept can be extended to more general multiple moving platform situations where precise RTK positioning is conducted with respect to multiple moving or mobile reference stations (Luo, 2001). Since each mobile user need to access differential corrections from multiple mobile reference stations, the narrow bandwidth, multiple-frequency usage as well as signal interference will make the method totally unpractical if using conventional radios for differential data transmission. In this regard, the Internet provides an excellent alternative with no bandwidth barriers and frequency/ interference concerns. The concept is described in Figure 3.

5 Field Tests and Data Analysis

The Internet-based prototype system described in Section 3 has been tested in the field to assess its positioning performance and feasibility under operational environments. The performance analysis is conducted in a kinematic mode using phase-based Real-Time-Kinematic (RTK) technology.

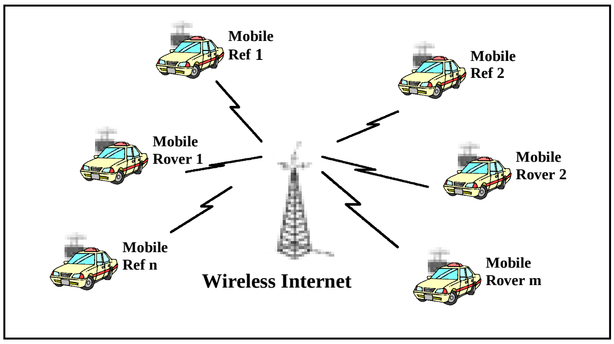

Figure 3: Concept of Mobile-to-Mobile RTK System

The wireless equipment used in the test includes an Ethernet NIC linking the reference station to the Internet and a Merlin Wireless PC Card from Novatel Wireless Inc to allow the rover user to wirelessly access the Internet via a Cellular Digital Packet Data (CDPD) network. In the city of Calgary, the CDPD service is provided by Telus™ Corporation with an operational speed of 19.2 Kbps which is sufficiently high for the RTCM message transmission in RTK positioning.

A kinematic field test was conducted in Calgary on February 11, 2001. Two Ashtech GPS+GLONASS single frequency receivers were used as the reference and rover receivers, respectively. The antenna for the reference receiver was setup on the roof of the Engineering Building at the University of Calgary with precisely known coordinates (Figure 4). During the test period, the reference receiver was connected to the server PC from which the differential data was made on-line over the Internet. The rover receiver was installed in a vehicle and the receiver antenna was set up on the roof of the vehicle (Figure 5). Connected to a laptop computer, the rover receiver retrieves the reference differential data from the CDPD modem installed on the laptop.

Figure 4: Reference Receiver Station

Figure 5: Rover Vehicle Station

During the field test, the vehicle was driven away from the campus and the maximum baseline length between the reference receiver and the rover receiver was up to about 12 kilometers. A data rate of 1 Hz was used for the kinematic test. In addition to the real-time RTK position outputs, the raw measurements from both the reference and the rover receivers were also saved for post-processing.

To assess the kinematic positioning accuracy, a high precision reference trajectory of the vehicle must be established. In this investigation, the raw measurements collected during the kinematic test were post-processed using a commercial software package and the position results were then used as the reference. Compared to the reference position results, the accuracy of the real-time RTK position outputs could then be assessed.

Shown in Figure 6 are the PDOP values and the number of visible satellites for the kinematic test during which the PDOP value was around 2.0 while the number of visible satellites was from 7 up to 9. Shown in Figure 7 are the time series of the position differences between the reference and the real-time position results. The results have indicated that the kinematic positioning accuracy was at the order of a few centimeters for all coordinate components.

The mean differential data latency over the Internet for the kinematic test is about 1.0 second while the minimum and the maximum latency values are 0.5 second and 3.3 seconds, respectively. The points with large latencies were an indication of heavy traffic between the reference and the rover receivers over the Internet.

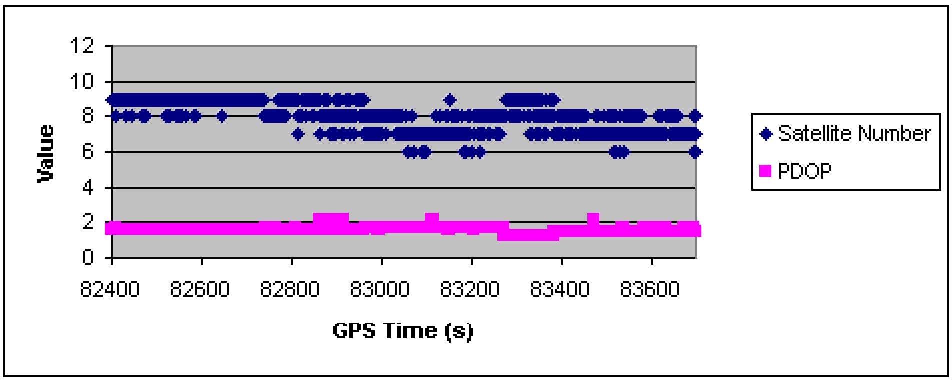

Figure 6: PDOP and Number of Visible Satellites

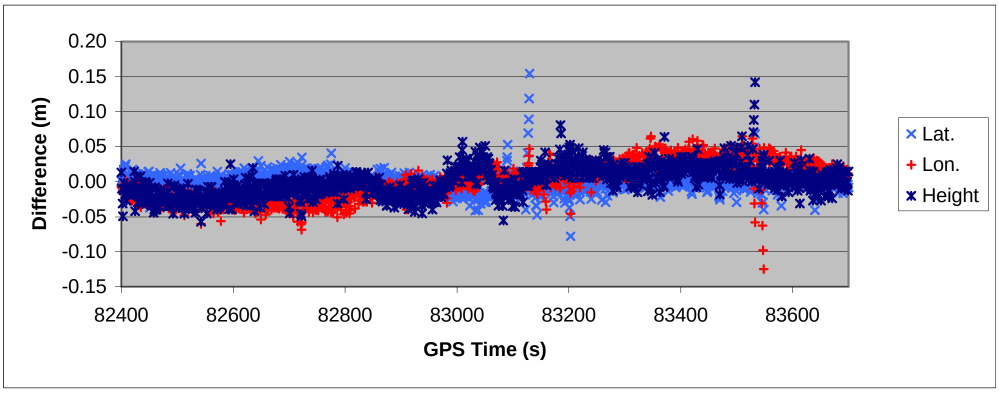

Figure 7: Kinematic Internet-based RTK Positioning Accuracy

6 Conclusions

The concept of differential GPS positioning using the Internet has been described in this paper. In addition to the Internet advantages for wireless communication, the use of the Internet to develop innovative applications using satellite navigation systems has also be explored including the introduction of a new mobile-to-mobile solution for multiple moving reference differential positioning and navigation.

To validate the concept, a prototype system has been developed and tested in the field. The test results have demonstrated that the data transmission latency over the Internet is typically at the level of one second while the obtainable positioning accuracy is at the centimeter level when using Real-Time-Kinematic (RTK) technology. As the fast advances of the Internet technology and its increased accessibility in the near future, the Internet will help the development of new location systems and devices to support a wide range of applications including the emerging location-based services.

Acknowledgement

This research is partially supported by the Geomatics for Informed Decision (GEOIDE) Program and the Co-ordination of University Research for Synergy and Effectiveness (COURSE) program.

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