A Web-Based Real-Time Monitoring System for GNSS Data Quality and Integrity

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Key words: GNSS, NTRIP, RTCM, real time monitoring, data quality control

SUMMARY

The single base real-time kinematic (RTK) positioning technique is distance-dependent in terms of accuracy and reliability of the integer ambiguity resolution. The Network RTK (NRTK) technique has been developed to overcome this limitation, so is able to be used over longer distances than is possible with single base RTK whilst maintaining centimetre-level accuracy. This multiple reference station approach provides a precise measurement correction to the RTK positions over long baselines by interpolating errors across the reference receiver network. In order to provide reliable corrections it is necessary for the NRTK service provider to have quality and integrity monitoring mechanisms.

The Department of Lands, New South Wales, operates a network of Continuously Operating Reference Stations (CORS) called 'SydNET' around the city of Sydney to provide real-time GPS data via the internet. It is, however, difficult to predict the variation in performance and the status of the reference stations. Therefore a scheme to monitor data streams in real-time has been proposed for dealing with the data quality control issue.

This paper presents a Web-based scheme for monitoring real-time Global Navigation Satellite System (GNSS) data streams from the SydNET stations. In order to demonstrate the feasibility of this Web-based monitoring system, a prototype was developed. Networked Transport of RTCM via Internet Protocol (NTRIP) was introduced to collect data streams.

The challenging part of this QC system is implementing a system that provides a real-time monitoring service of multiple stations simultaneously, and publishes quality parameters on the Web in a graphical chart with real-time updates, preferably at a 1Hz data rate. This scheme enables a visualisation of reference station performance by monitoring RTCM messages, and subsequently will be utilised to access quality control of such infrastructure, as well as supporting the Virtual Reference Station (VRS) Network RTK solution.

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1. INTRODUCTION

Distributing GNSS data through the internet has been accelerated with the growing popularity of permanent GNSS networks of Continuously Operating Reference Stations (CORS) internationllay to support Network RTK (NRTK) applications. The NRTK positioning method provides positioning solutions with errors independent of the rover/user location inside the CORS network (Vollath et al, 2000). Therefore, NTRK overcomes the distance constraints experienced with the single baseline RTK techniques.

As depicted in Figure 1, 'SydNET' is a CORS network deployed around the city of Sydney, in the state of New South Wales (NSW), Australia. SydNET is operated by the Department of Lands, NSW, in cooperation with the School of Surveying and Spatial Information Systems, University of New South Wales (UNSW) (Rizos et al, 2003). Currently, eleven active stations have been deployed around the Sydney basin area (and beyond), providing GNSS data streams via the internet.

Networked Transport of RTCM via Internet Protocol (NTRIP) is used as a delivery mechanism for real-time GNSS data streams in SydNET. NTRIP is a TCP/IP based network protocol used for transferring GPS data (Weber et al, 2005). It was developed by the national mapping agency, Federal Agency for Cartography and Geodesy (BKG) in Germany (BKG, 2008). NTRIP consists of three components: NTRIP Server, NTRIP Caster, and NTRIP Client. Figure 2 illustrates the interaction between these components.

As can be observed from Figure 2, indirect connections between stream providers and clients enables the simultaneous dissemination of hundreds of streams for thousands of clients. Such massive distribution is possible via internet connections such as HTTP and NTRIP. NTRIP provides seamless access globally in real-time, and is considered the de facto standard for streaming GNSS data via the internet.

Radio Technical Commission for Maritime Services (RTCM) recommends a standard format for differential GNSS data and corrections. It therefore facilitates interoperability between manufacturer-dependent receivers in a CORS network such as SydNET. SydNET provides reliable GNSS data streams for precise positioning such as single base RTK with GPS carrier phase ranges. Since the GNSS data is transferred via Ethernet, the TCP/IP connection has to be maintained during data transmission.

However, if a system fault causes a disconnection between a reference station and the server, network administrators have difficulty identifying this problem. The web-based monitoring system proposed in this paper is intended to address this issue for both network administrators and users. The real-time monitoring mechanism is desired during data transfer in order to deal with abrupt changes of the reference station(s) status and data availability.

Figure 1. Distribution of SydNET stations (SydNET, 2008)

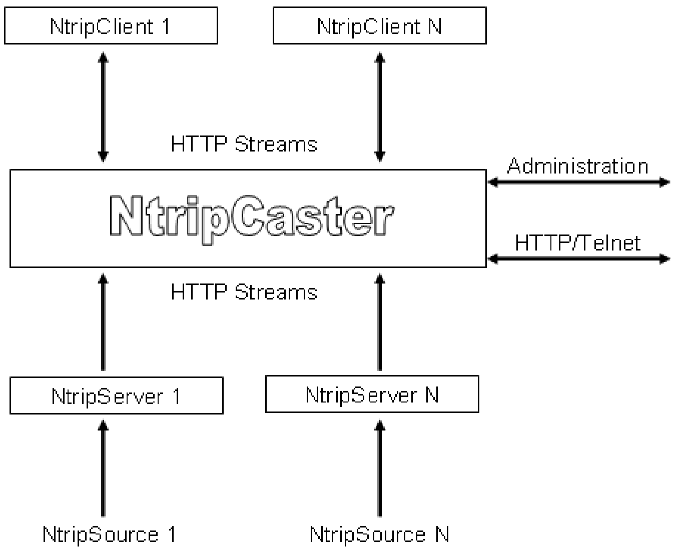

Figure 2. NTRIP System (Weber et al, 2005)

2. BACKGROUND

GNSS data quality control traditionally has been performed in post-processing mode with specialist software that generates a statistics report as well as graphical representations from logged data. For example, TEQC, developed by UNAVCO, provides a rich set of functions for general data quality assessment (Estey et al, 1999). Although such a software package is suitable for generating statistics on data completeness over time, it is critical for RTK service providers to monitor data dropouts in real-time. The degradation of services can be caused by many factors. For instance, any fault in the physical network connection may result in the degradation of expected data integrity, data dropouts and inconsistency of messages. Detecting such behaviour is important for providing quality of service to users. It is also a crucial requirement for NRTK to produce quality positioning solution by generating Virtual Reference Station (VRS) that simulates a local reference station near the rover/user receiver (Landau et al, 2002).

There are software packages that provide quality control and performance of GPS data streams in real-time. Real-Time Quality Control (RTQC), developed by Melbourne University researchers, checks the data quality of CORS networks for mobile users (Fuller et al, 2007). Another real-time GPS data quality software is known as 'GQC', an adapted version of 'Quimby', which was also developed at Melbourne University in collaboration with the Department of Sustainability and Enviironment (DSE) Victoria, Australia, for reference station monitoring. GQC has been used by DSE to monitor the quality and integrity of Victoria's permanent GPS reference network "GPSNet" (Brown et al, 2003). Details of GPSNet were presented at the XXII FIG International Congress in Washington, April 2002 (Neil et al, 2002).

This paper introduces a web-based monitoring system that performs data quality assessment in real-time. It has been implemented using Web technology and database technology. The Web-based monitoring system is a core component of a server-based RTK services (Lim et al, 2007).

3. SYSTEM ARCHITECTURE

Based on the user requirement, a Web-based real-time monitoring system for RTCM messages has been designed and developed. RTCM messages from a CORS are decoded and stored into a database in order to analyse the data quality. Therefore, data for a certain period of time (e.g. 1 second, 1 hour, etc.) can be extracted and represented by a time series chart in order to evaluate statistics and trends. A Web-based system is proposed because of its portability and independence of computer operating systems. In accordance with rapid development of Web technology, a structure-oriented interactive Web provides a rich set of functionality, flexibility, and scalability.

The monitoring system sends a request for multiple data streams to an NTRIP caster which broadcasts RTCM streams coming from NTRIP servers. The communication with the NTRIP caster is actually via TCP/IP sockets. The sockets are kept alive for a long period because the

NTRIP caster has to send RTCM streams continuously. Each data stream has to be decoded and converted into an appropriate format for storing into the database. As boundless amounts of data are expected, this process has to be very reliable and scalable.

Figure 3 illustrates the data flow and the system design of the Web-based RTCM data monitoring system. The data transfer method and the communication link between server computers and clients is discussed in the following sub-sections.

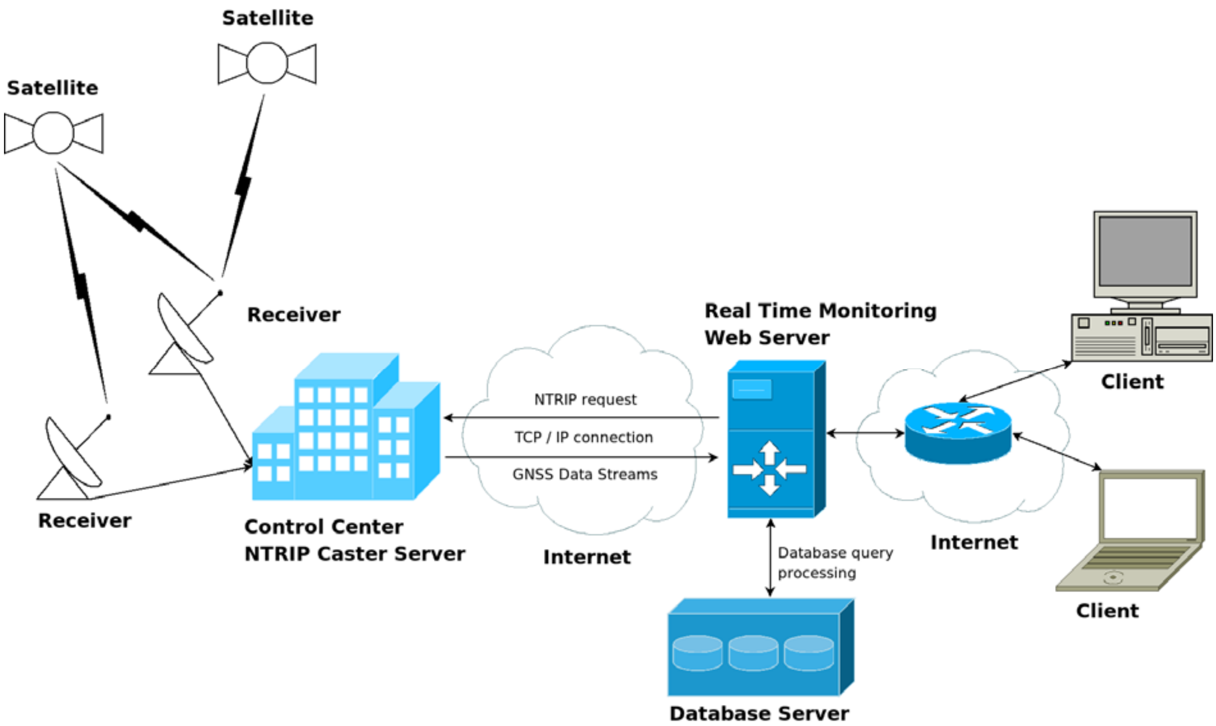

Figure 3. Web-based real-time GNSS data monitoring system

3.1 Communication

An NTRIP caster is located at the control centre and distributes GNSS data coming from NTRIP servers which acquire raw measurments from GNSS receivers. The real-time monitoring server acts as a data processing unit as well as a Web-server. Therefore, there are two main communication processes running on the system.

1) NTRIP Caster and Real-Time Monitoring Server
The real-time monitoring server communicates with the NTRIP caster as a client. The monitoring server sends HTTP requests to the NTRIP caster and receives multiple GNSS data streams transmitted via TCP/IP. Figure 4 shows the process between the NTRIP caster and the monitoring server. The incoming binary data must be decoded by RTCM decoders and inserted into a dedicated database in real-time. A GNSS database has been designed and implemented for this purpose. Data records can be extracted at any time (e.g. 1 second later) and converted to RINEX files for post-processing.

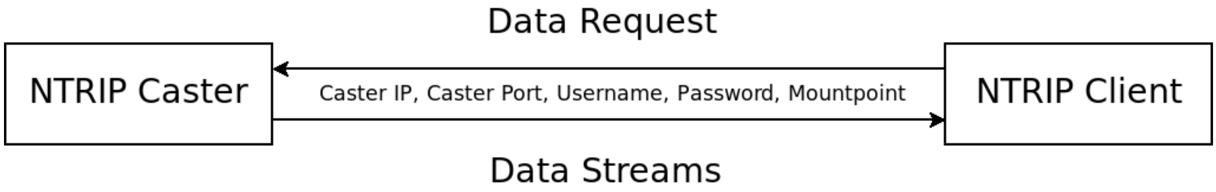

Figure 4. Communication between NTRIP caster and NTRIP Client

2) Real-Time Monitoring Server and Network Administrator
On the other hand, a Web application is running on the monitoring server waiting for requests from clients such as network administrators. When clients visit the Web-based real-time GNSS data system using their Web browsers, the monitoring server behaves as a Web-server. The Web application provides clients with interactive Web pages. Hence, users can select parameters of their interest, for example, a specific reference station from a specific CORS, satellites, monitoring period, history data, etc. The Web monitoring server performs database queries based on the user-defined parameters. The query results are organised with proper data structures and transmitted to the client as HTTP responses. The received data packets are processed on the client side and rendered on the Web browser in a graphical chart format. The chart refreshes at 1Hz in real-time.

3.2 Database-oriented application

Figure 5 illustrates the data flow on the Web monitoring server. Since the proposed design is a multi-process database application, the latency of data communication is unavoidable due to database query response time and switching time between processes. Hence it is really a”near” real-time application in this sense. In order to implement a ”true” real-time application, decoding and processing the data streams must be performed at the client side. This will reduce the database query response delay, but increases the client’s computational load.

To meet the user requirement, IP multicasting is the ideal option since it conserves bandwidth by reducing the number of live streams in use. However, implementing a real-time application using the multicast technique has not been attempted due to the following reasons. Firstly, it requires a specially configured network with a multicast-enabled router. Even if there are many multicast-enabled routers available on the network, it is common for network administrators to disable their routers from multicast packets to reduce traffic and increase performance/speed. This ensures efficient use of router memory resources. Secondly, most multicasts are UDP-based. Because of the characteristics of UDP, occasional packet drops are expected. This data loss can be a significant problem with NRTK. If multicast network topologies change, a large number of duplicate packets will be generated. Designing an application that handles occasional duplicate packets is not appropriate for real-time purposes. Thirdly, there is no congestion control, and overall network degradation will result as the popularity of UDP-based multicast applications grows. For example, peer-to-peer multicasting is becoming very popular.

As a result, the TCP connection is preferred for its reliability. TCP is a "hand-shake" connection protocol. Hence, the server computer has to wait until a client sends a request, and at the same time the server is receiving real-time data from NTRIP casters. In order to deliver the incoming data to the client in real-time, a data storage mechanism between the two is necessary. It can be accomplished by either file input/output or a database.

Utilising the database approach is inevitable for performing tasks such as reading and writing identical data when multiple streams are simultaneously accessed. Current database technology supports reasonably fast response time as well as multiple connections to an identical set of data. Hence it is feasible to supply information to numerous clients in real-time. Furthermore, once the RTCM messages from each station are stored in the database, analysing the data quality is feasible. For instance, a certain period of data records can be extracted by a database query and be represented by a time series chart on the Web in order to evaluate statistics on a (for example) hourly/weekly basis.

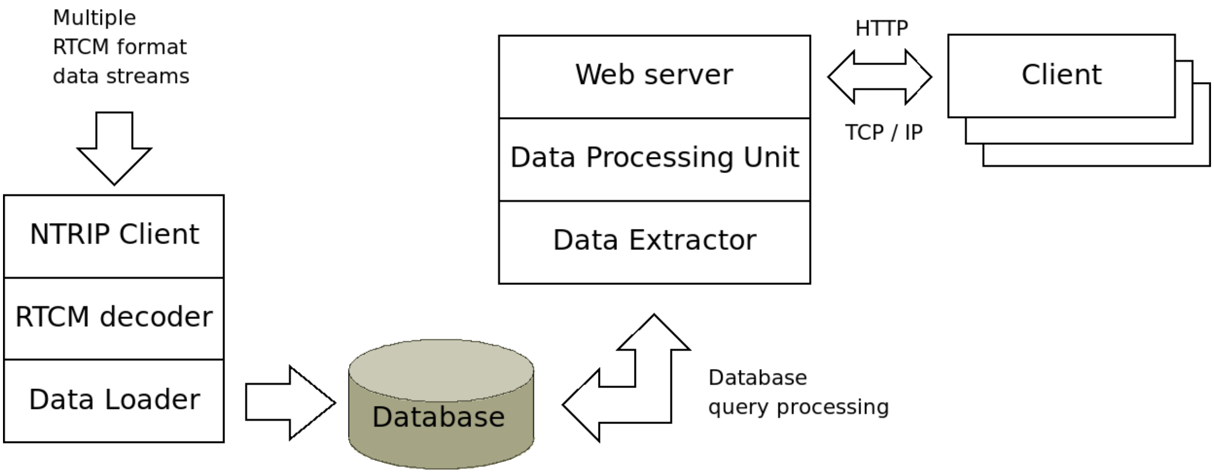

Figure 5. Data flow of the Web-based real-time GNSS data monitoring system

4. PROTOTYPE IMPLEMENTATION

A prototype of the real-time monitoring system has been developed based on the proposed system architecture. An NTRIP client, a RTCM decoder and a data loader have been developed and combined together to continuously feed incoming real-time data. Server-side applications and client-side applications have also been developed in order to communicate over a HTTP connection. These communication enablers transport user-defined requests and data streams between the server and the client.

This prototype has been built for the purpose of demonstrating the feasibility of real-time monitoring on the Web. The system is now operational and can be accessed at www.gnss.unsw.edu.au. Currently it is in an alpha-test stage. The Web application maintains each session for users. A step-wise configuration provides users with time-series parameters of their interest.

Currently, the variables for monitoring include raw measurements such as P1, P2, L1, and L2, their combinations such as P3 = P2 – P1 and L3 = L2 – L1, double-differenced measurements, ionospheric delay, and data dropouts. Cycle slips and data integrity parameters will be included in the near future. Figure 6 shows the screen shot of the Web page for user-defined configuration of parameters.

Figure 6. User defined configuration

Single reference station monitoring for P3 is shown in Figure 7. X- and Y-axis represent the time in GPS seconds and the unit of the parameters, e.g. metres or cycles, respectively. Double-differenced P3 is shown in Figure 8. That is, processing raw measurements with intensively computational algorithms and rendering the results in real-time is also possible. Data dropouts (see Figure 9) and a measure of ionospheric delay (see Figure 10) can be monitored as well.

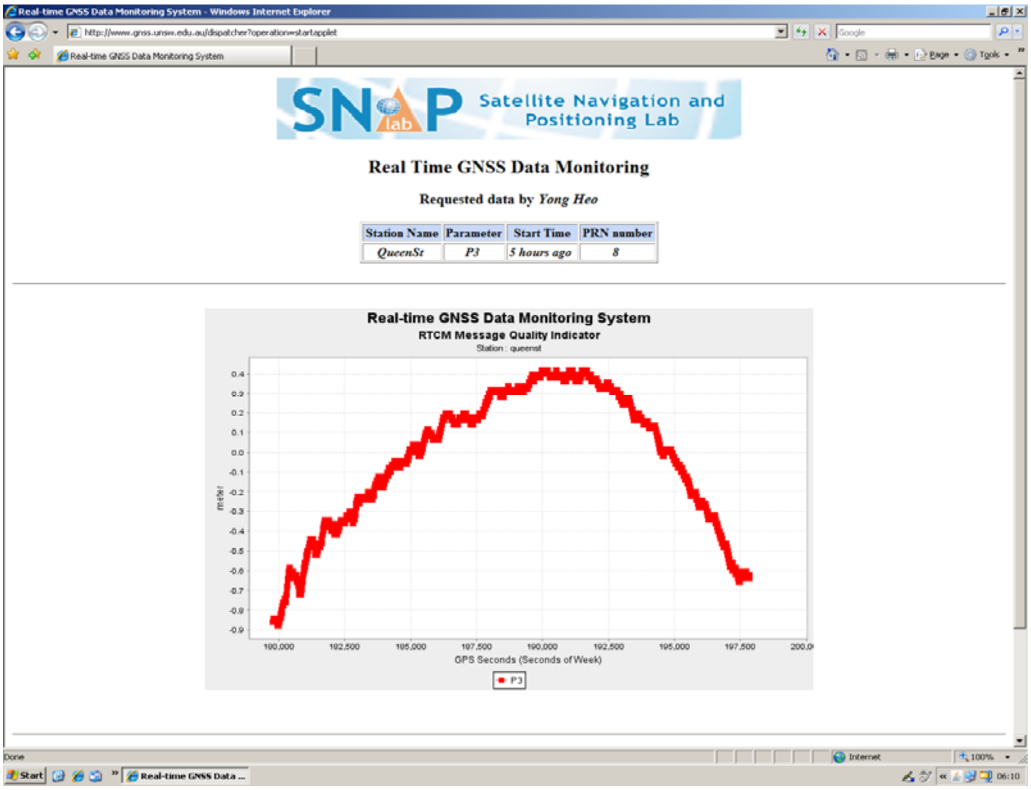

Figure 7. Monitoring of P3 data from a SydNET station

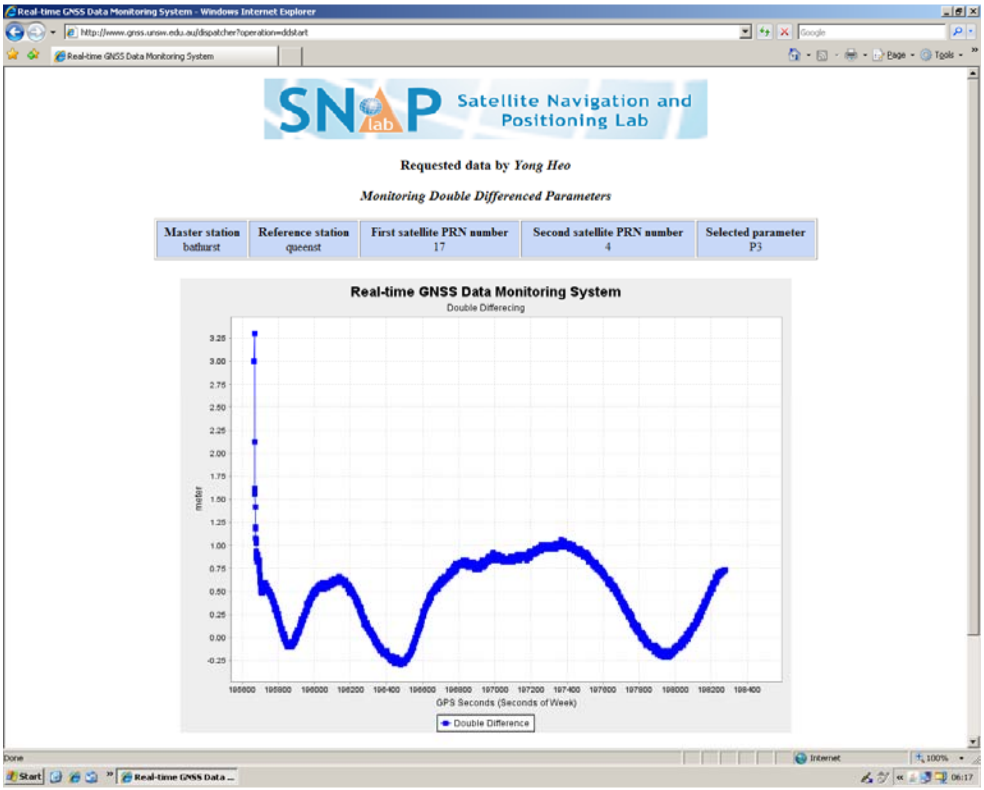

Figure 8. Monitoring of double-differenced P3

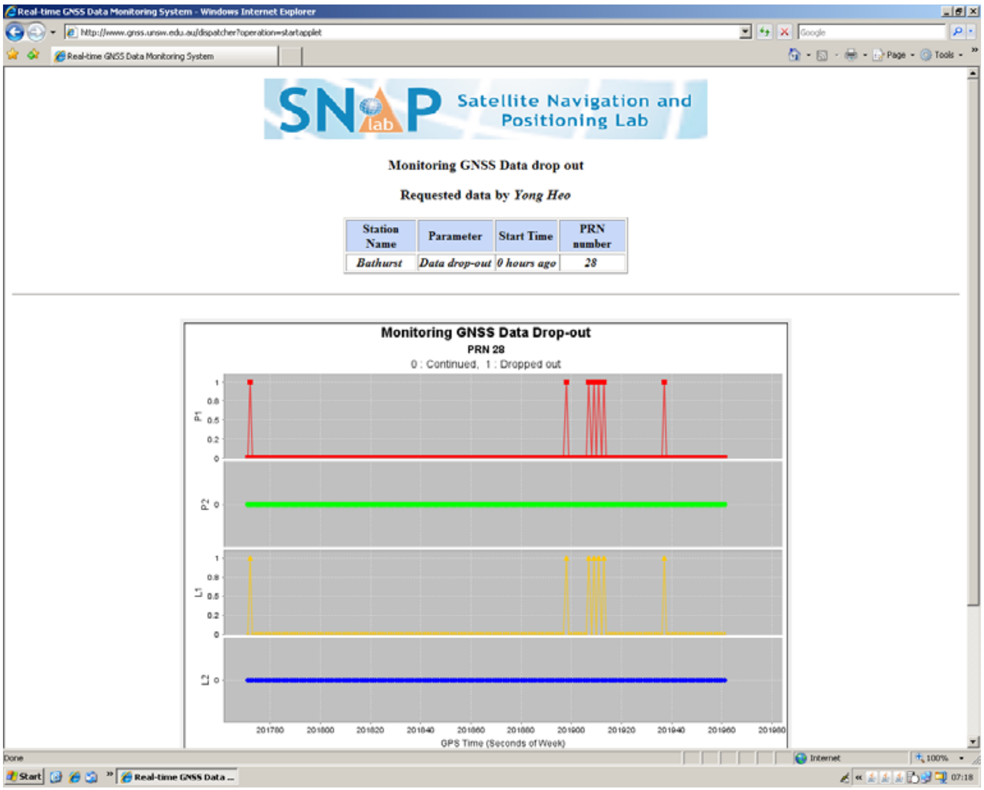

Figure 9. Data dropouts monitoring

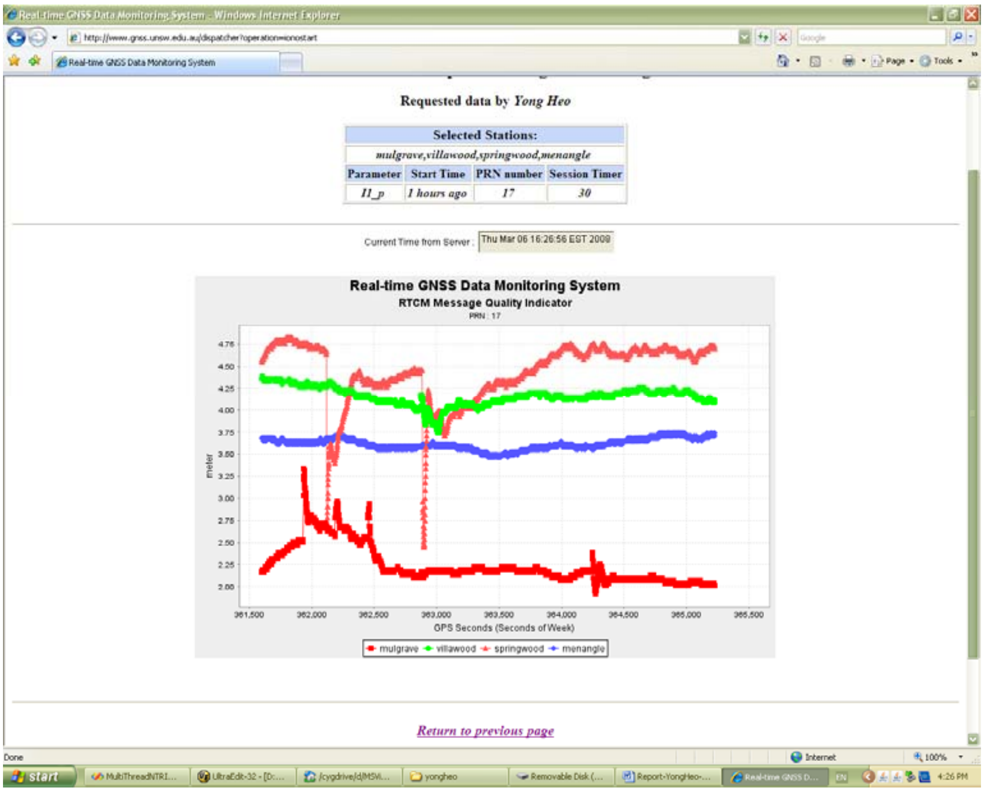

Figure 10. Ionospheric delay monitoring

5. CONCLUDING REMARKS

In this paper the feasibility of a Web-based real-time monitoring system that can check the quality of GNSS data streams from CORS networks (e.g. SydNET) has been investigated. The main objective of the Web approach is for visualisation of time-series variations as well as GNSS data quality information in real-time. This will support the quality control of the CORS network. The real-time Web application can provide monitoring services to not only administrators but also users on the internet.

TCP and UDP as communication protocols have been investigated as to their suitablility for data delivery. To demonstrate the feasibility of real-time monitoring, the proposed system has been implemented in a prototype and is currently up and running. The system architecture can be categorised into four components: a communication enabler, a database application, a Web server application, and a client-side application. These components are combined together to deliver the Web-based data quality services to users. Multiple modes, e.g. single reference monitoring and double-differenced parameter monitoring, have been developed to support user requirements.

Currently, the prototype system monitors all active SydNET stations from Department of Lands, New South Wales, and part of the Australian Regional GPS Network (ARGN) stations from Geoscience Australia. When the issue of scalability has to be taken into account in the future, a modern parallel computing technology will need to be implemented. This upgraded system will be incorporated into a NRTK system that can process multiple GNSS data streams at the server-side.

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BIOGRAPHICAL NOTES

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