Assessment of VRS performances of the Algerian-CORS-Network

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Abstract : The Algerian Continuously Operating Reference Stations Network, so-called AL-CORS-Net, is deployed to provide Network Real-Time Kinematic (NRTK) services based on Virtual Reference Station (VRS) method using Geo++GNSMART software. This paper investigates VRS performance in terms of precision, availability, integrity, Time-to-Fix-Ambiguity (TTFA), repeatability and PDOP. Several survey sessions were performed at different sites in the north of Algeria during October 2021 to January 2022. The results revealed good performance indicators. The precision was in the order of 1.3 cm in the horizontal component and about 2.2 cm in the vertical (at 1 sigma). The VRS solution's availability was 97.25%, its horizontal integrity was 98.8% and the vertical integrity was 94.9%. The TTFA ranged from a few seconds to a few minutes. The VRS measurements' repeatability presented similar measurement results throughout time.

Keywords : NRTK, AL-CORS-Net, VRS, performance, precision, integrity, availability, repeatability, TTFA, PDOP.

1. Introduction

The Network Real-Time Kinematic (NRTK) positioning concept is based on a network of GNSS reference stations connected to a Control Centre (CC) via data links. One or more servers at the CC continuously collect GNSS raw data streamed from all GNSS receivers. After processing, servers create real-time network models to mitigate GNSS errors such as ionosphere, troposphere and satellite orbits [1, 2]. The National Institute of Cartography and Remote Sensing (INCT-Algeria) deployed the Algerian Continuously Operating Reference Stations (CORS) Network, known as AL-CORS-Net. AL-CORS-Net is used to modernize the national geodetic infrastructure and to respond to the rising needs of different economic sectors in the field of precise navigation and positioning services. AL-CORS-Net consists of 189 GNSS stations that are evenly spaced out across the country ; it is subdivided considering its baseline lengths, into two networks : Northern and Southern (figure 1).

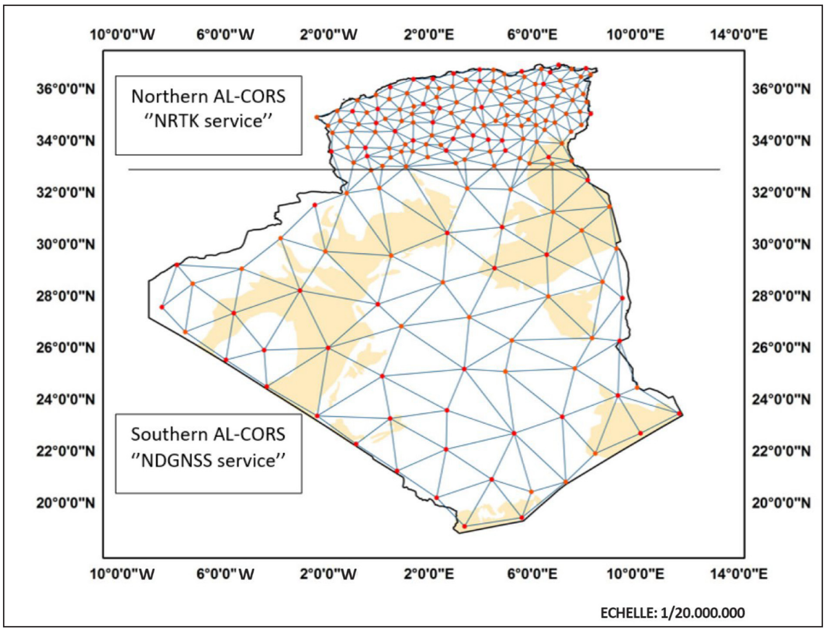

Fig. 1 Algerian CORS Network

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The northern part of AL-CORS is designed for NRTK service. It consists of 129 permanent GNSS stations with an interspacing of 30 km to 80 km. These GNSS stations continuously collect observations from GPS, GLONASS, and BeiDou satellites and transmit them to the Control Centre (CC) in real time. The observations are stored on an FTP server in order to make them available to different users as well as for future uses.

The GNSS Radio Technical Commission for Maritime Services(RTCM) streams from the CORS are processed at the CC using Geo++GNSMART software to provide NRTK corrections in different models such as FKP (Flächen Korrektur Parameter), MAC (Master Auxiliary Concept), and VRS (Virtual Reference Station) [2, 3].The latter are provided to users for working in real time, using RTCM 2.x and RTCM 3.x formats, via the VPN/3G/4G.

Several NRTK services based on different methods and using a variety of performance parameters were evaluated in the different countries in the world, such as : FinnRef network in Finland [4], LitPOS network in Lithuania [5], TERIA network in France [6] and Smart-Net in the United Kingdom [7]. In addition, The network RTK positioning performance based on BDS-3 new signal system was evaluated[8] ; The assessments of correction models in GNSS network based RTK positioning was performed [9], and performances of NRTK positioning system was studied in [2]. All the obtained results according to the precision criteria were at centimetre-level. In the other hand, we should note that a large part of ionospheric error could be modelled and removed in the network. However, during storms or ionospheric disturbances, large residual ionospheric errors remain, and that affect on the determination of the phase ambiguities and the performance of the network RTK [10].

The purpose of our paper is to assess the performance of the NRTK service yielded from the northern AL-CORS sub-network in terms of : precision, integrity, availability, repeatability, time to fix ambiguities (TTFA), and to understand how the different factors such as the number of satellites in view and their geometry, may affect the service as well.

This paper is structured as follows: we first present a review of the AL-CORS-Net infrastructure and operating in section (1). The concept of the VRS along with the related mathematical model is briefly introduced in section (2). In the section (3), we outline the test methodology and data collection for the assessment of the VRS performance. The results are discussed and assessed in section (4).

2. The VRS Concept

Using Geo++GNSMART software, the NRTK corrections are generated using the virtual reference station (VRS) approach. The concept of the VRS is to use the observables of multiple reference stations to produce the network corrections in the form of a virtual reference station at a nearby user's location (figure 2). The observation data from all the reference stations is first sent to the Control Centre, afterward this data is used to compute model errors to fix the carrier phase ambiguities between neighbouring reference stations. The information is interpolated over the entire area and is used to predict these errors at the user's location. A VRS is created at the user's approximate location, and corrections are sent to the users using RTCM messages [11, 12].

To construct the observations at the VRS, the VRS and the satellite known positions are firstly used to compute the range between the satellite and the VRS. Similarly, the range between the satellite and the master station is computed, where the master station is usually selected as the nearest CORS to the user [13].

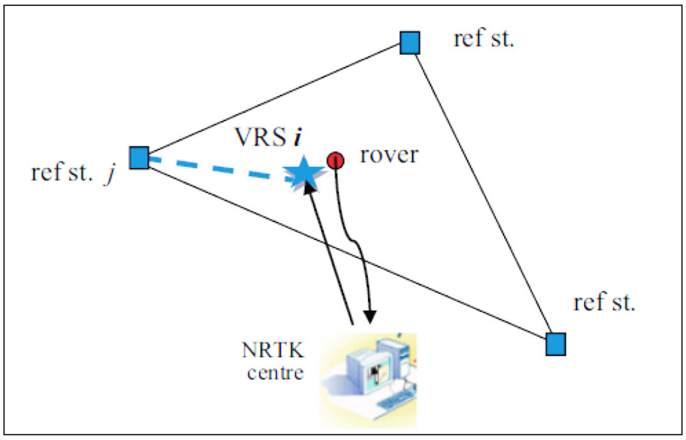

Fig. 2 The VRS concept [13]

The range difference between the VRS (point i) and master station (point j) with respect to satellite (s)reads (figure 2) [13].

$$\Delta R_{ij}^{s} = R_{j}^{s} - R_{i}^{s} \quad \textbf{(1)}$$

Where :

R_j^s ssatellite to VRS range

R_j^s ssatellite to the master station range

ΔR_{ij}^s srange difference

The interpolated distance-dependent errors, dispersive $\delta\Delta r_{ij_I}^s$ sand non-dispersive $\Delta r_{ij_o}^s$ or their total, at the VRS are added to the master station's observations to generate the VRS observations on a satellite by-satellite and epoch-by-epoch basis for L1 and L2 frequencies, such that :

$$\phi_{ij}^{s} = \phi_{i}^{s} + (\Delta R_{ij}^{s} - \delta\Delta r_{ij_I}^{s} + \delta\Delta r_{ij_o}^{s} + \Delta T_{ij}^{s})/\lambda \quad \textbf{(2)}$$

$$\mathrm{P}_{ij}^{s} = \mathrm{P}_{i}^{s} + \Delta R_{ij}^{s} + \delta\Delta r_{ij_I}^{s} + \delta\Delta r_{ij_o}^{s} + \Delta T_{ij}^{s} \quad \textbf{(3)}$$

Where ΔT_{ji} represents the difference in the modelled part of the troposphere, which is usually subtracted before computation of the network errors, and thus need to be reconsidered.

3. Methodology

The tests were designed in order to evaluate the NRTK performances based on VRS technique provided by the northern part of the Algerian CORS, according to the performance parameters used in this study. These parameters are precision, availability, integrity, repeatability, time-to-fix ambiguity (TTFA), number of satellites in view and their related geometry (PDOP).

The tests were based on several surveys conducted between October 2021 and January 2022, at various locations in the north of Algeria. Due to logistics considerations, the tests were based mainly on the central and eastern parts of Algeria. Several VRS measurement sessions during a few minutes of observations was collected. The training sites are thoroughly selected following to their distances from the reference stations. (Figure 3) illustrates the locations of training sites.

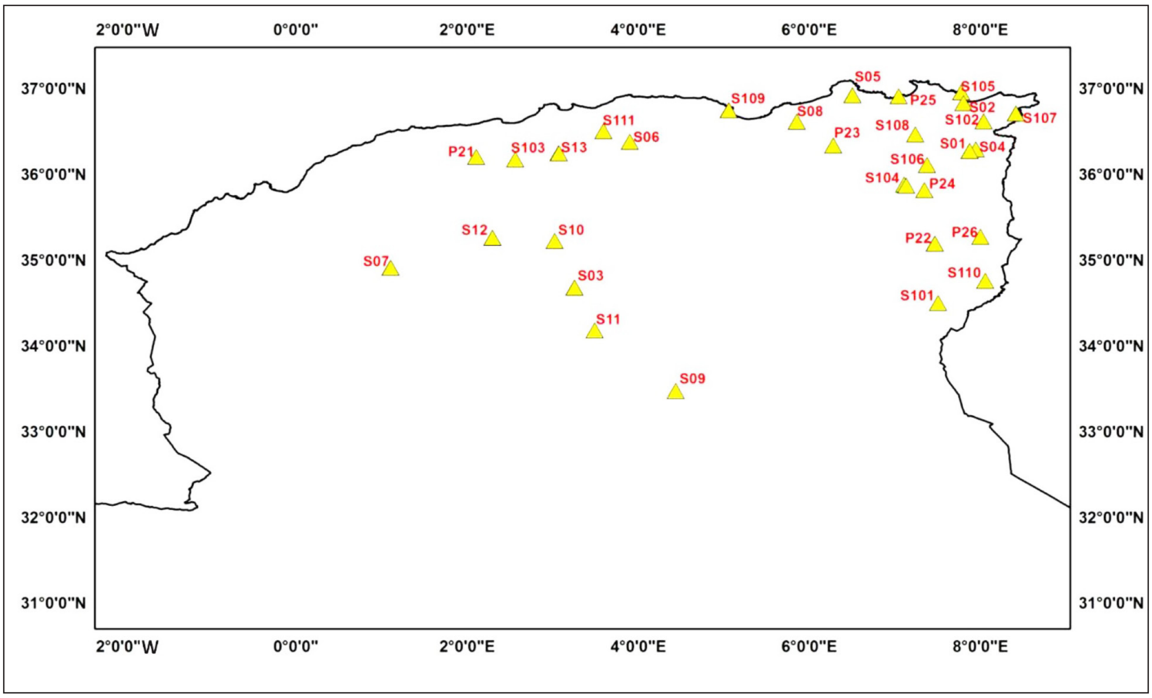

Fig. 3 Training sites in the north of Algeria

The tests were performed using a receiver integrated with the spectra precision GNSS receiver SP80. The correction was generated based on GPS, GLONASS and BeiDou signals :

The tests were designed as following :

- Test1 : Thirteen (13) sessions of VRS measurements named (S01, S02, S03, ..., S13), to investigate precision, availability and integrity ;
- Test 2 : Eleven (11) sessions of VRS measurements named (S101, S102, S103, …, S111), to investigate the TTFA ;
- Test 3 : Six (06) sessions of VRS measurements named (P21, P22, P23, …, P26), to investigate the indicator of repeatability measurements.

In total, 1021 VRS measurements were collected during the survey campaigns. The VRS streams generated by Geo++GNSMART software were based on GPS, GLONASS and BeiDou. The streams RTCM3.2 consider Message Types 1074 (GPS), 1124 (BeiDou), 1084 (GLONASS), 1033 (Antenna device).

4. Results and discussion

The (table. 1) displays the results obtained for the three tests conducted in different sites in the north of Algeria and the average results of the different performances parameters of the VRS measurements.

4.1. Number of satellites in view and their geometry (PDOP)

During the measurement, the registration also included the values of the PDOP in order to characterize the observation conditions at the measuring point. The DOP coefficients take into account the configuration of the positions of the satellites in relation to each other, and their geometrical relationship with the antenna of the satellite receiver. A lower DOP value indicates a higher probability of high positioning accuracy. The most commonly used DOP is PDOP, which is a dimensionless value expressing the quality of the relationship between the error in determining the position of the measurement antenna, and the error in determining the position of the satellites involved in the positioning [14].

In general, an increasing number of satellites give better results because of better satellite geometry and redundant satellites for ambiguity resolution. The RTK rover needs at least five common satellites with the base station to resolve the ambiguities. When there are more satellites visible, the RMS of observations is reduced and initialization times get shorter [15].

The test was achieved with the tracking of 9 to 21 satellites (figure 4). The analysis of satellite observation conditions with the use of the PDOP coefficients showed that the PDOP value varied in the range from 0.8 to 1.2.

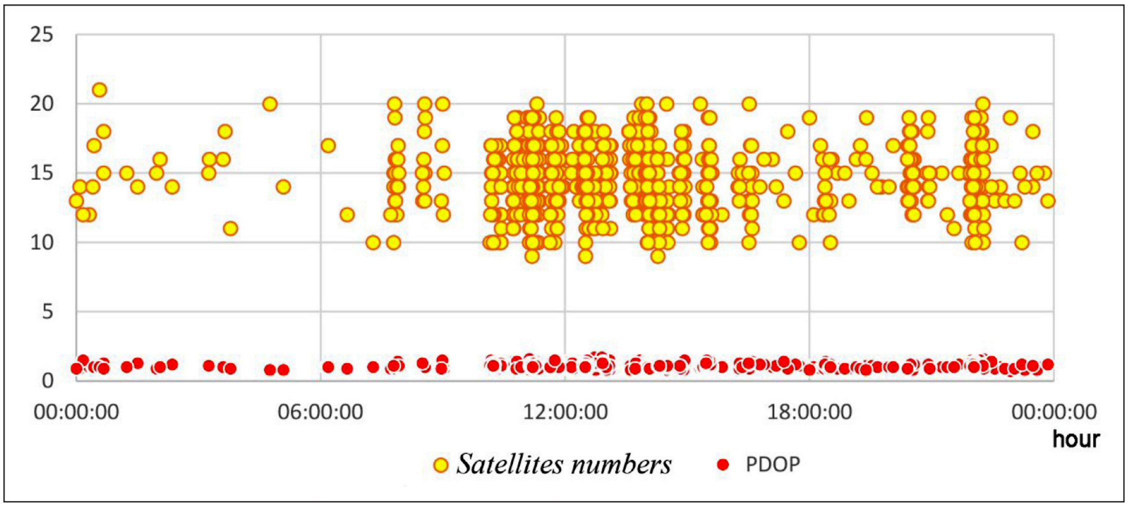

Fig. 4 Satellites numbers in view and their geometry (PDOP)

Tab 1. The obtained results of performances parameters of VRS measurements

Precision, Availability and integrity criteria(test1)

Session /site	Distance from the closest CORS (km)	Start time	Finish time	NB survey	Satellites number and PDOP		Precision average 1σ (cm)		Availability (%)	Integrity (%)	
					Sat	PDOP	Hz	Vt		Hz	Vt
S01	0.1	16:29:49	16:35:27	25	16	1.0	1.0	1.6	100%	100	100
S02	0.1	13:35:07	13:48:06	25	14	1.0	1.2	1.9	100%	100	90
S03	03	14:01:00	00:40:00	65	15	1.1	1.0	1.9	97%	100	97
S04	07	07:47:01	07:54:45	26	16	1.2	0.9	1.8	100%	100	96
S05	30	14:47:47	14:56:14	45	17	0.8	1.2	2.1	100%	100	97
S06	30	12:09:12	18:30:59	27	14	1.3	1.8	3.2	100%	96	86
S07	31	22:09:09	22:16:34	52	13	0.9	1.1	1.5	100%	100	100
S08	35	13:33:41	13:39:55	25	10	1.2	1.7	5.4	70%	100	50
S09	39	14:15:17	15:35:47	45	15	0.8	1.2	2.1	98%	100	98
S10	49	13:57:39	14:33:07	78	12	1.1	2.2	3.1	62%	82	72
S11	50	20:23:59	20:34:20	49	12	1.0	1.1	2.3	100%	100	98
S12	59	21:56:25	22:04:22	55	15	1.0	1.4	2.1	100%	100	96
S13	65	10:09:07	10:18:33	25	17	1.0	2.4	3.6	80%	88	67

TTFA criteria(test2)

Site/ Session	Distance from the closest CORS (km)	TTFA min :sec
S101	0.1	00 :09
S102	0.1	00 :11
S103	0.1	00 :25
S104	2.3	00 :26
S105	14	02 :32
S106	33	01 :12
S107	35	00 :23
S108	35	01 :47
S109	49	00 :23
S110	58	01 :11
S111	60	03 :22

Repeatability criteria(test3)

Site	RepeatabilityFactor (RF)	
	Hz	Vt
P21	1.11	1.25
P22	1.00	1.03
P23	1.08	1.05
P24	1.00	1.04
P25	1.08	1.05
P26	1.00	1.04

Average results of the total test

Total VRS points	Test /sessions	Criteria	The average results
1021	Test1 : 13	Precision	Hz: 1.3 cm Vt: 2.2 cm
		Availability	97.25%
		Integrity	Hz : 98.8 % Vt : 94.9 %
		Sat	15
		PDOP	1.0
	Test2 : 11	TTFA	66 seconds
	Test3 : 06	Repeatability	RF:1.06

4.2. Precision

The precision of the NRTK methods is the degree of dispersion (spread) of the measurement results ; Itshould be considered as the consistency of the results obtained from multiple measurements of the same points [14]. We aim in this experience to show the quality of the measurements throughout the day (in 24 hours). The precision should be represented by the standard deviation of the measurements at one sigma (1 sigma, about 68% of the observations) [7]. The (figure 5) displays the horizontal (Hz) and vertical (Vt) deviations of the NRTK positioning during the day (24 hours).

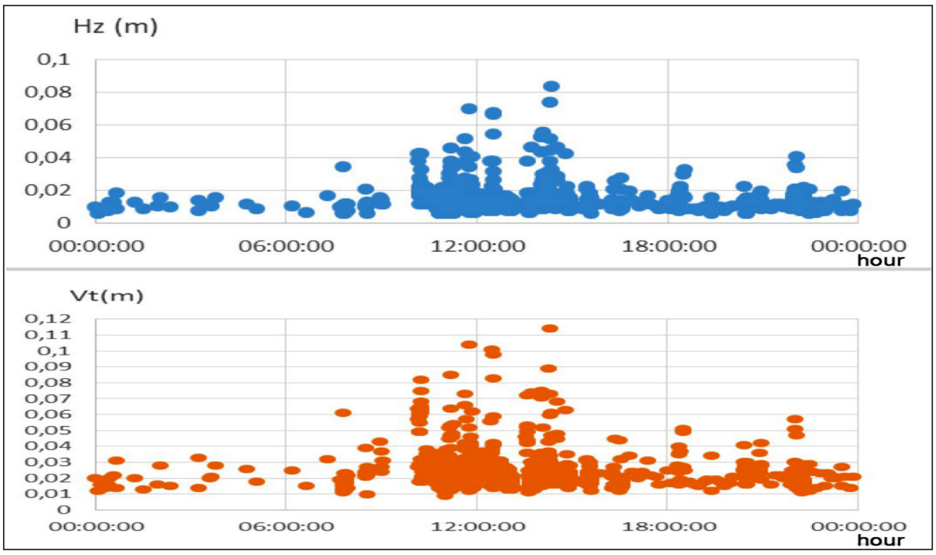

Fig. 5 Horizontal (Hz) and vertical (Vt) deviations of VRS positioning on 1021 survey points over the 30 training sites

The results are convincing, particularly at night and in the early morning in the absence of sun radiation. However, some values exceed the mean value of errors between 10 am and 3 pm, during strong sun radiation. This is due probably to the diurnal ionospheric activity and should be explored in the future works.

Additionally, we observe that precision improves with a shorter baseline from the master station and increases with a longer baseline (table. 1).

The results of precision presented at the (table. 1) show that the precision for the horizontal component was in the order of 1.3 cm on average (1 sigma) and around 2.2 cm in the vertical.

4.3. Availability

Availability was determined as the percentage of observations for which aVRS solution was obtained during testing (Integer Phase Ambiguities resolved). The availability numbers are normally expected to be in the 97-99% range. [16, 17].

Availability proved to be a vital factor for the good performance of the VRS service. As demonstrated in the (table. 1), the precision of the results directly depends on whether the ambiguity in the obtained solution was fixed in its integer value.

The availability of repetitive measurements of the VRS service was achieved at a level of 97.25% as shown in (table. 1). Most sites displayed the maximum level of availability. For the sites S08, S10, and S13, the availability was slightly lower than the expected values ; it was only 62%, 70%, and 80%, respectively. The reason could be returned to the impact of the baseline lengths or probably due to the intermittent mobile phone coverage in the testing areas.

The availability is determined by the effectiveness of the entire chain of NRTK solution conducted on the sites up until the reception of NRTK corrections by users.

4.4. Integrity

Integrity was evaluated as the percentage of observations during which the NRTK solutions were available at an accuracy level better than 5 cm. The Integrity of measurements for the Smart-Net RTK service in United Kingdom was in averages of 98.87% in the Easting, 91.90% in the Northing and 77.41% in the vertical [7].

A summary of integrity results is presented in table n°1. An average of 98.8% in the horizontal and 94.9% in the vertical were generally obtained. The integrity is proportional to the availability. The sites S01, S02, S03, S04, S05, S06, S07, S09, S11, and S12 achieve an outstanding integrity of 85-100% when the availability is greater than 97%.

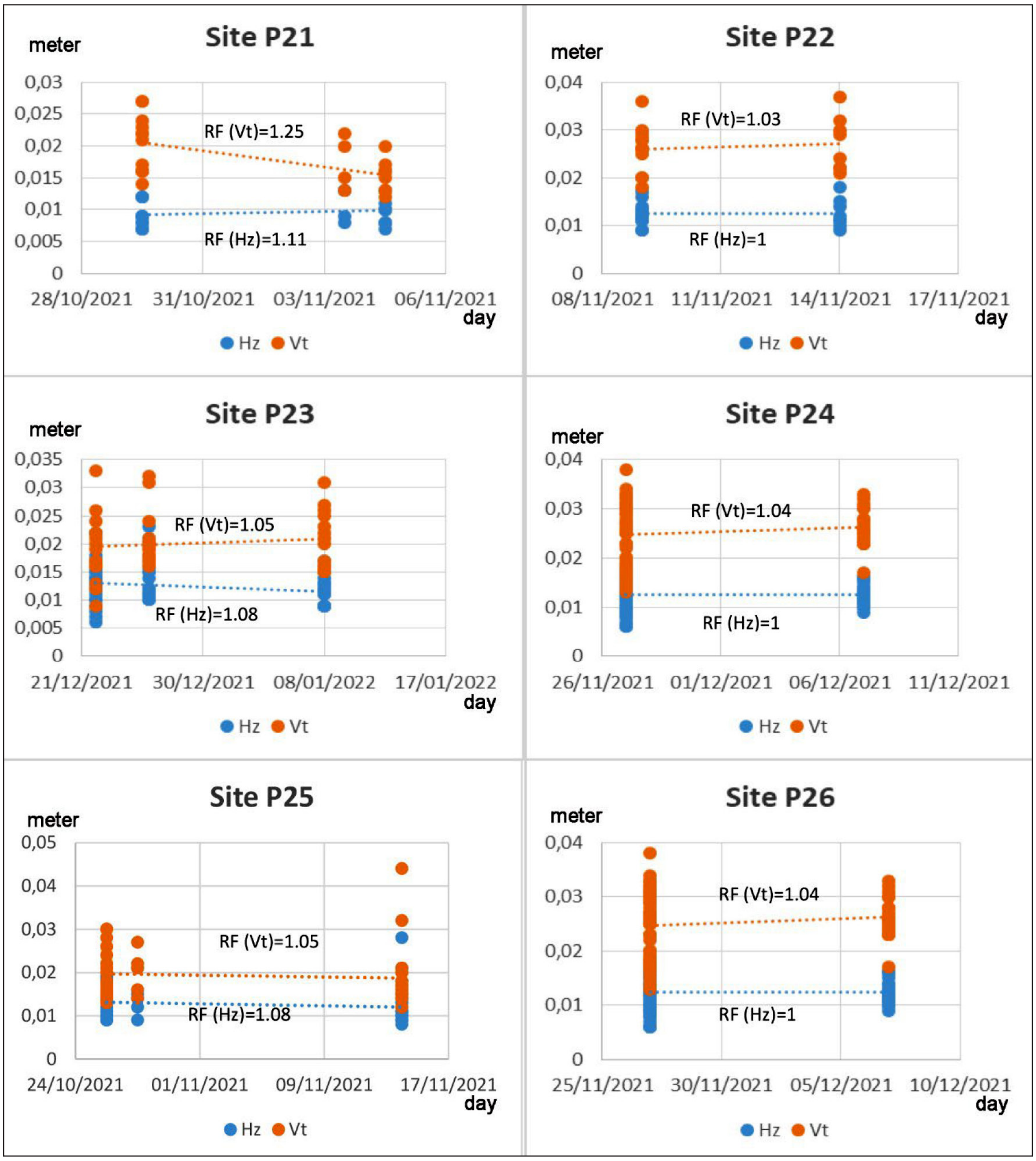

Fig. 6 Repeatability measurements

Integrity for the vertical component was attained between 50% and 72% at sites S08, S10, and S13, and it was concluded that results for the horizontal (82% to 100%) were conclusive.

4.5 Time to fix ambiguities (TTFA)

Time to fix ambiguity (TTFA) is the term used to describe the amount of time required for the receiver to achieve a fixed position (centimetre precision). This period of time is closely related to the issue of integer ambiguities in the GPS phase measurements as well as to residual errors (atmospheric, ionospheric, and orbital errors), which make it more difficult to resolve ambiguities [6].

The results of the TTFA are presented in (table. 1).The fixing time was determined at an average of 66 seconds. Depending on the user's proximity from the closest CORS, the fixing time was achieved between a few seconds and a few minutes. The worst TTFA is shown in the extended baseline within the network.

4.6. Repeatability

Repeatability is considered as how similar measurement results are at the same point between two tests achieved during two different days [18]. Thus, repeatability is described by "Repeatability Factor (RF)"and is given by :

$$RF = \overline{\delta}_{X,d_1} / \overline{\delta}_{X,d_2} \quad (4)$$

Where :

X=Hz or Vt, related to horizontal and vertical measurements respectively ;

$d_1$and d_2 stand for the first and the second day of the test, respectively ;

$\overline{\delta}_{X,d}$ is the mean of standard deviation observed at each VRS survey during the concerned day d.

We note, good repeatability factor should take values that are very close to 1.

A series of VRS measurements were completed in a few minutes in different training locations (6 sites), and that were taken on different dates at the same time of the day.

The results shown in (figure 6) indicate that the horizontal and vertical deviations underwent only a weak evolution over time, which is why the repeatability factors (RF) of the training tests at five sites (P22, P23, P24, P25, and P26) are nearly equal to 1 while P21 shows vertical deviation slightly greater than l (table. 1). In the other hand, the analysis of the series of measurements reveals that observing for a few minutes to obtain an averaged position reduces the effects of individual coordinate solution outliers.

5. Conclusion

This research investigates the performance of the VRS service yielded by the northern part of AL-CORS according to the variety of performance parameters including: precision, availability, integrity, repeatability, time-to-fix ambiguity (TTFA), and number of satellites in view and their related geometry (PDOP). According to the results obtained, AL-CORS can provide a conclusive VRS performance, similar to those achieved by the operating commercial NRTK systems over the world. Actually, the tests show that AL-CORS delivers high precision of horizontal and vertical components in the order of 1.3 cm and 2.2 cm, respectively (average at one sigma). Also, it was observed that the VRS solution's availability was 97.25%,its integrity was 98.8% in the horizontal component and 94.9% in the vertical. Nevertheless, it is worth to note, the integrity is proportional to the availability and it was good only when NRTK was available. The TTFA ranged from a few seconds to a few minutes depending on baseline lengths. The worst TTFA was shown in the extended shortest baseline within the network i.e larger than 50 km in the tests. The VRS measurements' repeatability presented similar measurement results throughout the time. High satellite numbers have been tracked. Their geometry (PDOP) was ideal. In addition, observing for a few minutes to obtain an averaged position reduces the effects of individual coordinate solution outliers.

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