The 9th International Conference "ENVIRONMENTAL ENGINEERING"
22–23 May 2014, Vilnius, Lithuania
SELECTED PAPERS
eISSN 2029-7092 / eISBN 978-609-457-640-9
Available online at *http://enviro.vgtu.lt*

Section: Technologies of Geodesy and Cadastre

GNSS reference network real-time service control techniques

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Abstract

Differential corrections and services for real-time kinematic method (RTK) in many cases are often used for official activity. For that reason, services which allow to perform precise GNSS measurements should be constantly monitored to minimize the risk of any errors or unexpected gaps in observations. Additionally, all users should be provided with information on actual status of the system, containing possible accuracy available on each survey epoch. System providing such control is the subject of the work carried out under the grant no. NR09-0010-10/2010 conducted by the Military University of Technology. This study has been made to develop the concept of monitoring real-time services of Polish reference network ASG-EUPOS and the implementation of software providing users with information on system accuracy. The main objectives of all concepts were: maximum use of existing infrastructure, while minimizing the cost of installation of new elements, as well as providing users with calculation results via website. Furthermore, the concept assumes openness of the module which allows successive development of applications and integration with existing solutions. This paper presents several solutions and algorithms which have been implemented and tested. There are also some examples of data visualization methods included.

Keywords: GNSS; VRS; RTK; monitoring; reference network.

1. Introduction

The ASG-EUPOS is a system ensuring stable and uniform reference frame in Poland [1]. It is a part of unified system for precise positioning called EUPOS which involves countries from Central and Eastern Europe. One of the main tasks of ASG-EUPOS network is to support precise positioning using GNSS observations for measurements in real time (RTK or DGNSS) and in post-processing. It is a basic horizontal geodetic network of the country and it provides services for position determination using satellite observations, including services, such as VRS or MAC, to perform differential measurements in real time at the accuracy level of few centimeters [2–3]. Also, the system may constitute a base for building own applications for user, using the positioning or navigation functions. Differential corrections and services for real-time kinematic method (RTK) in many cases are used to support surveys, which are used as a base for administrative decisions. Therefore, services which allow to perform GNSS measurements should be constantly monitored to minimize the risk of any errors or unexpected gaps in observations. In existing networks, process of generation and distribution of corrections is done by the firmware supplied by the company which created the network or is not executed at all. Importance of real-time services and the problems that are associated with them, make crucial to ensure additional controls that provide users with high quality information about the availability and the expected accuracy of a particular service. System providing such control was the subject of the work carried out under the grant no. NR09-0010-10/2010 conducted by the Military University of Technology. This article describes the developed concepts of monitoring real-time services of ASG-EUPOS system, their advantages and disadvantages. As a crucial part of the paper, algorithms and sample results of concepts are presented.

2. Concept

In order to develop optimal methods for real-time monitoring services of ASG-EUPOS, the following criteria were assumed:

- The solution should use maximum elements of the existing infrastructure with minimizing the installation cost of the new components.

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http://dx.doi.org/10.3846/enviro.2014.230

– ASG-EUPOS users should be informed about actual accuracy of the controlled services via system website or other dedicated utility.
– Developed modules should be characterized by an open architecture, which allows successive development of applications.
– Possibility of integration of ASG-EUPOS with other commercial systems.

The control module will include only solutions designated for stations that do not have satellites visibility limitations. Therefore, the data in the form of expected accuracy of the method may be different from the actual data received by users of the system working with partially obscured horizon. In addition, due to the minimal use of differential correction in post-processing, the whole development has been focused on the kinematic method.

Monitoring the real-time service (RT) can be performed with one of the following three methods or, according to the adopted configuration, these methods can be used complementarily:
– Option 1: determining the accuracy of ASG-EUPOS services using a subnetwork of independent receivers.
– Option 2: using external software, which performs independently and determines the position of the RTK technology using the existing physical infrastructure of CORS stations.
– Option 3: hardware solutions based on standard receivers, installed on in? the system and in tandem with the essential functions of ASG-EUPOS. This option, however, requires switching of operation modes, which will be described in chapter 3 and can be a problem in a technical sense.

3. Method using physical stations

This method is based on GNSS receivers subnetworks that do not participate in the real-time services of ASG-EUPOS (Fig. 1). According to the information given on the ASG-EUPOS website (www.asgeupos.pl), the following stations: CBKA, ELBL, OLST, POZN, WLAD do not participate in generating the corrections. This information is crucial in order to preserve the independence of the control service of the system generating GNSS corrections and virtual observations. In addition, when ASG-EUPOS system will be expanded, the main goal should be to set up the subnetwork that would be control element of reference stations and real-time services. Moreover, it could be used for monitoring RTCA service from EGNOS. Control module for ASG-EUPOS not necessarily has to be based only on building a separate system of the station. Alternative way is to create a system which extracts data from the receivers currently operating as corporate networks, created independently of ASG-EUPOS. Additionally, in this variant it is possible to use a single permanent station, which is maintained by different companies, such as supervising the work of mining etc. Such solutions require only appropriate arrangements with the managers of these systems and the separation of data streams for control measures.

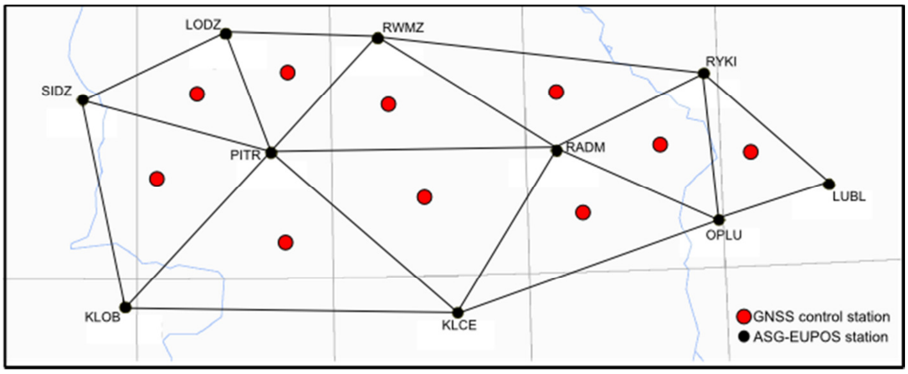

Fig. 1. Example of physical control stations locations

In case of obtaining data from GNSS receivers operating independently, the created control module is shown in the Figure 2. In this solution the following configuration was adopted:
– Monitoring receiver must be able to receive data in the RTCM format and determine position using the data from the VRS/MAC format.
– Data from the services, which is used by the internal software to calculate the position and to send the result to computational center in the NMEA format, will be delivered to the receiver.

Described method is implemented in two variants (Fig. 2). In the first case (blue arrows) control receivers are used in RTK mode. Corrections in the RTCM format are sent to the receiver from one of the selected service. Receiver determines the RTK position (based on observation and corrections) using built-in software and sends it in NMEA format to the control centre. Subsequently, its position is compared to the real value, which is determined on the basis of long-term observation, developed by the EPN Local Analysis Centre in MUT [5]. Finally, the average error is specified. System user receives a general information about selected service and its expected accuracy in the triangle. The first variant is possible only if the control receiver does not work as the reference for RTK receivers. This is due to the fact that most of the receivers, such as the Trimble NetR9, are not operating in RTK mode, while generating the data in the RTCM format.

In order to solve this problem, the second variant was applied (red arrows). In this solution, data are collected both from real-time ASG-EUPOS service and from the control receiver.

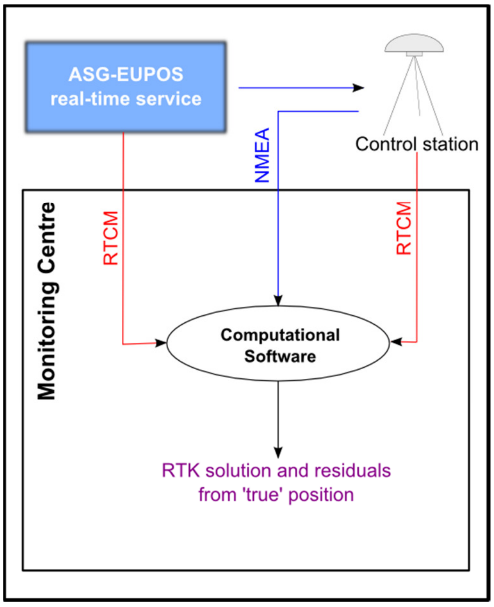

Fig. 2. Control method using physical station implementation schema

The advantage of the above concept is a possibility to carry out a full independent control of the offered services, and the ability to simultaneously monitor many of them (using a variant with an external program). However, this concept is highly expensive due to the need of installing a dense network of new GNSS receivers such arranged, that at least one new receiver is located in any triangle of the ASG-EUPOS reference stations as is shown on Figure 1.

Control solution based on observational data streams forming RTK correction in the ASG-EUPOS by definition does not have full independence. The correlations that exist when improvements and models are generated by the system software does not allow fully independent verification of the results obtained with different services. On the other hand, use of existing network infrastructure and distribution system greatly reduces the financial aspect of the implementation of system. Therefore, the developed concept assumed significantly worse conditions than those which are used by the users of RTK correction. Additionally, it was assumed that during the operation of the monitoring system actual relationship between user error and the errors indicated by the system will be examined. On top of that, map of the surface errors distribution will be created. The main element of this method is an external application, executing coordinates in real time on the basis of the data sent directly from the ASG-EUPOS system. Diagram of the control system for this variant is shown in Figure 3.

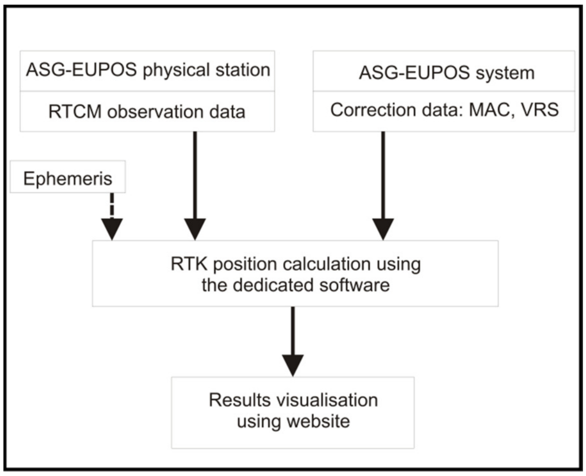

Fig. 3. Scheme of control solution using dedicated software

Presented diagram (Fig. 3) is based on the assumption that the data supplied to the control module are streams from a single physical station. Because the RTK correction determination involves several stations (Real Time Network) choice of a particular control point is representative of the group of 4 to 6 CORS stations. Item marked with the broken line is an optional part of the module, which can be omitted if the RTCM (v.3.x) contains records 1019 and 1020 with ephemerides data [4].

4. Method using virtual stations

Raw data generated for virtual point by ASG-EUPOS system not only is used for real time process but also it could be used for static survey. For that reason, accuracy assessment of VRS data is one of the main elements of designing monitoring system. Control method is based on virtual triangle network, which part is shown in the Figure 4.

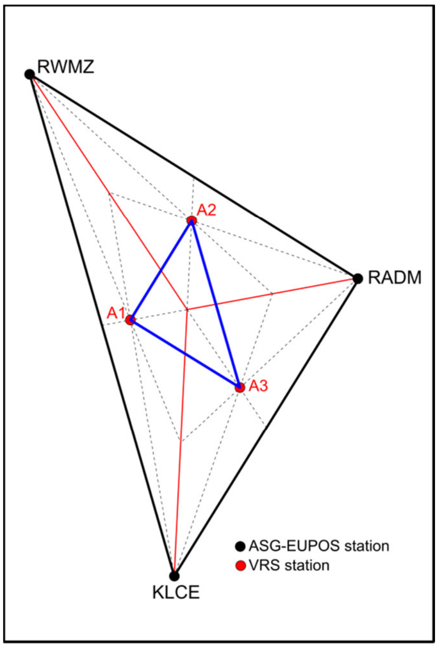

Fig. 4. Location of virtual control stations (red dots) and vectors for calculation (blue lines)

Each triangle in the ASG-EUPOS is divided into three smaller triangles (Fig. 4) using the center of gravity. Afterwards, the coordinates of the three points, which are the centers of gravity of small triangles are determined. These coordinates are sent by the NMEA GGA frame to the ASG-EUPOS using the developed NTRIP client. In the response, a corrections in the RTCM 2.3 or 3.1 format (depending on the service) are received. The first step of control is to determine, whether the coordinates generated by the VRS service agree with the sent values. For this purpose, developed software checks the RTCM header. In case of a failure, the algorithm immediately returns an error that the VRS system is not working properly. Provided that everything is correct, the next step is to calculate the vector between the VRS points (for example A1 and A2) using RTK method and compare the determined value with the theoretical value. The whole process is conducted using dedicated software developed by Centre of Applied of Geomatics. Operational schema is shown in the Figure 5.

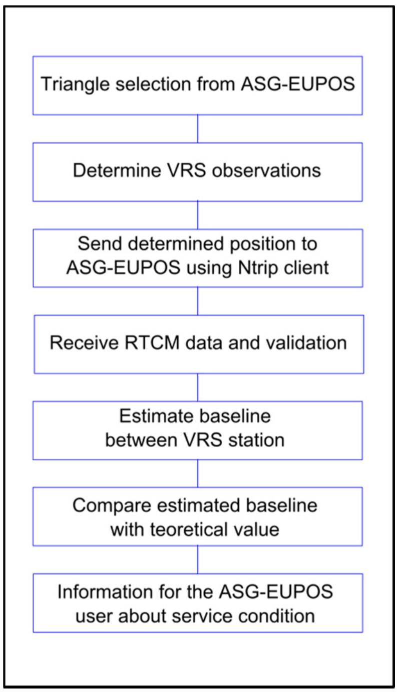

Fig. 5. Operational schema for control method using virtual stations

5. GNSS receiver test

Methods described above assume that the receiver should output raw data and process RTK services simultaneously. To confirm technical capabilities of such solution some test were conducted. The main goal of these tests was to determine whether the GNSS receivers are able to transfer the observation data and to determine the position in the RTK method simultaneously. For this purpose, receivers which are part of the ASG-EUPOS are selected for the test (e.g. TrimbleNetR9, Leica Viva GS15 and Leica GRX1200). All receivers have at least two serial ports with simulcasting, which is basic criteria that has to be fulfilled. During the tests the RTK correction data from ASG-EUPOS system was supplied to the receiver through the cable connection. In test, the RTKLIB [6] software was used for verification of incoming result from receivers in NMEA format. Tested receivers were set in two modes: as a rover or as a base station with RTCM output. In the first case all receivers to which the correction stream in RTCM was delivered, calculated the position in RTK mode and send the results in the NMEA GGA format properly. The problem appeared when a base station mode was set up with RTCM stream output option. The receiver was unable to calculate both the position in precise mode and output position determined by single point positioning method. It means, that receivers which are the base stations and send observation by RTCM cannot perform a control function. The obtained results showed the need to develop special software based on the observation from the station which will independently determine the position in RTK mode. This software has been developed and included in the monitoring system

6. The system structure

The main task of developed monitoring software is to evaluate coordinates using RTK data regardless of any firmware. This software provides solution of determining user position accuracy, based on data generated by ASG-EUOPS. Additionally, such system could process data in a variety of process models.

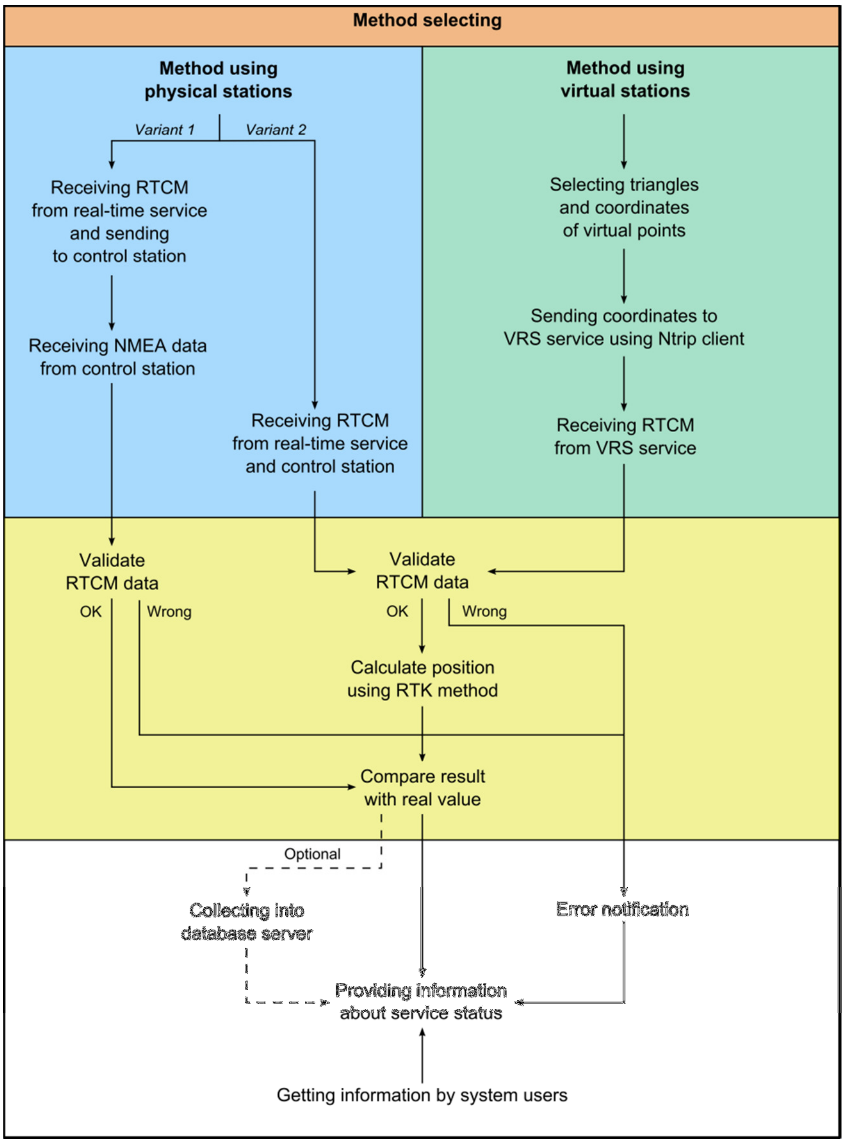

Fig. 6. Schema of monitoring system structure

The real-time monitoring ASG-EUPOS services system is composed of several intertwined elements shown in Figure 6. The most important of these is the developed software, which is responsible for receiving, processing, performing calculations and managing the entire process of monitoring. At first, the application receives the data in one of the two formats, RTCM or NMEA. The appropriate format is dependent on the selected method. If physical stations are used (which are not the reference stations at the same time), the application receives data in the NMEA format, which contain the coordinates calculated by the station receivers using an internal RTK algorithm. Otherwise, a stream in the RTCM format is received from both ASG-EUPOS and control stations. A similar situation occurs when the method with virtual station is used. In this case software receives a stream for VRS points directly from the ASG-EUPOS which are sent in RTCM 2.3 or 3.0 version (depending on the service used). In the first variant, the software receives the fixed coordinates so the only task is to compare the solution with the real value. In the second variant it is necessary to calculate the position of control or virtual stations with RTK method. This function is also developed in the software. Regardless of the method, all the results can be archived on a database server for future analysis. This is, however, an optional functionality. The real-time services users shall be provided with the information about the current service's status in the first place. The last element of the system is to provide users of the system with data, what will be achieved using the website.

7. Results

The results of the developed system are presented in Figure 7. Tests were carried out on commercial VRSnet.pl network which belongs to the company Geotronics Polska. The real time service offering VRS correction was controlled. Figure 7 presents the map locating the VRSnet.pl stations and monitoring results. The baseline inside the triangle shows accuracy of generated VRS observation. The green color of a baseline indicates that the value was fixed in a given epoch and the red one is for float value or others. Also, the time series of the selected vectors calculated in the developed software are present. The triangle color shows general expected accuracy of RTK solution.

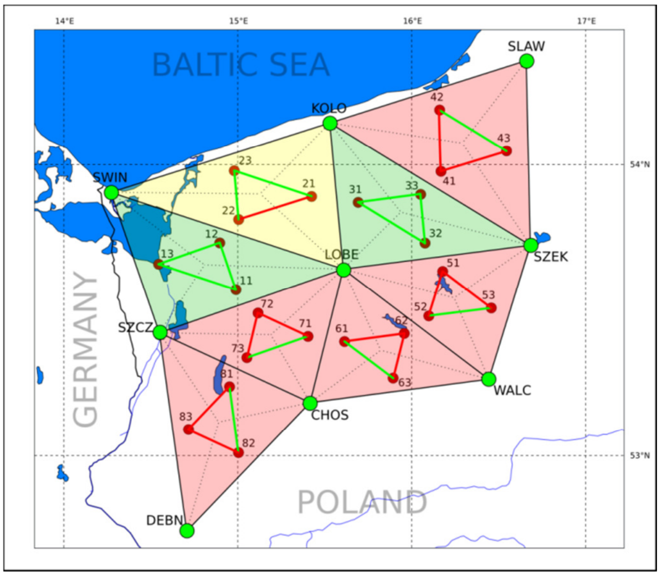

Fig. 7. Example results for VRSnet.pl network.

8. Summary

The advantage of the first method is to conduct a fully independent control of offered services and the ability to simultaneously monitor many of them (using a variant with the external software). However, it requires a large budget that is necessary to install a dense network of new GNSS receivers. In the cheaper solution a network belonging to commercial companies would be used. In this method, the physical RTK receivers are replaced by virtual ones. This solution reduces potential costs of implementing, but unfortunately the retrieved data in a VRS format are strongly correlated with each other, which makes obtaining a fully independent control impossible. Therefore, it was decided to use a three points in each triangle to verify the results.

Acknowledgements

This research was a part of the project financed by the Polish Ministry of Science and Higher Education, grant no. NR09-0010-10/2010. The research was supported and by the Faculty of Civil Engineering and Geodesy of the MUT statutory research funds. Special thanks to the Geotronics Polska company for providing data for testing.

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