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ISKANDARnet CORS Network Integrity Monitoring

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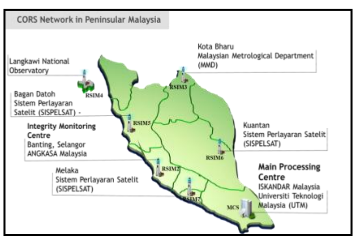
Graphical abstract



Abstract

The increasing use of real-time high precision Global Positioning System (GPS) methods has leads in raising number of Continuously Operating Reference Station (CORS) establishment. However, it is complicated to expect the disparity in the performance and status of the reference stations. Thus, a system for dealing with data quality control in order to supervise data streams in real-time has been proposed. This paper focuses on the number of existing approaches to review the quality of raw GPS observations and presents architecture for the development of a real time quality control system in Peninsular Malaysia.

Keywords: Real-time; GPS; CORS; data quality; quality control

Abstrak

Penggunaan kaedah Sistem Kedudukan Global (GPS) untuk kegunaan masa hakiki semakin meningkat pada masa sekarang. Kaedah Sistem Kedudukan Global (GPS) memberi ketepatan yang tinggi telah membawa peningkatan dalam bilangan penubuhan Stesen Rujukan (CORS) Operasi Berterusan. Walau bagaimanapun, perbezaan dalam pelaksanaan dan penentuan status stesen rujukan adalah sukar untuk dijangkakan. Oleh itu, satu sistem untuk berurusan dengan kawalan kualiti data bagi memantau aliran data dalam masa hakiki telah diusahakan. Kertas ini memberi tumpuan kepada bilangan pendekatan yang sedia ada untuk mengkaji semula kualiti pemerhatian GPS mentah dan membentangkan kerangka kerja untuk pembangunan sistem kawalan kualiti masa yang sebenar di Semenanjung Malaysia.

Kata kunci: Masa hakiki; GPS; CORS; kualiti data; kawalan kualiti

■1.0 INTRODUCTION

The importance of Global Positioning System/Global Navigation Satellite System (GPS/GNSS) has brought the Continuously Operating Reference Station into the limelight, with many CORS being established by both private and government organizations. The CORS network has contributed significantly to high precision geodetic positioning by providing easy and accurate access to the reference station.[1]

The current CORS establishment can be presented into five different models or tiers with each model representing different reasons of establishment of CORS. [2] Model 1 is more of an institutional CORS infrastructure with no commercial services. This includes CORS which are established and maintained by government agencies for free for the use of the public. For example, in Universiti Teknologi Malaysia (UTM), a network of CORS is being used to provide real-time data streaming through the Internet and gather data in a control center for monitoring and management purpose. Model 2 and 3 are government-backed CORS. Whilst Model 2 operates commercial services such as RTK services for the users, Model 3 provides commercial services which are licensed to one or more commercial companies to be the service provider. Model 4 and 5 are both privately own CORS for commercial services and the difference between them is that for CORS in model 4 they are cooperatively setup and managed by a group of company.

However, in the CORS network, it is difficult to predict the deviation performance and status of each reference station. As the frequency and time reference of space satellites, satellite clock has a direct influence on GNSS service performance and as a result, it is necessary to monitor its integrity. [3] Therefore, a system is designed for instantaneous monitoring of data streams is being proposed to handle data quality control issue. Integrity is the availability of a system to provide timely warnings to user when the system should not be used for navigation. [4]

UTM has established GPS CORS network known as ISKANDARnet in the urban area of ISKANDAR Malaysia.

ISKANDARnet was developed to support a variety of positioning techniques of high precision applications using GPS. A research has been done to monitor and supervised the CORS integrity by collecting the data in the control center.

Integrity is a measure of trust, which can place in the correctness of the information supplied by the total system and able to provide valid warning to users.[5] Integrity becomes a major concern since the adoption of GPS/GNSS in safety of life critical applications.[6] For example, Malaysia is a country which experience monsoon season throughout the year with high density of rainfall catalyzing the risk of landslides to inevitably disaster. Therefore, more significant scientific studies are necessary in order to monitor the rate of deformation or displacement which could be possibly happens again anytime in future.[7] Integrity monitoring could also be used to provide safety of travel besides, contribute to the economic growth, trade and productivity.[4]

This paper is focused on the performance of ISKANDARnet integrity monitoring to support precise navigation activities within Peninsular Malaysia. The approached is based on the establishment a new of network which is supported by an existing regional network. Thus, the quality of the position is intrinsically linked to the quality of the external service from a local GPS base station, a regional CORS network, or a global correction service.[8]

This paper is organized as follows. The architecture of CORS network is presented in Section 2. The flow chart of the study is given in Section 3. The performance of CORS network which comprised the processing, results and analysis provided from the reference station is discussed in Section 4. Finally, the summary and concluding remarks are presented in Section 5.

■2.0 ARCHITECTURE OF CORS NETWORK

The Network

The ISKANDARnet has been established by Universiti Teknologi Malaysia in collaboration with National Space Agency (ANGKASA) and Malaysian Marine Department (MMD) as a platform to support positioning activities in Peninsular Malaysia. The ISKANDARnet consists of six CORS stations that cover the whole of Peninsular Malaysia as shown in Figure 1. This system is an extension of the first phase of ISKANDARnet system. The integrity monitoring system will include all ISKANDARnet stations which are situated in the southern part of Peninsular Malaysia and some selected MMD stations which as navigational-aid for vessels navigating in Malaysia's water. The location of these stations is shown in Figure 1.

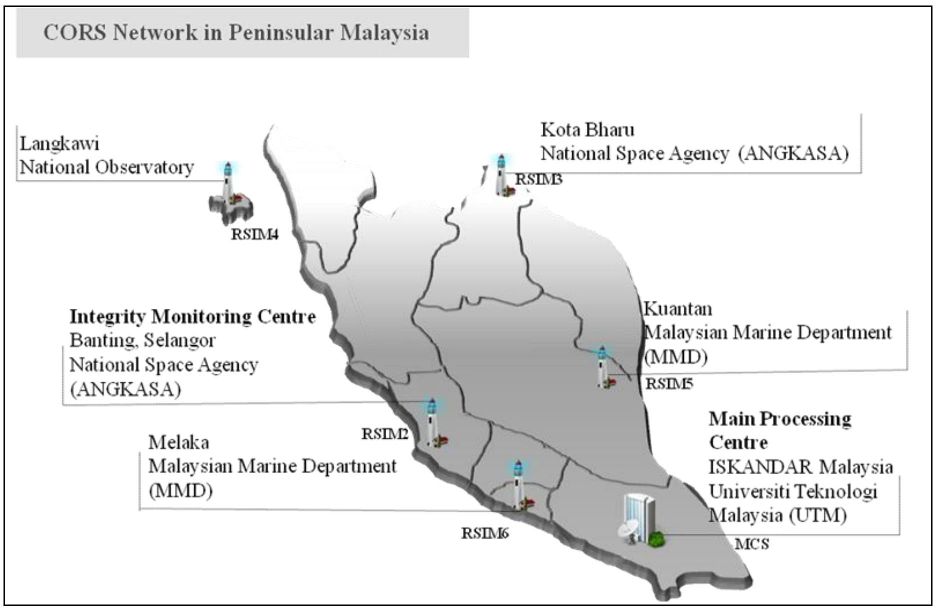


Figure 1 ISKANDARnet CORS Network within Peninsular Malaysia

In Figure 1, the southern part of Peninsular Malaysia is covered by the first phase of ISKANDARnet system. For west coast of Peninsular Malaysia, there are two established CORS stations located at Langkawi National Observatory and in Banting. These two stations were provided by ANGKASA. Another station established by the MMD is located in Melaka. Meanwhile, at the east coast of Peninsular Malaysia, only two CORS stations were within the scientific network which is located at Kota Bahru and Kuantan.

The System Architecture Design

The system architecture for this integrity monitoring is illustrated in Figure 2. The processing centre in UTM is responsible for data gathering, processing and distribution. Basically, each CORS station is equipped with GPS antenna and receiver to provide information on GPS ephemeris and raw data. Consequently, this requires additional investment in providing hardware, software, communication links, technical support and expertise especially to handle such sophisticated real-time system.[9] Thus, in this study, the data is logged by a computer server and formatted into Receiver Independent Exchange (RINEX) through the BKG NTRIP Client (BNC). BNC is an open source of multi-stream client program which is designed for a variety of real-time GNSS applications. NTRIP provides seamless access globally in real-time, and is considered the *de facto* standard for streaming GNSS data via the Internet.[10]

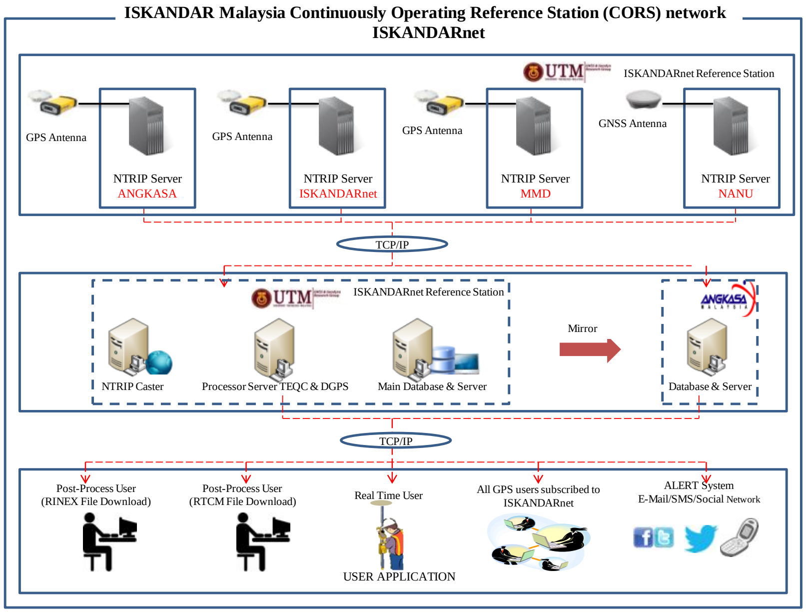


Figure 2 The integrity monitoring system architecture using ISKANDARnet CORS network

Network Transportation RTCM via Internet Protocol (NTRIP) system will stream data via the Internet in real-time. The NTRIP consists of three components: server, caster and client as shown in Figure 2. The server will stream data from the caster through NTRIP Server via Internet Protocol (IP). These data can later be retrieved from the caster through the NTRIP client. The data is decoded in RTCM and converted into RINEX. Each data streamed will be stored as long binary in MySQL format in the database. The server will restore the raw and process data in every half an hour for post process and keep in achieve. During data transmission, it is important to keep the internet connection through Transmission Transfer Protocol (TCP/IP) at all times in order to have a smooth flow of the system.

This architecture system can be divided into three (3) phases: data streaming, data processing and data performance. Generally for phase 1, the raw data in RTCM format from the each ISKANDARnet CORS will be streamed from the database server via Internet Protocol (NTRIP) as mentioned before. Thus, every ISKANDARnet CORS will continuously send raw data in real-time to the database server. For phase 2, the raw data will be processed at the UTM processing centre by using RTKlib software. In phase 3, status and information pertaining to each CORS will be stored in server every half an hour.

CORS Application

The CORS infrastructure is being used to support various applications as explained below.

Data Quality Checking

The real time data quality checking for integrity monitoring system has been implemented as research basis collaboration with other agencies. It is important to ensure valuable discussion and sharing for high navigation accuracy within Peninsular Malaysia. Data quality checking is used for user level monitoring. The data produce shows the station positioning performance. An experiment had been done using ISKANDARnet and will be discussed in Section 4.

DGPS

The ISKANDARnet can also be used to apply DGPS technique via internet base to reduce error in the user position at the unknown location. The ISKANDARnet will transmit a range error correction to the stations that typically improve positional accuracy between 1-3m. Basically, the reference station estimates the error by relying on a comparison of satellite-receiver range measurement, satellite clock error, atmospheric and orbit biases.[11] which formulate the pseudorange correction (PRC) then broadcast the correction to users by using the Internet. This technique has been examined within UTM Johor campus in dynamic motion.[12]

■3.0 INTEGRITY MONITORING IMPLEMENTATION

This section will discussed every important parameter that embraces the integrity monitoring implementation which involves data quality checking and DGPS.

Data Quality Check

NTRIP is a generic, stateless protocol based on the Hypertext Transfer Protocol HTTP/1.1.[13] The HTTP is enhanced for GNSS data streaming. A software program was designed to provide a simultaneous real-time data quality checking from multiple stations. The data was streamed from the Caster in the RTCM format and converted to RINEX file through Federal Agency for Cartography and Geodesy (BKG) Ntrip Client (BNC). The data is continuously streamed in real time and RINEX files are created in the expected interval of every two minutes for the completion of the quality analysis process.

A system was developed to process the raw data for quality check. This system was able to process raw data continuously and save it in a file for all CORSs simultaneously. Simulation process in real time was carried out using ISKANDARnet. All processes are running continuously in real time and with each full process is expected to be completed within 2 minutes.

Results from this quality analysis produced nine (9) separate parameters that provide data of the satellite at instant of time. The data was channeled to database immediately after the result was obtained. The results were channeled to database server as Long Binary Large Object (LBLOB).

DGPS Technique

The DGPS utilises a reference station at a known location to estimate error sources such as satellite clock, atmosphere and orbit biases for each receiver-satellite range measurement.[14] The DGPS technique to support precise navigation activity of ISKANDARnet system is illustrated in Figure 3.

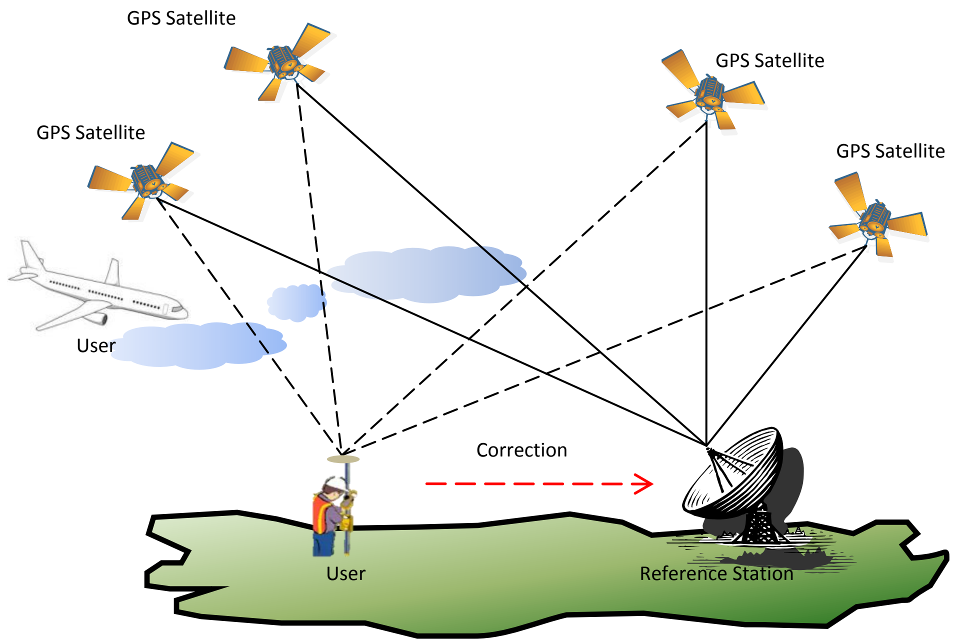


Figure 3 DGPS Technique

Database

The data flow to the database is explained in Figure 4 below. The develop application will send the TEQC and DGPS results to the database. The database server keeps data in RTCM and RINEX format for multipurpose such as post process and could be requested anytime for data evaluation. It will provide data to the processing engine if the NTRIP server experiences some problem. The real-time data is stored in the server as LBLOB in MySQL database.

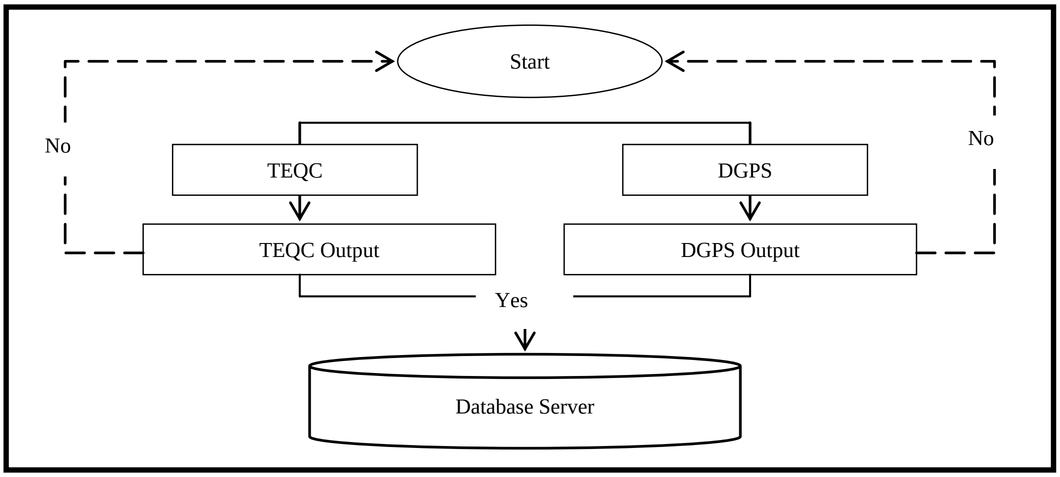


Figure 4 Data operational framework

Data Collection

In this study, data was streamed in real-time from various CORSs to control centre and processed by using Translating, Editing, and Quality Check (TEQC) and RTKlib software. Before the actual data collection, an example of the RTCM data was used to test the variation database. For preliminary test of this study, data from CORS at ISK2 and ISK3 were used. The outputs of the quality checking are nine (9) parameters namely Multipath1 and Multipath2 for L1 and L2 signals in meter respectively, Signal noise ratio1 and Signal noise ratio2 for L1 and L2 signal in arbitrary unit correspondingly, Ionospheric delay observable in meters, derivative of ionospheric delay observable in meter per minute; Satellite azimuth, Satellite elevation and Summary of all the parameters involved during the observation. Next, these output parameters are stored in MySQL database. For DGPS the output file is PRC with message type format 1, 3 and 19. The raw data from ISKANDARnet are also stored in the database.

■4.0 PRELIMINARY RESULTS

Performance of CORS Network

Integrity is the availability of a system to provide timely warnings to user when the system should not be used for navigation. [4] As the frequency and time reference of space satellites, satellite clock has a direct influence on GNSS service performance. Since the frequency and time reference are related to space satellites, thus satellite clock has a direct influence on GNSS service performance. Therefore, it is deem necessary to monitor its integrity. [3]

Quality Check

The BNC program retrieved the GPS/GNSS data through NTRIP Caster and converted into RINEX file as mention before. The output for data quality analysis will be in the form of graphic and text display in the server. The graphic display will show all pertinent information of every CORS and will be updated in real time for every 5 minutes. Figure 5 shows an example of graphic display of this study that has been done on July 16th, 2012 through Kota Bahru CORS.

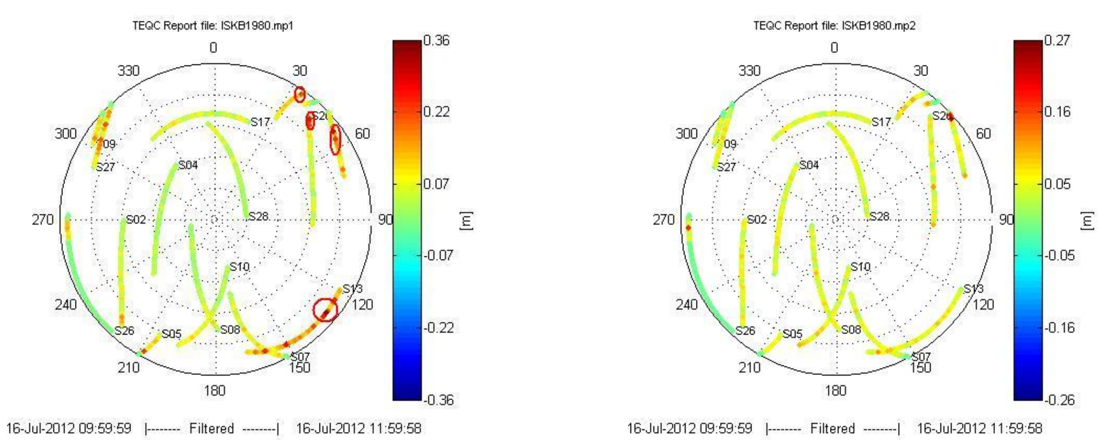


Figure 5 Graphs show multipath polar plot. The average number of satellites involve were 16. The graphical information on each CORS will be updated every 2 minutes

Performance of CORS network can be seen from the quality of data that was streamed from the CORS. The data quality analysis will be based on 3 categories as shown in Table 1 below:

Table 1 Category that could affect the performance of CORS network

Category	Atmospheric Delays	Completeness of The Data	Data Quality
Component	Troposheric Delay Ionospheric Delay	Data Gaps Missing Epochs	Signal to Noise Ratios (SNR) Multipath Cycle Slip

The value of the graphical chart is coming from data analysis results which are given in 9 different parameters. The parameter is about the satellite which is the position, multipath, and signal noise ratio, ionospheric condition and summary of all parameter for every satellite in 2 minutes data.

Performance of ISKANDARnet DGPS

The performance of ISKANDARnet CORS was evaluated from a real-time testing that has carried out at ISKANDARnet3 (ISK3) as rover and ISKANDARnet2 (ISK2) as base station on May 30th, 2013 from 18:42:03 to 19:59:53 UTC time. The two stations were separated about 56.4 km from each other.

Figure 6 and 7 show the scattered plot of coordinates for ISK2 that applied correction from International GNSS Service (IGS) reference station (precisely scattered). Figure 6 indicate the results obtained from RTKlib software that was used to process DGPS data. Meanwhile, Figure 7 shows the graphical results for ISKANDARnet DGPS performance that has been evaluated through Microsoft Excel. Both graphs show the positional accuracy of ISK2. The accuracy of ISK2 is shown in Table 2 below

Table 2 Accuracy of ISK2 in GDM 2000

Observation line number	Latitude	Longitude	Height
Original	1.362089306	103.553324100	52.6310
1	1.495332503	103.9124943	47.0615
2060	1.495335389	103.9124887	46.3061
4145	1.495340576	103.912488	46.08
Average	0.13324685	0.359166233	6.14846667
Accuracy	0.38398629		

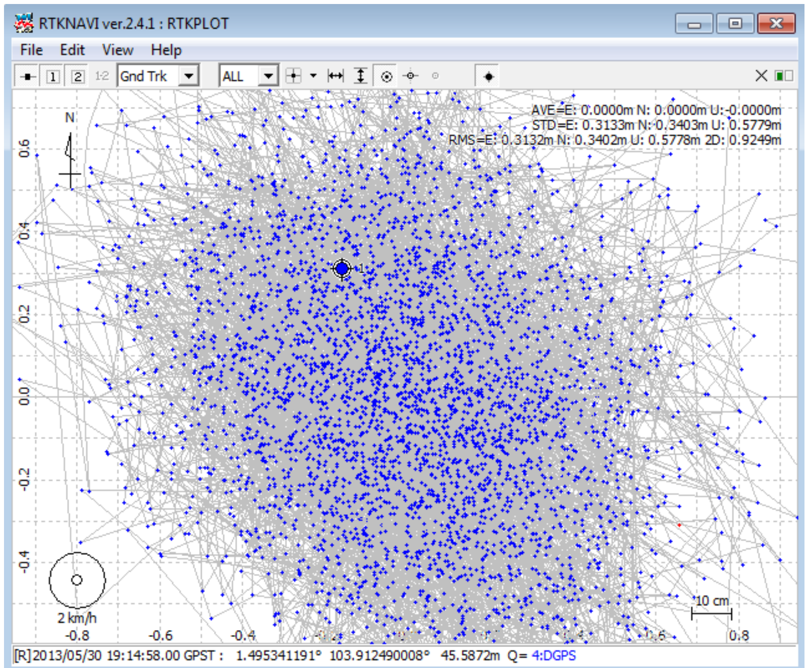


Figure 6 Positional accuracy of ISK2

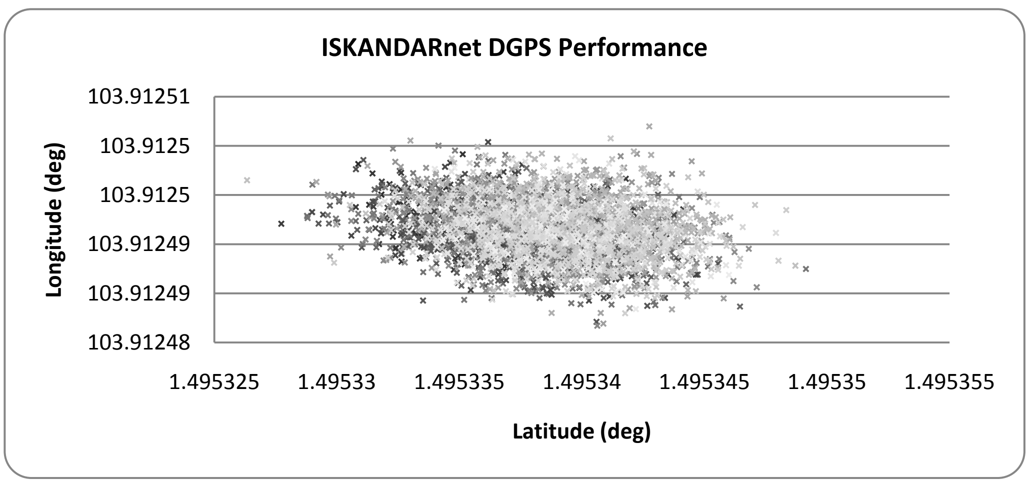


Figure 7 The Graphical Results for ISKANDARnet DGPS Performance. Accuracy is at ±0.38398629

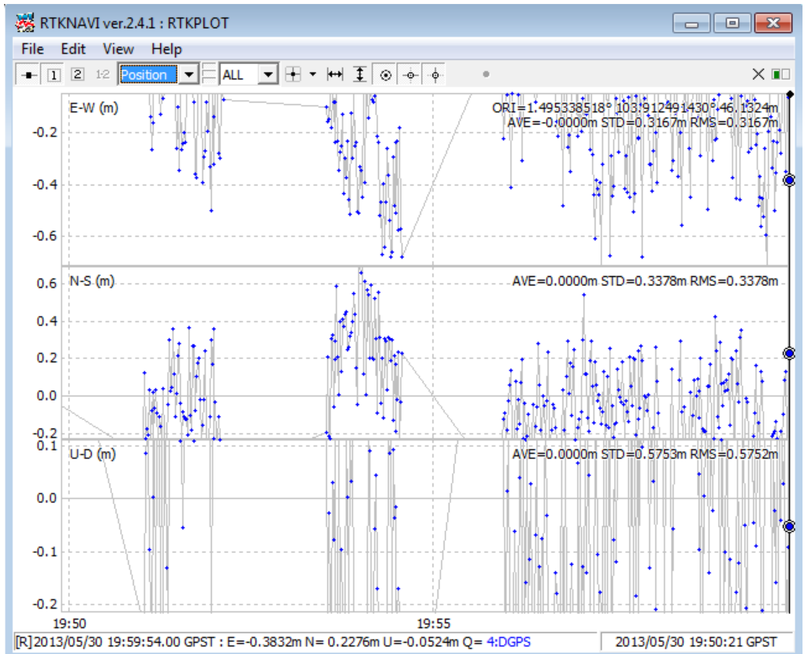


Figure 8 Standard deviation of ISK2.

From Figure 8, the standard deviation of ISK2 lies in the range of 0.3m to 0.5m for all three graphs respectively. Therefore, it is proved that by having DGPS correction from a reference station, the accuracy of the user position can be improved up to cm level.

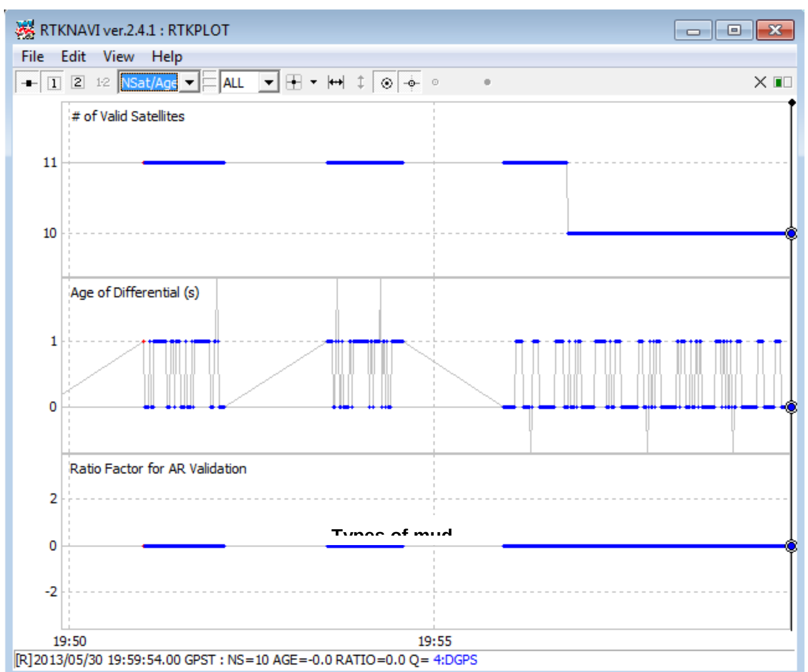


Figure 9 Number of valid satellites, age of the differential and ratio factor.

The first part of graph illustrated in Figure 9 shows the number of valid satellites for positional accuracy solution proportional to time (UTC). Basically, the number of satellites needed for solution is four but by having more than 4 satellites will give a redundancy data which can give a good result. From the result, it shows that there are eleven (11) satellites in view at the moment, therefore the spatially decorrelated error that vary with space can be reduced and may improve the positional accuracy of the user around ISK2. So, it can be concluded that, ISK2 and ISK3 were good with less sky view obstruction in the area. In addition, the second graph in Figure 9 shows that the time different between the observation data epoch of the rover receiver and the base station in second (age).

The result shows that, although the two stations were separated about 56.4 km from each other, the age of the differential still within the range of one second for most of the time and only some occasions it goes less than one second i.e. at 18:47:30 and 18:53:50. It is expected that during that time, the Internet connection was down for a moment. Generally, it can be summarized that ISKANDARnet CORS are stable, giving the correction with no hardware problem during that time.

4.0 CONCLUDING REMARKS AND FUTURE WORKS

This paper described a strong collaboration between the Government agencies with the University. The recent establishment is supported by an existing ISKANDARnet CORS network. The paper is focusing on the performance of ISKANDARnet integrity monitoring for supporting precise navigation activities within Peninsular Malaysia. Thus, the GPS/GNSS data is processed for quality checking and DGPS. The data quality will be indicated through graphical chart. Last but not least, the processed data is kept in the UTM server. All the operation system must be of real-time data streaming.

Further study needs to be done in order to upgrade the network development over the nationwide. Some primary outages need to be aware by notifying the user through social network and email. As a conclusion, the improved facility will bring extra benefits not only for the collaborative groups, but also for all service subscribers in supplying consistent GPS service in support of precise activities within Malaysia.

Nomenclature

CORS	- Continuously Operating Reference Station
DGPS	- Differential GPS
GNSS	- Global Navigation Satellite System
GPS	- Global Positioning System
ISKANDARnet	- ISKANDAR Network
MCS	-Master Control Station
NTRIP	- Network Transport of RTCM via Internet Protocol
RINEX	- Receiver Independent Exchange Format
RTK	- Real-Time Kinematic
TCP	- Transmission Control Protocol
UTM	- Universiti Teknologi Malaysia

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