# Internet Based VRS Code Positioning

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**Abstract**

Absolute positioning – the real time satellite based positioning technique that relies solely on global navigation satellite systems – lacks accuracy for several real time application domains. To provide increased positioning quality, ground or satellite based augmentation systems can be devised, depending on the extent of the area to cover. The underlying technique – multiple reference station differential positioning – can, in the case of ground systems, be further enhanced through the implementation of the virtual reference station concept.

Our approach is a ground-based system made of a small-sized network of three stations where the concept of virtual reference station was implemented. The stations provide code pseudorange corrections, which are combined using a measurement domain approach inversely proportional to the distance from source station to rover. All data links are established trough the Internet.

Keywords: *GNSS, DGNSS, GPS, DGPS, VRS, distributed systems.*

## 1 Introduction

The motivation behind this project is the development of a tracking system for mobile platforms equipped with standard single frequency Global Positioning System (GPS) receivers. This paper describes the virtual reference station (VRS) module implemented to supply real time differential GPS (DGPS) code-based pseudorange corrections. The VRS module is a component of local area differential positioning system supported by a small-sized network of three reference stations. Our goal is to provide rovers located within the scope of our network with real time positioning with at least 3 m level accuracy while using the Internet as the sole data transportation medium. This latter requirement results from the fact that the equipment available for outdoor navigation is made of low-cost standard commercial products: single frequency DGPS enabled receivers with USB, PS2 or RS232 interfaces.

Our differential network is made of three reference stations (RS), the minimum number required to implement a multi-station DGPS network. We were granted access to two reference stations located in our area: Gaia RS, which has a dual frequency receiver, and IDT RS that is equipped with single frequency receiver. Although both stations were fully operational, they did not provide real time differential data, i.e., they were configured to generate files for post-processing only. The third station, called ISEP, was implemented from a single frequency low-cost commercial receiver. Currently, all stations generate real time pseudorange differential correction messages and provide a DGPS service through the Internet. The resulting differential network is a real time pseudorange differential correction multi-station system.

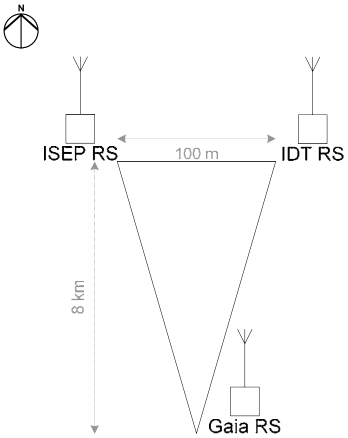

**Figure 1 – RS Network Topology.**

Finally, to further increase the accuracy of the supplied service, we implemented the virtual reference station (VRS) concept, which simulates the continuous presence of stations near client rovers. The virtual reference station is accomplished through a measurements domain approach where the differential corrections from the network stations are combined according to each rover location.

We intend to prove that is possible to provide a VRS pseudorange differential correction service with the exclusive support of the Internet and with standard low-cost equipment. In this work we used cable (Ethernet), wireless (Wi-Fi) and mobile data links (GPRS and UMTS) to establish the connections between RS, the VRS module and the rovers.

The remainder of the paper is organized as follows. In Section 2, we introduce satellite based real time positioning, differential positioning, virtual reference station positioning and the more relevant real time code-based augmentation systems. Section 3 describes the VRS module. Finally, in Section 4, we discuss our work and describe our future plans.

# 2 Satellite based Real Time Positioning

Global Navigation Satellite Systems (GNSS), such as the United States of America (USA) Navigation Timing and Ranging Global Positioning System

(NAVSTAR-GPS) and the Russian Federation Global Navigation Satellite System (GLONASS), provide a continuous, worldwide, all weather absolute positioning service to end-users. A GNSS receiver performs code and carrier phase measurements. Unfortunately, a number of error sources affect these measurements: (i) the receiver uses estimates (calculated from the satellite ephemeris data) rather than precise satellite positions; (ii) the satellite and the receiver clocks are not synchronized and are subject to drifts; (iii) the atmosphere affects the GNSS signal propagation; (iv) the site dependent signal multipath deteriorates the quality of measurements; and (v) the electronic noise and resolution of the receiver condition the accuracy of the measurements. As a result, the receiver, instead of determining the exact geometric ranges to the satellites in view, only computes approximate values, known as pseudoranges.

Code pseudorange measurements use the concept of time-of-arrival (TOA) ranging to determine the user position. This concept entails measuring the time that a signal transmitted by an emitter at a known location takes to reach a user receiver. This time interval, referred to as the signal propagation time, is then multiplied by the speed of the signal to obtain the emitter-to-receiver pseudorange. By measuring the propagation time of signals broadcasted from multiple emitters (at least four) at known locations (the GNSS satellites), the receiver can determine its position. However, this standard absolute positioning service does not support, *per se*, our intended 3 m accuracy level. We use single frequency NAVSTAR-GPS (usually designated by GPS) receivers and work with code pseudorange measurements.

Carrier phase pseudorange measurements, although more accurate, are ambiguous. The value measured – the phase of the carrier signal upon arrival at the receiver – provides no clue regarding the initial integer number of cycles between satellite and receiver. This quantity, known as the integer ambiguity, remains constant as long as the tracking of the satellite is not interrupted (no cycle slips occur). Once the integer ambiguities are solved, the receiver is able to compute the satellite-to-receiver pseudoranges. For each satellite in view, it adds the integer number of cycles with the carrier phase measurement and multiplies the result by the carrier wavelength. In order to solve in real time the integer ambiguities, users are required to use top quality receiver equipment.

## 2.1 Accuracy

GPS has two levels of navigation accuracy: precise positioning service (PPS), intended for military users, and standard positioning service (SPS) for civil users. PPS is accurate to 30 m with 95 percent confidence. Originally, SPS was accurate to 100 m. Since the selective availability (SA) mechanism was switched off, SPS post-SA accuracy is $< 25$ m ($< 13$ m horizontally and $< 22$ m vertically) [4]. In other words, absolute GPS positioning nowadays is accurate to 25 m.

To enhance real time GPS positioning accuracy, differential GPS (DGPS) positioning was developed in the nineties. According to the 2001 Federal Radionavigation Systems (FRS) report [4], DGPS is accurate to 10 m. The DGPS accuracy may vary from < 1 m to < 10 m depending on the quality on the end-user equipment and on the distance between receiver and reference station; typically it stays within the 5 m level [9].

High accuracy differential positioning, also known as real time kinematic (RTK) corrections, achieves centimetre level accuracy. However, to apply real time carrier phase corrections, it is necessary to use top quality equipment such as double frequency receivers with the ability to solve the integer ambiguities on-the-fly.

## 2.2 Differential Positioning

Differential global satellite navigation systems (DGNSS) are complementary systems intended to augment the performance of the underlying GNSS. DGNSS methodology relies on one or more reference stations, installed at known locations, to compute and broadcast the range errors of the GNSS satellites in view. The corrections are the difference between the computed satellite-station geometric range and the raw satellite-station pseudorange measurement. There are two real time differential positioning methods – the code and the carrier phase methodologies. Since our work only involves code pseudorange corrections, we will disregard carrier phase corrections.

The RS generates correction values for the pseudorange measurements, i.e., a pseudorange correction for each valid satellite in view. The computed corrections are to be applied, within a given time-window, to the measurements of rovers situated in the vicinity of the RS. A user equipped with a DGNSS enabled receiver expects to eliminate the error sources that affect in the same way both RS and rover. These so-called “common errors” include position-dependent error sources (e.g., the variable propagation delays introduced in the GNSS signal when it crosses the ionosphere and the troposphere) and position-independent error sources (e.g., the ephemeris and clock errors of the GNSS satellites). However, due to the spatially correlated error sources, as the distance between rover and RS (baseline) grows, the quality of the differential correction degrades.

The code range from station *RS* to satellite *S* at reference epoch $t_0$, or more exactly, the pseudorange measured by the receiver of the station at $t_0$, may be modelled by

$$PR_{RS}^{S}(t_0) = \rho_{RS}^{S}(t_0) + \Delta\rho_{RS}^{S}(t_0) + \Delta\rho^{S}(t_0) + \Delta\rho_{RS}(t_0)$$ **Equation 2.1**

where $PR_{RS}^{S}(t_0)$, $\rho_{RS}^{S}(t_0)$, $\Delta\rho_{RS}^{S}(t_0)$, $\Delta\rho^{S}(t_0)$ and $\Delta\rho_{RS}(t_0)$ are the pseudorange measurement; the geometric range from station *RS* to satellite *S*; the range biases depending on both reference station and satellite positions (e.g., effects of radial orbit error, atmospheric refraction on the satellite signals); the range bias of the satellite (e.g., the effect of satellite clock error); and the range bias of the receiver (e.g., the effects of receiver clock error and multipath) [7].

The pseudorange correction computed by station *RS* for the pseudorange measurement of satellite *S* at reference epoch $t_0$ is defined by

**Equation 2.2**

$$PRC_{RS}^{S}(t_0) = \rho_{RS}^{S}(t_0) - PR_{RS}^{S}(t_0)$$

where $PRC_{RS}^{S}(t_0)$, $\rho_{RS}^{S}(t_0)$ and $PR_{RS}^{S}(t_0)$ are the pseudorange correction for satellite *S*; the geometric range from station *RS* to satellite *S*, which is obtained from station *RS* known position and the broadcasted ephemeris of satellite *S*; and the pseudorange measurement of satellite *S* [7]. Additionally, the station also computes the range rate correction parameter $RRC_{RS}^{S}(t_0)$ for satellite *S*, which models the rate of change of the pseudorange correction of satellite *S* according to station *RS*.

The standard protocol used by ground based augmentation systems to transmit differential corrections is the Radio Technical Commission for Maritime Services Special Committee N. 104 protocol [13] – referred in this paper as "RTCM SC-104". Traditionally, RS transmit the differential corrections via a radio data link.

### 2.2.1 Applying Pseudorange Corrections

Receivers apply the pseudorange correction values to the correspondent pseudorange measurements, i.e., the pseudorange of satellite *S* will be corrected only by the transmitted pseudorange correction for satellite *S*. The problem of lack of corrections for all satellites in view is not addressed here – in our case it will be very unlikely that the rovers located within the network-covered area will use satellites unseen by the surrounding stations. A receiver, upon reception of a valid pseudorange correction message, extrapolates the correction values to the current epoch *t* and, then, adds the results to the correspondent current pseudorange measurements. The received pseudorange corrections will diverge from the proper value as time elapses, i.e., as messages grow old [13]. Equation 2.3 holds the formula for the pseudorange correction of satellite *S*,

$$PRC_{RS}^{S}(t) = PRC_{RS}^{S}(t_0) + RRC_{RS}^{S}(t_0) \times (t - t_0)$$ **Equation 2.3**

where $PRC_{RS}^{S}(t)$, $PRC_{RS}^{S}(t_0)$, $RRC_{RS}^{S}(t_0)$, $t_0$, $t$ and $t - t_0$ are the correction value extrapolated to the measurement time *t*; the received pseudorange correction; the received range rate correction, the pseudorange correction reference epoch, the user receiver measurement time; and the correction latency. The pseudorange of satellite *S* measured by the rover *R* – $PRM_{R}^{S}(t)$ – is corrected using Equation 2.4

$$PR_{R}^{S}(t) = PRM_{R}^{S}(t) + PRC_{RS}^{S}(t)$$ **Equation 2.4**

where $PR_{R}^{S}(t)$ is the differentially corrected pseudorange of satellite *S* [13].

## 2.3 Network based DGNSS

The need for multiple RS in DGNSS evolved from the continuous and growing demand for enhanced positioning quality. Single RS systems suffer from two main problems: they are rover-RS distance-dependent (as the distance between rover and RS grows, the quality of the corrections degrades) and very sensitive to RS measurement errors (any RS error is automatically reproduced in all rover measurements). One way to mitigate these problems is to implement a network of multiple RS and, instead of applying the corrections from just one RS, use the corrections from the RS surrounding the rover. This approach reduces not only distance-dependent errors but also minimizes the measurement errors of the receivers [10]. As a result, network based differential systems provide increased accuracy, integrity, availability and reliability when compared to single RS solutions.

Multiple RS networks use three main algorithms to generate network based differential corrections: the measurement domain, the position domain and the state-space domain algorithms [1].

The measurement domain algorithms perform a weighted mean of the scalar correction data (e.g., code pseudorange and range rate corrections) from several RS to create a DGNSS network solution [6]. These differential systems require a high density of RS since the quality of the corrections degrade as the users moves away from the various RS centroid. They are called local area augmentation systems.

The position domain algorithms first compute the different DGNSS position solutions obtained from each of the available differential corrections and then calculate a weighted mean of the individual position solutions [1].

The state-space domain algorithms use multiple RS equipped with dual frequency receivers and complex software to generate highly accurate corrections. These algorithms model separately the individual error sources that affect the differential positioning quality. This modelling includes not only the GNSS error sources (signal propagation errors and satellite-dependent errors), but also the receiver error sources. Users receive the satellite clock corrections, satellite ephemeris corrections and ionospheric corrections in separate components and are expected to integrate them with the locally measured data. These differential systems require a much lower density of RS and are called wide area augmentation systems.

### 2.3.1 Virtual Reference Station

Since real time DGNSS positioning accuracy depends on the distance between rover and RS, a new concept emerged – the Virtual Reference Station (VRS). The VRS algorithms simulate the existence of a reference station located at the rover’s approximate location. This approach requires: (i) the availability of multiple RS in the rover’s neighbourhood; (ii) to know the approximate location of each rover throughout the entire operation; and (iii) to know the exact coordinates of the RS locations. As a result, the VRS approach requires the establishment of a bi-directional data link between the VRS module and each client rover. It is through this connection that the rover conveys its whereabouts and the system communicates the customized pseudorange corrections. These customized correction messages are generated as if by a reference station located at the rover’s approximate location. Thus, the position-dependent errors are better modelled than when using a distant reference station.

### 2.3.2 GNSS Augmentation Systems

Augmentation systems, which enhance the accuracy, integrity, availability and continuity of service of the underlying GNSS[1], can be satellite based augmentation systems (SBAS) or ground based augmentation systems (GBAS). Both ground and satellite based systems rely on differential positioning to increase the positioning accuracy. While GBAS can be local, regional or nation-wide DGNSS supported by some network of RS, SBAS are wide-area systems supported by large terrestrial networks of RS deployed over the coverage area that use geostationary satellites to broadcast the wide area differential corrections. There are two main SBAS: (i) the Wide Area Augmentation System[2] (WAAS) from the USA that has been operating for aviation use since July 2003; and (ii) the European Geostationary Navigation Overlay System[3] (EGNOS) from the European Space Agency that is currently under certification process for commissioning. As far as accuracy is concerned, WAAS provides < 2 m in the horizontal and < 3 m in the vertical planes; EGNOS < 2 m horizontal and < 4 m vertical planes. All SBAS signal formats and message contents conform to the Radio Technical Commission for Aeronautics RTCA 229 standard [12], whose requirements were specified by the International Civil Aviation Organization. SBAS enabled receivers comply with the RTCA 229 standard.

When we started this project, EGNOS was in an early pre-operational phase.

## 2.4 DGNSS over the Internet

The idea of disseminating real time code based RTCM SC-104 corrections over the Internet is also addressed in [5], [15] and [16].

In 1999, W. Rupprecht[4] developed a DGPS data server called DGPSIP to disseminate DGPS data received through a radio interface from a USA Coast Guard base station transmitter. The DGPSIP is basically a multithreaded server that allows both unicast (TCP) and multicast (UDP) clients.

In 2000, we started a project intended to provide *campus*-wide real time access to Differential GPS (DGPS) data trough the Internet. In [15] we describe the three-layered distributed system and the frame-based protocol designed. The architecture separates the transportation over the Internet (from multiple remote RS to the *campus*) from the dissemination of real time RTCM SC-104 corrections within the *campus* intranet. The Internet transportation is achieved through unicast (TCP) connections and the dissemination through connectionless multicast (UDP). This approach does not allow direct connections between RS and end-users, avoiding possible RS server modules and network congestion. The frame-based

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[1] http://esamultimedia.esa.int/docs/egnos/estb/egnos_faq.htm

[2] http://gps.faa.gov/

[3] http://esamultimedia.esa.int/docs/egnos/estb/egnos_pro.htm

[4] http://www.wsrcc.com/wolfgang/gps/dgps-ip.html

protocol supports multiple RS operation and increased message control quality. The VRS module we present in this paper is a component of this system.

In 2001, the European Space Agency (ESA) undertook a new project called Signal-In-Space through the Internet (SISNET). The main objective was to provide access through the Internet to the wide-area differential corrections and the integrity information of EGNOS. Since February 2002, the system has been pre-operational, broadcasting an EGNOS-like signal through the Internet – the EGNOS System Test Bed (ESTB) signal. SISNET data is comprised of two sets: wide-area EGNOS correction messages in RTCA 229 format and text messages conveying additional information [16]. To apply the EGNOS messages directly to a receiver, it must be an EGNOS enabled receiver; otherwise, one must convert from RTCA 229 to RTCM SC-104 prior to send the corrections to the receiver.

In 2002, the European Reference Frame (EUREF), which is a Sub-Commission of the International Association of Geodesy, decided to set up and maintain a differential GNSS infrastructure on the Internet using the RS of its European GPS/GLONASS Permanent Network. The goal was to disseminate RTCM SC-104 corrections over the Internet in real time for precise differential positioning and navigation purposes. So, EUREF installed some DGNSS trial servers, which are connected to RS scattered over Europe, to provide real time RTCM SC-104 corrections through the Internet using the RTCM SC-104 protocol over TCP.

In 2003, EUREF developed a protocol called Networked Transport of RTCM SC-104 via Internet Protocol[5] (NTRIP) [5], which became in 2004 an RTCM standard for streaming GNSS data in real time over IP networks [14]. The NTRIP protocol defines also a three-layered replicable architecture. Nowadays, EUREF uses NTRIP to transport GNSS and DGNSS data in several formats (RTCM SC-104 messages, RTCA 229 messages and raw measurements) from hundredths of RS (located in Europe, America, Asia, Oceania and Africa) to anyone connected to the Internet. EUREF also supplies software applications for those who wish to access the real time GNSS and DGNSS data available.

## 3 Virtual Reference Station Module

The multiple reference station system described in [15] provides a real time code based differential service through the Internet. The application is a three-layered distributed application. The first layer represents the client applications (end-users connected to the Internet using Wi-Fi, GPRS, UMTS or Ethernet). The intermediate layer acts as a proxy: fetches data from the remote RS to disseminate among the first layer applications. The third layer – the servers of DGPS data located at the remote RS – acts as the data provider layer. The first and third layers are insulated. This approach prevents the potential congestion of the data source servers and allows the adoption of different transport protocols between the first and second layers and between the second and third layers. Furthermore, the data

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[5] http://igs.ifag.de/index_ntrip.htm

can be sent in frame mode or in raw mode. The byte stream mode, which is the default RS output mode, was kept for compatibility reasons, i.e., to serve existing DGPS client software applications. The frame mode, which was a novel transmission approach, supports the simultaneous operation of multiple RS and provides increased message quality control.

The VRS module is a component of this multiple reference station system. We use a measurement domain algorithm to generate in real time the VRS DGPS corrections. The message-combining algorithm implements a weighted mean inversely proportional to the RS-rover distance.

## 3.1 Architecture and Functionalities

The application, which is illustrated in Figure 3.1, consists of three main components: (i) an input data processing module, (ii) a shared memory block called blackboard and (iii) an output processing unit. The data input processing is performed in parallel, and for each data source, reads, decodes the incoming RTCM SC-104 messages and outputs the decoded messages to the blackboard. The blackboard module only allows asynchronous read, write and delete operations. The output processing, which is performed per rover, implements a distance-based linear interpolation method for combining the decoded parameters, encodes the combined values back to RTCM SC-104 and outputs the result to the rover.

The data stream from each data source requires independent processing since the decoding/encoding algorithm for each data source must be sequential, i.e., to decode a RTCM SC-104 data word one must use parameters from the previous word. As a result, the simultaneous data processing from the multiple sources requires a parallel approach. This is achieved by using a finite collection of threads. Each thread is capable of (i) inputting data from a remote DGPS data source or from a DGPS data file, (ii) decoding the DGPS data and (iii) writing the result into the data blackboard.

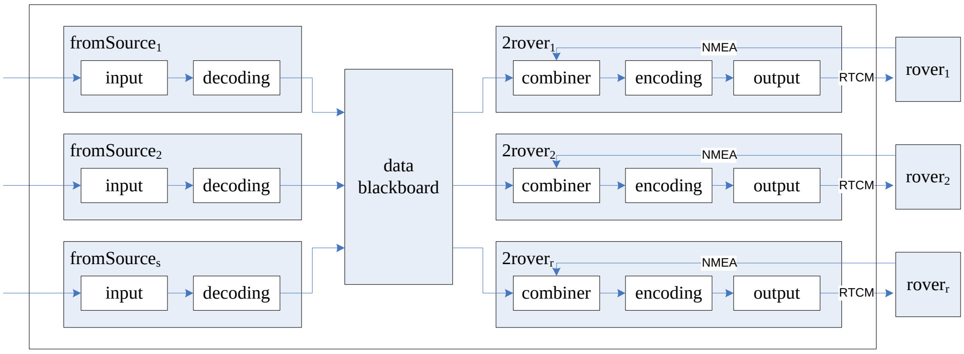

**Figure 3.1 – Architecture of the VRS module.**

The output streams, which are created for each rover, also require independent processing since the distance-based linear interpolation method depends on the rover's approximate location. As soon as the combiner modules detect a set of combinable messages at the blackboard, the creation of new messages is triggered. Each combiner unit applies the distance-based linear interpolation algorithm to the set of combinable messages and forwards the new RTCM SC-104 message to the encoding block, where it is encoded according to the GPS satellites signal specification algorithm [8]. Finally, the encoded message is sent to the rover.

The rovers are expected to send periodically to the combiner module their approximate location. This information is usually contained in a NMEA-0183 [11] GGA message type and consists of the geodetic coordinates of the rover. The geodetic coordinates must be converted into ECEF coordinates prior to be used. The combiner always uses the most recent coordinate set to perform the distance-based linear interpolation.

## 3.2 Measurement domain Algorithm

The combination block generates new RTCM SC-104 messages from the messages collected from all data sources. The RTCM SC-104 messages are combined according to their type and epoch. When combining messages with different reference epochs, the oldest data has to be extrapolated to the most recent data epoch beforehand. The scalar correction data is generated only for the satellites that are present in all RS messages. We chose to implement a measurement domain approach that calculates for each epoch a weighted mean of the corrections provided by the several stations. The distance-based linear interpolation method [3] calculates the weights to apply to the correction values generated by the different data sources. These weights are inversely proportional to the distance between rover *R* and data source *RS*.

First, for each rover *R* and reference station *RS*, the algorithm computes the coefficients to apply to the correction data using Equation 3.1 and Equation 3.2

$$w_{R,RS} = \frac{1}{d_{R,RS}} \quad ; \quad w_R = \sum_{RS=1}^{n} w_{R,RS}$$ **Equation 3.1**

$$c_{R,RS} = \frac{w_{R,RS}}{w_R} \quad ; \quad \sum_{RS=1}^{n} c_{R,RS} = 1$$ **Equation 3.2**

where *n*, $d_{R,RS}$ and $c_{R,RS}$ are the number of reference stations; the distance between reference station *RS* and rover *R*; and the coefficient to apply to the corrections from reference station *RS*.

Next, it uses Equation 3.3 and Equation 3.4 to determine the VRS pseudorange correction with reference epoch $t_0$ for satellite *S*,

$$PRC^{S}_{R,RS}(t_0) = c_{R,RS} \times PRC^{S}_{RS}(t_0)$$ **Equation 3.3**

$$PRC^{S}_{R}(t_0) = \sum_{RS=1}^{n} PRC^{Si}_{R,RS}(t_0)$$ **Equation 3.4**

where $n$, $c_{R,RS}$, $PRC_{RS}^{S}(t_0)$, $PRC_{R,RS}^{S}(t_0)$ and $PRC_{R}^{S}(t_0)$ are the number of reference stations; the coefficient to apply to the corrections of station *RS*; the reference station *RS* pseudorange correction for satellite *S*; the contribution of reference station *RS* to the pseudorange correction of rover *R*; and the VRS pseudorange correction for satellite *S* and rover *R*.

## 4 Discussion

We enhanced a code based multiple reference station differential system with a virtual reference station realisation. Our measurement domain approach combines standard and precise pseudorange corrections for the common satellites tracked by all RS. Successful tests concerning decoding/encoding RTCM SC-104 messages and the message-combining algorithm using multiple data sources (we used our RS as well as some EUREF RS) were performed. In these tests we combined both standard and precise pseudorange RTCM SC-104 messages (message types 1 and 21). Currently, we are committed to determine the positioning accuracy of our VRS code based DGPS system and to refine of our algorithms.

So far, all our results indicate that it is viable to implement a differential VRS positioning system exclusively supported by Internet data links. This statement is backed by the results presented in [15]. There, we showed that the operation of a real time DGPS network through the Internet is successful – the average communication latency is bellow 2 s.

Our ultimate goal – the development of a tracking system for mobile platforms – poses additional challenges. The idea is to adopt a surveillance mode approach. In this mode, the rovers communicate their approximate location and raw measurements to the tracking platform. Finally, the platform computes the differential position solution for each rover using the corrections provided by the described VRS differential system. To further improve our positioning accuracy, we plan to apply real time ionospheric corrections from SISNET.

## References

[1] Abousalem, M., Lusin, S., Tubatin, O., Sala, J. (2000) “Performance Analysis of GPS Positioning Using WAAS and EGNOS”, Proceedings of GNSS 2000 – Global Navigation Satellite Systems Conference, Royal Institute of Navigation.

[2] Batchelor, A., Ochieng, W. Y., Vooght, A. E. (1996) “Design Features of D-GNSS Reference Stations”, Fifth International Conference on Satellite Systems for Mobile Communications, London.

[3] Dai, L., Han, S. *et al.* (2003) “Comparison of Interpolation Algorithms in Network-Based GPS Techniques”, Navigation, Journal of the Institute of Navigation, N. 4, Vol. 50.

[4] Department of Defense, Department of Transportation (2001) “2001 Federal Radionavigation Plan”, United States Government.

[5] EUREF (2003) “Networked Transport of RTCM via Internet Protocol – NTRIP”, Version 1.0. Published by Federal Agency for Cartography and Geodesy (BKG). Available at http://igs.ifag.de/index_ntrip.htm.

[6] Hofmann-Wellenhof, B., Legat, K., Wieser, M. (2003) “Navigation – Principles of Positioning and Guidance”, Springer-Verlag.

[7] Hofmann-Wellenhof, B., Lichtenegger, H., Collins, J. (2001) “Global Positioning System – Theory and Practice”, Fifth, revised edition, Springer-Verlag.

[8] Joint Department of Defense and Department of Transportation (2001) “Review of the Global Positioning System Standard Positioning Service Signal Specification”, DoD, USA.

[9] Kee, C., Parkinson, B. W., Axelrad, P. (1991) “Wide Area Differential GPS”, Navigation, Journal of the Institute of Navigation, Vol. 38, N. 2.

[10] Lapucha, D., Huff, M. (1993) “Multisite Real-Time DGPS System Using Satellite Data Link: Operational Results”, Navigation, Journal of the Institute of Navigation, Vol. 40, N. 3.

[11] National Marine Electronics Association (1992) “NMEA 0183 Standard for Interfacing Marine Electronic Devices”, Version 2.00.

[12] Radio Technical Commission for Aeronautics Special Committee 159 (2001) “RTCA DO-229C, Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment”.

[13] Radio Technical Commission for Maritime Services Special Committee 104 (2001) “RTCM SC-104, Recommended Standards for Differential Navstar GPS Service”, Version 2.3.

[14] Radio Technical Commission for Maritime Services Special Committee 104 (2004) “RTCM SC-104, Recommended Standards for Networked Transport of RTCM via Internet Protocol (NTRIP)”, Version 1.0.

[15] Soares, M. G., Malheiro, B., Restivo, F. J. (2004) “Evaluation of a Real Time DGPS Data Server”, Proceedings of the First International European Conference on the Use of Modern Information and Communication Technologies (ECUMICT’2004), Gent, Belgium.

[16] Torán, F., Ventura-Traveset, J. (2002) “SISNET, User Interface Document”, European Space Agency, GNSS-1 Project Office.

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