SERVIR: The Portuguese Army CORS Network for RTK

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ABSTRACT

Traditionally the Portuguese Army Geographic Institute (IGeoE) used, for different surveying applications, GNSS RTK (Real Time Kinematic) equipments operating in single base station positioning mode. This mode of RTK operation has several limitations, mostly related with the decrease of accuracy when the distance between the base station and the rover increases and the need of additional human resources.

To minimize these problems, the IGeoE has been implementing in Portugal since the end of 2005 a GNSS network of reference stations for RTK using the VRS (Virtual Reference Station) method.

During this period several Positional Quality Control tests were made in order to evaluate if the needs of the clients were met and also to determine the quality of the positioning obtained using different equipments.

The tests that were made with this CORS network included an assessment of accuracy, by computing differences between the measured and the known coordinates of the same point.

This article describes the main phases of the tests that were made concerning the Positional Quality Control of the positioning methods referred above.

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INTRODUCTION

The 1:25000 military maps are the only ones covering the entire Portuguese territory and always served its engineer corps and the country. The Portuguese Army Geographic Institute (IGeoE) finished recently the acquisition of all the geographic information in digital format and is now concerned with the update of such information. For institutions like IGEoE, it is mandatory to have these update cycles performed as fast as possible, so that the needs of our customers, both military and civilian, can be fulfilled. To achieve this objective it is also essential that the way the geographic data are collected must be up-to-date with the latest technology available.

One of the phases of the production process, the survey support, represents an enormous time consuming task. The fastest way to have 3D coordinates of points, either for photogrametric methods, for quality control objectives, or any other purpose, was achieved using the Single Base Station (SBS) Real-Time Kinematic (RTK) technique. However, the limitations of this technique represented a serious obstacle to fulfill our goal of having up-to-date geographic data available to our costumers demands.

The need of the SERVIR (VIRtual GNSS Reference Stations System) project became evident when we realized that the survey support was to slow and the human, material and financial resources were too high. We needed something more efficient.

This SERVIR project was conducted by IGeoE and it uses the communications network of the Portuguese Armed Forces, under the supervision of the SICOM (Communications Integrated System of the Armed Forces) and the Signal Regiment. One of the keys of the success of the project is the optimization of the existing network infrastructure, which has also high reliability. It is possible to reduce almost to zero the amount spent in communications between the reference stations and the servers in the computation center. In order to take advantage of this fact, most of the reference stations are installed in military facilities, because they have a network point of access and ensure the needed security of equipments. A cooperation with the Faculty of Sciences of the University of Lisbon has also been established since the beginning of the project.

The SERVIR network has presently 25 stations spread throughout Portugal mainland, as shown Figure 1.

Single Base Station Real Time Kinematic vs Network Real Time Kinematic

The RTK methodology is based in the concept that the errors that affect the GPS computation of the absolute position are the same within a certain geographic area. Those errors are mainly due to the effects of the ionosphere, neutral atmosphere, satellite orbits, satellite and receiver clocks, and geometry of the GPS constellation. Under these conditions the coordinates measured in absolute mode may vary from 1 m to 10 m. If a GPS receiver, usually called Reference Station or Base, is set up in a point with known coordinates (a 3D control point for instance), one can compare these known coordinates with the coordinates that are being computed at each instant. Using this methodology, the receiver computes differential corrections that are send, using a radio modem, to other receivers, usually known as rovers. With those corrections the rover receiver can compute more accurate coordinates.
The Differential GPS (DGPS) technique uses this real time positioning process to apply corrections to pseudo-ranges with accuracy of 1 m, whereas the RTK positioning uses phase corrections, in order to obtain accuracies at the centimeter level.
The Single Base Station RTK technique has, however, some operational limitations. Some of them are:

- The distance between the base and the rover(s) must be less than 10 km (Rizos, 2003);
- It is necessary, at least, 2 GPS receivers with radio equipment to transmit the differential corrections;
- Two survey teams are needed, one to operate the base receiver and other to operate the rover;
- The accuracy degrades as the rover stands away from the base;
- Possibility of radio interferences from other radio equipments operating in the area;
- Radio signal propagation problems due to natural and/or artificial obstacles.

To avoid these limitations, the RTK network technique uses several GPS or GNSS reference stations working together in a network environment. These stations are placed in points of known and accurate coordinates. Through the continuous processing of GNSS observations, it is possible to model the systematic errors in a certain geographic area and to reduce their influence. Moreover when compared with the SBS technique, we can have a much larger area without degradation of the coordinates of the rovers and a much lower initialization time.

VIRTUAL REFERENCE STATION (VRS) CONCEPT

The VRS concept is based in a network of permanent reference stations (CORS – Continuous Operation Reference Station) connected through a communications system to a Control Center

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The data from the reference stations are transferred to the Server in the Control Center. Based in the available information, the Server computes the errors due to neutral atmosphere, ephemeris and clocks and ambiguities both to L1 and L2 carriers.
A rover receiver working in a certain area establishes a two-way connection with the Control Center, using a cellular phone by Global System for Mobile Communications (GSM) or General Packet Radio Service (GPRS), and sends its position, in absolute mode, to the

Control Center using a standard NMEA (The National Marine Electronics Association) message in GGA (Global Positioning System Fixed Data) format.

The Control Center receives the NMEA message, computes corrections and sends to the rover these corrections using the RTCM (The Radio Technical Commission for Maritime Services) or CMR (Compact Measurement Record) format. When the Rover receives these corrections, it computes a new solution in DGPS mode. This solution has now an accuracy of about 1 m. This new position is sent again to the Control Center, which computes new corrections that are sent to the rover. The computed corrections are calculated not to the true position of the rover but to a virtual position in a close neighborhood of the Rover position. This virtual position is called Virtual Reference Station and gives the name to this technique. Because the system has a network solution to each point under the reference station influence, it uses all the available information from all the stations to compute the solution.
Mathematically, the software uses a special interpolation technique which includes a least-squares adjustment and a heavy linear approximation.

THE SERVIR REFERENCE STATIONS

The SERVIR network has presently 25 stations spread throughout Portugal mainland, as shown Figure 1.

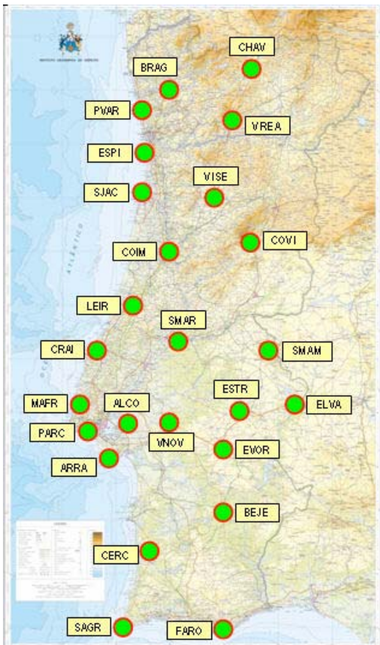

Figure 1 – SERVIR network

With the exception of COVI, all the stations are located in Army, Air Force or Navy facilities. This fact has evident benefits: the security of equipments and the possibility of using Portuguese Armed Forces internal communications network which is very reliable and has latency times that are extremely low. Typically a reference station has the following components:

- GNSS antenna Trimble Zephyr Geodetic;
- Receiver Net R5 or RS;
- Emergency power supply.

NETWORK ARCHITECTURE

The network architecture of the project was designed in such a way that security, reliability and operation speed is always assured. Through the simultaneous operation of two different computation servers (named RTKNet1 and RTKNet2), it is possible to guarantee the premises referred above. Thus, if a problem happens with one computation server, the other one has the capacity to replace it in a way that the service is always available. The system has the possibility of 50 simultaneous user connections.

Those servers are also responsible for the following tasks:

- Quality verification of the data observed and transferred from each reference station;
- Validation of the RINEX files stored before those files are available to the clients;
- Correction of the center phase of the GNSS antennas;
- Estimation and modeling of the ionospheric, tropospheric and ephemeries errors;
- Preparation of the RTCM (2.3 or 3.0)/ CMR (or CMR+) messages to be send to the users.

The computer named SPLITTER is responsible for the communication between the control center and the reference stations, ensuring that all the GNSS observations from those stations are received by the computation computers. It is possible, using this computer, to remotely control the stations and change some of the settings.

The communication with the users is guaranteed through a fourth computer named WebServer. In this machine is also hosted a web page (that is used as an interface with the client) and a database (where data related with data access permissions to the clients is stored).

To establish a connection to the network there are some possibilities:

- Using a radio. This service is available only to military units. The differential corrections for RTK positioning are send to users using a radio modem;
- Using GSM for RTK positioning, but only if the Web Server computer fails. In this case the communication is assured by eight GSM modems directly connected to the computation computers. However this possibility is more expensive that the GPRS option and it is not possible to know who is using the network. It is only possible to know the phone number dialing. For commercial purposes it is much more complex to manage the network in this environment;
- Using GPRS through the NTRIP protocol. This is the cheapest way for a client to have RTK corrections. In terms of management of the network, this is also a better solution, as it is possible to know the client, when he establishes a connection;

- By HTTP (Hyper Text Transfer Protocol) allowing users to download of RINEX files from the Web page. The number of hits is controlled by the username and passwords that the client must type before logging in;
- By FTP (File Transfer Protocol) only available for large amount of data. This option raises some security problems related with the ports that must be open through the firewall.
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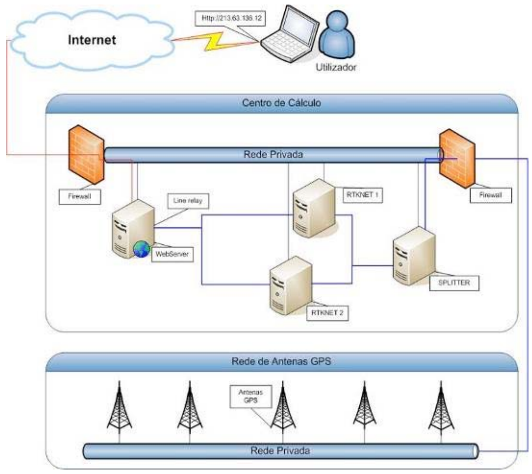

Available services

The services that are available are (http://213.63.136.12):
- DGPS. The differential corrections are available using RTCM 2.3 format message;
- RTK. The differential corrections are available in CMR, CMR+, RTCM 2.3 and RTCM 3.0 format messages;
- RINEX files. Download available through the web page. It is possible the download of the RINEX files of the reference stations or create a VRS station in the neighborhood of the point we want to process and the system creates RINEX files to that VRS position.

QUALITY CONTROL

In RTK mode

Since April 2006 that the reference stations have coordinates referred to the International Terrestrial Reference Frame 2000 (ITRF2000), epoch 2006,16.
Once implemented the network, it was necessary to evaluate how it was working and what kind of accuracy is expected when using the differential corrections in RTK mode. The methodology that was adopted to perform the tests was the following:
- Test involving the longest baseline connecting two reference stations. This baseline was 68 km long and represents the worst situation;
- Tests in the middle of the baseline, and transverse to the direction of the baseline, by choosing 3D control points at 5, 10, 15 and 20 km, both inside and outside the network;
- For each of these points, perform 3 hours observations sessions in static mode, in order to derive their positions ITRF2000 (epoch 2006,16), to be used as ground-truth coordinates;

- Measurement of the same points using a Rover Trimble GNSS R8 with the corrections received from the network and the RTK SBS technique;
- Compare the coordinates from the same point using both techniques with the fixed coordinates and the compute the differences between them.

The first conclusion we had was that more tests needed to be done. However it was possible to have a first idea of how the network was working. We realized that the RTK-network technique is more precise than the RTK-SBS technique and the accuracy is better than 5 cm both inside the network and outside the, up to 15 km distance from the baseline.
Another field test was made, independent from the previous, in another location, inside the network, to confirm the values of accuracy we had and to measure the time needed to measure the coordinates of a point.

In the top of the IGeoE building there is a point of known coordinates in ITRF2000, epoch 2006,16 (IGeoE station). As before, we used a Trimble GNSS R8 receiver, a Leica GPS1200 receiver and a stop-watch. In 2 different days, in the morning and in the afternoon of each day, we made 100 measurements. In each measurement were registered the coordinates and the time since the moment of the beginning of the GPRS connection until the rover is fixed and ready to measure coordinates. The tests confirmed the accuracy better than 5 cm with both receivers and the initialization time is less than 30 seconds.
New tests will be made as soon as all the reference stations will be set up and the network processed all together in a new reference frame.

In DGPS mode

In the same IGeoE station above a new test in DGPS mode was carried out. Again the objective was to realize the accuracy we had when using the corrections from the network and the time since the beginning of the connection until the receiver is ready to measure the coordinates. It was used a Trimble GeoExplorer XH normally used in Geographic Information System (GIS) field work. We measured the coordinates from the point using the network corrections and the EGNOS corrections. After the measurements were made the coordinates from those two sources were compared with the “true” coordinates of the point. The results are shown in the table 1. The initialization time is less than 30 seconds

Table 1 Mean differences between DGPS solutions obtained with the SERVIR network and EGNOS, for the IGeoE station

	Horizontal (m)	**Vertical (m)**
SERVIR	0,81	0,82
EGNOS	2,30	1,09

Users

In addition to the internal users, anyone who needs precise positioning can use the information available through the network. This means that a large variety of users are registered. From large construction companies to small surveying teams, from students to investigation centers or high-technology development companies, the users are diversified.
As March 2008, there are about 482 registered users either to RTK, DGPS or RINEX service. On a daily basis we have an average of 30 users for the RTK service. Monthly we have an average of 65 users. The message format which is more used is RTCM 3.0 followed by the CMR+. Table 2 summarizes the number and type of access. Based on those numbers we can say that the number of connections is increasing rapidly and exceeding our best perspectives.

			Number of connections by message format	
Months	**Number of users**	**Number of connections**	**RTCM 3.0**	**CMR+**
October 2007	14	88	26	30
November 2007	17	115	39	37
December 2007	15	80	37	19
January 2008	17	189	146	15
February 2008	20	126	66	19
March 2008	31	131	72	52

FUTURE EVOLUTIONS

It is planned the full coverage of Portugal mainland until the end of 2008, by installing three new reference stations. Afterwards, new coordinates will be computed to all stations in a new reference frame. At this time the network will be stable and it will be possible to perform new tests throughout the entire territory.

CONCLUSION

There are several applications that may take advantage of the SERVIR network. The services are available to everyone and the interoperability with all the surveying equipment is possible. The results of the tests that were carried out show that the accuracy of the positions, in RTK mode, is better than about 5 cm within the network, with identical levels of accuracy extending to up 15 km outside a base line. If DGPS technique is used, the accuracy of positions is about 80 cm.
To the IGeoE, the SERVIR network represents a great improvement in productivity (from an average of 8 points measured with the SBS RTK technique, it is now possible to measure 20 points per day) and reduction of the human effort. To the civil and scientific community, this network constitutes certainly one of the best continuous operation reference stations network of the Europe.

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BIOGRAPHICAL NOTES

António Afonso is the Chief of the Cartographic Production Center, Army Geographic Institute, Lisbon. He holds a degree in Geographic Engineering and a Master Degree in 2004.

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