Establishment of KSA-CORS Network, its Performance and Future plans

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Key words: GNSS, KSA-CORS, Reference Frame

SUMMARY

Geographically, the KSA-COR network has greatly expanded to almost encircling the Kingdom's two million square kilometers. The 209 CORS that make up the national KSA-CORS network were designed with several challenges as described in this paper. Many governmental organizations continuously build different independent CORS networks for their specific businesses, which causes duplication and wastes resources from the government's budget. To give the geospatial user community uniform references, it has been decided to unify these networks. The progress of the networks' unification and the difficulties encountered are also described in the paper. The preliminary assessment of the network shows that real-time network for horizontal plane does not exceed 1 cm and close to 3 cm for height component.

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1. INTRODUCTION

Before the establishment of the Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) networks in the Kingdom of Saudi Arabia, the geodetic control network of the General Directorate of Military Survey was called the Primary Geodetic Network (PGN). It comprised of 722 passive pillar monuments. The networks lacked kingdom-wide coverage, density, and accuracy for continuous deformation monitoring and contribution to international reference frame realization. Nevertheless, a temporary GNSS campaign ranging from a few hours to days was observed to define the old geodetic reference called ITRF2000 at reference epoch 2003.1993 y (GDMS 2007). Users normally access the geodetic reference by setting up their receiver of the passive network and making measurements. The PGN was a viable geodetic reference, however foreseeing the future of geodetic frames and global trends, the national reference frames are transitioning from passive to active reference frame.

Next came the requirement for a GNSS network that constantly tracked satellite signals, providing more precise and up-to-date positioning data, and are easy to connect to real-time positioning networks. The GNSS CORS network is a critical tool for accurate and precise positioning in a variety of applications, including surveying, mapping, and navigation. Alqahtani et al. (2022) noted how numerous GNSS CORS governmental networks in the Kingdom caused inconsistent data accuracy, and interoperability. The authors point out that having multiple CORS networks in the Kingdom lead to data discrepancies due to different geodetic references, and increased government cost for CORS network maintenance. They suggested that unifying all the governmental CORS networks into a one unified network would solve these issues, improve efficiency, and reduce wastage.

The General Authority for Survey and Geospatial Information (GEOSA) was established with the purpose of serving as the kingdom's regulatory body for the survey and geospatial information industries. A spatial reference frame is an essential geodetic foundation for surveying and mapping. It gives users the ability to precisely pinpoint a location, including latitude, longitude, ellipsoid height, and orthometric height. The General Directorate of Geodesy (GDG) of GEOSA creates, maintains, and distributes a precise Saudi Arabian National Spatial Reference System (SANSRS).

This paper serves as a valuable resource for GNSS CORS owners and researchers who are interested in understanding the establishment, performance and future plans of a typical GNSS CORS network.

2. **KSA-CORS NETWORK OBJECTIVES**

Al-Kherayef et al. (2015) propose deploying an SASNRS that covers the entire kingdom and should be more accurate than any other geodetic-derived activity. In order to reach these goals, the following strategic objectives were outlined by GEOSA:

2.1. Define and maintain an accurate kingdom-wide Geodetic Reference Frame (GRF)

The KSA-CORS network's primary objective is to define and maintain an accurate kingdom-wide Geodetic Reference Frame (GRF) and to determine the Arabian plate inner movement which contributes to the maintenance of the precise KSA-GRF. Ali and Abdelrahma in (2022) indicated that the Arabian Shield region is prone to seismic activity and needs further research to understand its seismic hazard implications. Furthermore, Alzahrani et. Al. (2022) reported a study on the seismicity of the Neom megaproject area in northwestern Saudi Arabia, the authors findings shows that the Neom area is seismically active. To ensure the best methods for achieving the the KSA-CORS objectives, a CORS geodynamic level network was designed and desployed following IGS, UNAVCO and IGS CORS monumnetation standards. This geodynamic level network, dubbed Fundamental-CORS (F-CORS), has all "Ground type" stations. The F-CORS was planned to have a geodynamic grade IGS standard monument and a homogenous distribution throughout the kingdom except where its geological activities and other interests necessitate a higher density. The F-CORS was designed to ensure high precision coordinates and velocities determination that allows a correct and precise deformation monitoring and the KSA-GRF definnintion and maintainence.

Atmospheric conditions and land movements can cause GNSS positioning inaccuracies. One example is the work of Guerova, and Simeonov (2022), and Sevilla, (2011), where they all reported that connecting a GNSS CORS to a tide gauge can improve positioning and provide sea level changes over time. The international geodetic community are increasingly aware of the importance of collocating the tide gauge stations with GNSS CORS networks (Schöne, et. al. 2009). The GEOSA recognizes the value of collocated geodetic observables and reference stations for these reasons: Correcting for the movements of the tide gauge reference point is an important step in analyzing and interpreting water level data from a tide gauge. This is because the movements of the tide gauge reference point, which can be caused by tides, currents, and waves, can result in errors in the water level measurements. A tide gauge collocated with a Ground type GNSS CORS is the best way to distinguish those motions. Installing GNSS CORS at the vicinity of all the kingdom's national tide gauges allows the ability to reference all tide gauges to the same highly accurate SANSRS, which allows for better comparison and analysis of data across the network of tide gauges. This also improves the Kingdom's national height reference system called the KSA Vertical Reference Frame 21 (VRF21). During the KSA-CORS network design phase, the deployment of ground type stations near the 12 national tide gauges and establish connection was taken into account. The KSA-CORS were deployed several kilometers away from the tide gauges.

2.2. Provide user community with accessibility to KSA-GRF

Once KSA-GRF definition and maintenance was ensured by F-CORS deployment, the next objective was to provide high-accuracy accessibility to KSA-GRF for users working around the kingdom.This was achieved through further densification with additional ground type and roof type CORS. The desnsification to a 70 to 100 km spacing provided network real-time kinematic correction, online post processing and raw/virtual GNSS data download for post processing. The GEOSA leveraged the International GNSS Service (IGS) and the National Geodetic Survey (NGS) standards. Despite the importance of GRF for the Saudi Arabia geospatial users, accessing and using the geodetic reference has been a chanllenge for many users. The GEOSA has made efforts to provide the user community with improved access to KSA-GRF includinghe development of web-based portal and the creation of user guides to assist users in navigating the KSA-GRF. The KSA-CORS network leveraged differential positioning based on Virtual Reference Station (VRS) model to improve the accuracy and efficiency of GNSS positioning. The VRS model is a technique that uses a network of reference stations to create a virtual reference station that provides highly accurate GNSS positioning for a user's location. KSACORS network services is provided through Internet, and the file oriented services is based on HTTPS and SFTP services. The real time streaming of GNSS corrections is supported by NTRIP protocol. NTRIP is a RTCM standard for the distribution of GNSS data over Internet and has been adopted by many manufacturers for many years and has been proven to be an efficient protocol for this critical service link.

3. KSA-CORS NETWORK INFRASTRTURE

3.1. KSA-CORS Monumentation

According to Janssen et al. (2011), creating a CORS network is not an easy task. The author's study was in the context of establishing a GNSS CORS network in Austrailia. The design, deployment and operational circumstances under which the network must function in KSA were investigated in this paper. Using this information, it was determined where certain criteria needed to be constrained by further performance requirements or even more explicit specifications. In the specification definition process, it was a significant goal to identify which requirements need to be restrained in order to avoid an unsatisfactory solution. A high level operational requirement was established and the constraints that were not believed to have a substantial impact on the solution were avoided.

GEOSA is aware of the harsh environment where this system will be operating on, and took the required precautions in defining a feasible solution that will be operated in the long term. An initial validation of the station density values estimated on the positioning services (DGNSS and NRTK) was also been performed based on several network geometries simulations. Apart from the international standards used,further local GEOSA modified standards that matched the soil studies and the equipment cabinet temperature model were applied. These standards were based on GEOSA research. In some parts of the kingdom, the interior temperature of cabinets during the height of summer could reach up to 55°. Each cabinet has an air conditioning system in place to assist maintain the temperature below 35°. Geodynamic monuments for GNSS CORS networks are essential for realizing and maintaining a stable geodetic reference frame, providing accurate and reliable positioning and navigation services, and improving interoperability with other geodetic reference frames. The ground type reference stations are based on pillars according to the mention guidelines. Less restrictive requirements were in place for RTK rooftop KSA-CORS. These stations are located at selected area and will afford the required interstation distance of 50-90 km in order to provide centimeter accuracy positioning by using NRTK service at selected areas. The high precision requirement makes necessary a high-stability monument but centimeter accuracy can easily be reached with stations installed on top of buildings. Figure 1 and 2 shows an example of a ground type and roof type KSA-CORS reference stations.

Figure 1: A typical KSA-CORS Ground Type station

Figure 2: A typical KSA-CORS Roof Type station

3.2. Network Control Center

The Network Control Center (NCC) in GEOSA data center in Riyadh and a network of active reference stations form the KSA-CORS network infrastructure. NCC controls the entire KSA-CORS network and it is responsible for receiving the raw observations from the reference stations, storing and processing them, and then providing positioning services to the user community. The NCC also operates, monitors and communicates with the field technicians in ensuring the KSA-CORS newtwork remains active. The team at the center monitors the reference station components health status, server status, and caster/user activities. The center also has a call unit where users can call in for support. The functionalities currently operating in the KSA-CORS NCC includes:

– A CORS network management software that is used to manage and operate the KSA-CORS. The software provides a variety of tools and features to support the operation of the network such as quality control, network configuration, data and user management and data distribution.
– The servers that enable the efficient management and distribution of GNSS data, as well as the provision of positioning services to a wide range of users. The KSA-CORS servers are set-up in a high availability. The redundant servers are deployed to provide backup and failover capabilities. This is achieved through load balancing method. The

system is designed to automatically switch to the backup servers in the event of a failure, without any interruption to the real-time services provided to users.

- The database management system manages user accounting information, queries and retrieves network data, among other functionalities. The backup acccounting database is swtiched into log shipping mode that allows it to be updated from the primary database.
- The Storage efficiently stores reference station stream data and processed data. The storage is configured with a backup and disaster recovery in Jeddah city of Saudi Arabia.
- System administrators at the NCC can monitor and gather environmental health data from each remote KSA-CORS station using GEOSCADA's remote control and monitoring system. Cabinet air-conditioning status, cabinet temperature, station grid or photovoltaic power status, and connectivity are measured. KSA-CORS administrators can quickly identify and fix issues remote with the SCADA. The system can restart the reference station's air-conditioning system, primary and backup communication routers, GNSS receiver, and grid power system.
- In order to receive the service via the KSA-CORS network, 1 Hz of GNSS stream must be collected from multiple KSA-CORS reference stations, and the stream data must then be processed in the server to produce accurate location and timing data. This involves accounting for errors such as atmospheric delays and satellite clock errors. The processed data is then distributed to registered users through the internet. KSA-CORS users access the data in real-time through three mounts points for network real-time kinematic, single station real-time kinematic, and differerntial GNSS positioning.

3.3. Communication and Power System

The KSACORS network uses a network-based Multi-Protocol Label Switching (MPLS) Virtual Private Network (VPN) to link reference stations to the Network Control Center in Riyadh and efficiently streaming GNSS data streams and reference station component health status data. Each reference station is designed with a high availability. Each station comprises of a primary and backup communication router and power supply

The main power supply at each station is grid except for station located in desert areas. Four flooded deep cycle batteries create a 24V DC backup power supply. If power fails, backup power can last more than 8 days. This gives the mainteanance team ample time to travel to make corrective maintainance.

Figure 3: KSA-CORS Cabinet Components

4. EVALUATION OF KSA-CORS NETWORK PERFORMANCE

This section presents the results of some of the evaluation of the KSA-CORS network performance based on the KSA-GRF17 reference frame. The result presents the accuracy that was reached from KSA-CORS network in real-time solution. The objective of the campaign was to investigate accuracy of real-time measurement by cordinate comparison between static and RTK mode.

The test campaign was conducted on the monuments of the Primary Geodetic Network (PGN) across the kingdom. The field campaign lasted more than a month. During this period, random points were visited in the eastern and western provinc of the kingdom. All the observed and not observed points are shown in Figure-4.

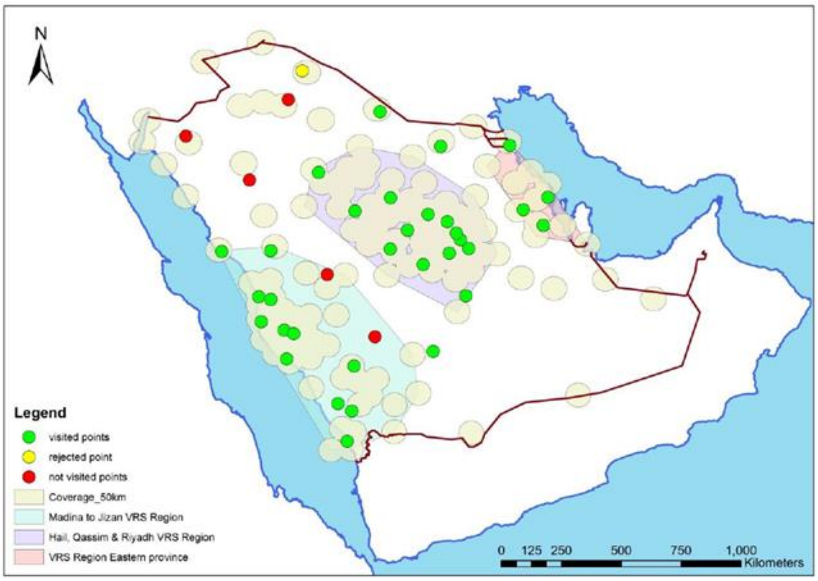

Figure 4: Status of tested points after field campaign

$$\Delta = X^{(RTK)} - X^{(Static)} \quad (1)$$

Statistical analysis was done to residuals and results. The mean value and standard deviation (std) have been calculated using formula (2) and (3).

$$mean = \sum \frac{\Delta}{n} \quad (2)$$

$$std = \sqrt{\frac{\sum(\Delta - mean)^2}{n-1}} \quad (3)$$

No outliers were found for East, North and Height components. Furthermore, Standard Error (SE) was computed using formula (4).

$$SE = \frac{std}{\sqrt{n}} \quad (4)$$

The horizontal component standard deviation was less than 1 cm, whereas the height component was about 3 cm.

The computation and analysis of residuals from RTK single-station solutions were identical. Based on the findings, we may conclude that real-time observation employing a single-station solution at a distance of more than 70 km from the closest CORS is not advised.

The spatial distribution shows the biggest residuals are at the edges of the network real-time kinematic coverage zones or when increasing interstation distances

It may be concluded that adopting NRTK techniques with short observation times is more economic than classical long time static GNSS observations and they provide appropriate accuracies for many surveying applications.

5. DUPLICATION OF GOVERNMENT–OWNED GNSS CORS NETWORKS

Saudi Arabia has been actively working to upgrade its positioning infrastructure in recent years. In the early years, several governmental agencies has developed a network of GNSS CORS to provide high-precision positioning data to support their respective operations. However, there has been some concern about the duplication of government-owned GNSS CORS networks in Saudi Arabia. Many of the networks offer similar goods and services, and their network coverage areas overlap. According to Alqahtani et al. (2022), the existence of several reference frames, confusion among users, and extra costs to the government have all resulted from the duplication of governmental CORS networks in the same geographic area, as all networks require maintenance, upgrades, and equipment replacement.

The Saudi Arabian government has taken a number of measures to consolidate the redundant networks in order to address this issue. By royal decree, the General Commission for Survey was given the authority to regulate the GNSS CORS network operation sector as well as the surveying and geospatial industries in the Kingdom starting in 2020. The commission was upgraded to an Authority and now called General Authority for Survey and Geospatial Information (GEOSA), The GEOSA has been tasked with developing a national geodetic reference system that integrates the KSA-CORS network, providing a unified and reliable positioning infrastructure for all users.

Furthermore, the GEOSA has initiated a project to unify governmental GNSS CORS networks into one unified network that will be available to all government agencies and private enterprises for geospatial applications. The project will expand network coverage to include areas that the KSA-CORS network does not currently serve and upgrade the infrastructure with the newest technology. This will enable GEOSA to decommission the duplicated CORS within a few kilometers of each other and eliminate the duplication of services, saving resources and improving the overall efficiency of the government's positioning infrastructure.

6. APPLICATIONS OF KSA-CORS NETWORK

The KSA-CORS network offers products and services to a wide range of applications across numerous sectors, including surveying, construction, agriculture, transportation, and geosciences. Here are some instances of how the network is being used in Saudi Arabia.

- Surveying: The network subscribers have used the high-precision positioning data in surveying for mapping, minning, cadastral surveys, and boundary marking.
- Construction: The network ensures accurate and compliant construction survey in the Kingdom. Users of KSA-CORS have taken advantage of the network to monitor road compaction and design compliance while it is being built. This guarantees that the road

is constructed with the appropriate density and strength and authorizes contractor payment.

- Autonomous Vehicle: Autonomous vehicle researcher groups within the kingdom leverage the network for navigation purposes. The network provides high-accuracy positioning data that can be used for localization and navigaion. The network helps to improve the accuracy, intergrity, availability and continuity of localization for autonomous vehicles.
- Geosciences: Seismic monitoring and geodetic studies have used the network. It has provide accurate measurements of ground deformation and crustal motion, which are critical for earthquake prediction and hazard assessment.
- Hydrography: KSA-CORS network has given hydrographers with a powerful tool for nearshore mapping and monitoring water bodies.
- Research: Few geodesy and Hydrography studies have shown KSA-CORS network performance. El-Daisy (2020) examined the performance of the real-time network solution for Saudi Coastal Maritime Navigation and investigated whether the achieved accuracy met the International Maritime Organization (IMO) standards. A Trimble BD982 GNSS receiver was used on a hydrographic surveying vessel in Sharm Creek, Jeddah, Saudi Arabia. The study contrasted the NRTK solution from KSA-CORS network and a processed Post-Processed Kinematic (PPK) survey data. The real-time network solution evaluated root-mean-squares error errors at 95% confidence level for 2D horizontal positioning and 1D vertical solution. The author concluded that the real-time network solution accuracy was less than 0.10m, satisfying IMO accuracy standards at 95% confidence level for Saudi Coastal Maritime Navigation applications for three major phases in port navigation and autonomous docking.

7. CHALLENGES AND LIMITATIONS OF KSA-CORS NETWORK

The KSA-CORS network has many advantages and potential applications, but it also has certain drawbacks now.

- Network Coverage: The KSA-CORS network covers most of the kingdom, but some isolated and hard-to-reach places are unreachable. Applications that need high-precision location data in certain areas may struggle because of non-availability of real-time network.
- Maintenance and Upgrades: The KSA-CORS network needs periodic maintenance and upgrades to function properly and provide reliable data. The network contains many stations around the kingdom and with the plans to densify the network; this can be expensive and time-consuming.
- Scalability: Keeping up to date with upgrading the network control center infrastructure is a challenge with the current physical data center.
- Interoperability: Interoperability between GNSS CORS networks equipment and other components or systems is necessary to guarantee smooth positioning and navigation services. Interoperability can be difficult to achieve, though, because of variations in technology, data formats, and protocol.

- Communication and Connectivity: To transfer data in real time to the Riyadh data center, KSA-CORS units require dependable communication links. We found it challenging to transfer data in real-time during sandstorms or rainy periods in remote and desert areas where satellite communication systems are implemented.

8. FUTURE PLAN AND CONCLUSION

The KSA-CORS network has been instrumental in supporting various industries in Saudi Arabia, and it is expected to play an increasingly vital role in the future. However, there are still some critical areas that needs to be addressed to ensure the network's sustainability and effectiveness. In this regard, the following are the plans for the network.

- Unification / Network Expansion: In the kingdom, various government agencies run about 500 GNSS CORS networks. A new GNSS CORS network design has been analyzed to satisfy all parties and have a unified CORS network that will provide high precision real-time positioning data to almost all the entire kingdom. This will improve data sharing and interoperability among governmental and private agencies.
  This project's goals are to first unify the spatial references and then to unify the GNSS CORS network infrastructure. Moreover, duplicate GNSS CORS will need to be decommissioned as part of the project.
- Collocation with other networks: The establishment of a GNSS CORS near the 12 tide gauges and the national geodetic network is a crucial step towards improving our understanding of sea level rise and coastal hazards. By connecting the KSA-CORS to a geodetic vertical network, this will enhance the accuracy and reliability of the vertical positioning. It can also be used to monitor the height changes in the GNSS CORS. It will provide more accurate and reliable data to support scientific research, policymaking, and disaster risk reduction efforts. The relative heights of the national tide gauge and the closest KSA-CORS is planned to be measured by means of precise geodetic levelling.
- Capacity building and workshops: GEOSA will increase the engagements with stakeholders through workshops to ensure that the local communities, researchers, and policymakers can effectively use the KSA-CORS network data for their specific needs.
- Network Migration: The migration of the KSA-CORS network to the cloud will improve data accessibility and enable real-time monitoring. Migrating the unified KSA-CORS network to the cloud will provide easy scale up or down based on changing demands.

In conclusion, the duplication of government owned GNSS CORS networks in Saudi Arabia has been a concern in recent years. However, the GEOSA who is responsible for regulating the survey and geospatial industry has taken significant steps to address this issue by establishing initiating a project to unify the duplicated CORS networks. This will enable the government to provide a more reliable and efficient positioning infrastructure to all users, ultimately benefiting the country's economy and society.

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BIOGRAPHICAL NOTES

Eng. Saad Al-Qahtani

An accomplished department manager who has spent over 10 years in the field of Geomatics and Geodesy. He received his bachelor's degree in Survey Engineering from King Saud University and later went to earn his master's degree in Geospatial information science from the University of Flinders. He currently manages the CORS department from the General Directorate of Geodesy at GEOSA. He is passionate about geospatial technology.

Eng. Abdulwasiu Salawu

Holds a bachelor's degree in Environmental Engineering and a master's degree in Geoinformatics. He is also a graduate member of Nigeria Society of Engineers. He has worked for both the private and government sector in various areas including geodesy, land survey, hydrography, and business analysis. He currently works a Consultant for KSA-CORS network for GEOSA in Riyadh where he continues to apply his skills and expertise in geospatial technology. He is passionate about the creation of new geospatial ventures and business strategies that will help organizations to leverage the power of geospatial technology for business success.

Eng. Abdullah Al-Qahtani

Is the General Authority for Survey and Geospatial Information in Saudi Arabia's Directorate of Geodesy. From King Saud University, he received his degree in Survey Engineering. He earned a master's degree in geospatial engineering from the University of New South Wales. He oversees the development of the Saudi Arabian National Spatial Reference System (SNASRS). He participates on behalf of Saudi Arabia in the ISO geodetic registries' Consultation Group and Sub Committee of Geodesy (SCoG) of the UN Committee of Experts on Global Geospatial Information Management (UNGGIM).

Eng. Abdullah Al-Thawwad

Hold a bachelor's degree in Survey Engineering from King Saud University in Riyadh. He worked in the construction industry prior to joining GEOSA. He currently heads the KSA-CORS network operations team where he is responsible for overseeing the daily operations of KSA-CORS business. .

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