PERFORMANCE ANALYSIS OF GPS AIDED GEO AUGMENTED NAVIGATION (GAGAN) OVER SRI LANKA

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ABSTRACT

With the growing demand for accurate and reliable positioning and navigation in various surveying and mapping applications, car navigation, aviation, maritime, and numerous geospatial and remote sensing applications, there has been a significant move towards the use of real-time GPS augmentation systems with local and wide area differential positioning capabilities. Accordingly, two networks of Continuously Operating Reference Stations (CORS) were established very recently in Sri Lanka covering a part of Colombo district for real-time augmentation as a paid local area service.
However, Satellite-Based Augmentation Systems (SBAS) are being developed worldwide due to their unique advantage of wide area coverage. The US Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay system (EGNOS) and the Japanese Multi-functional Satellite Augmentation System (MSAS) are good examples. Similarly, GPS Aided Geo Augmented Navigation (GAGAN) is an Indian implementation of SBAS, developed jointly by Airports Authority of India (AAI) and Indian Space Research Organization (ISRO) and announced its full operation potential in year 2013 with three (03) geo stationary satellites in space covering a huge area beyond Indian Territory, extending from Africa to Australia.
With the availability of GAGAN signal-in-space (SIS), this study focused on analysing the improvement in position solution with GAGAN corrections over Sri Lanka. In order to test its performances, several dual and single frequency GNSS receivers have been used for this experiment and one receiver is configured as SBAS receiver and other two were kept as GPS stand-alone receivers. It is found that accuracy in position improved significantly in SBAS receiver due to real-time GAGAN corrections. Moreover, for the initial investigation of its coverage over Sri Lanka; observations were carried out over seven (07) known control stations of 6 different districts and the results confirmed its usability over tested areas.

1. BACKGROUND

Global Navigation Satellite System (GNSS) technology enables land, sea, airborne and space users to determine their three dimensional position, velocity and time, twenty four hours a day, in all weather, anywhere in the world. GNSS is based on several globally available satellite based positioning systems including the United States' GPS, Russia's GLONASS, China's Beidou, the expected European Union's Galileo, and the Regional systems such as Japan's Quasi Zenith Satellite System (QZSS) and Indian Navigation Satellite System (IRNSS), etc. It has been noticed that the use of satellite based positioning and its integrations in various applications are growing rapidly within Sri Lanka after its three decades of civil war. The country is on a rapid infrastructure development and within next several years of which can obviously expect a higher growing demand for accurate and reliable satellite based positioning and navigation in various surveying and mapping applications, car navigation, aviation, maritime, and numerous geospatial and remote sensing applications in and around Sri Lanka. According to the average number of GNSS satellites expected to be visible across the globe by 2020 (http://www.multignss.asia/campaign.html), the future GNSS applications in Sri Lanka will benefit significantly through higher visibility of GNSS satellites. While the higher availability ensure the reliability of satellite based positioning and navigation and it also encourages the use of GNSS in most of all possible applications. According to the EU market research on GNSS for the year 2015 (https://www.gsa.europa.eu/2015-gnss-market-report); the use of GNSS devises by 2020 would be almost same as the world population due to the significant improvement of location based services (LBS) with respect to the applications in Road Transportation, Aviation, Maritime, Rail, Agriculture, Surveying and, Timing & Synchronisation. However, all of these LBS's are directly link to a GNSS device with slandered positioning capabilities. Irrespective to the rapid development of positioning and navigation satellite systems and innovative applications with advanced hardware and software, the ultimate accuracy of positioning and navigation would still significantly influence by measurement errors. The most acceptable and reliable possibility to ensure the accuracy of the GNSS is to use one of the key benefit of differential GPS (DGPS) to reduce or eliminate many of the measurement

errors as a group. To cater the present day requirements of GNSS applications there has been a significant move towards the use of real-time differential augmentation systems with local and wide area differential positioning capabilities.
However, the accuracy and reliability of the differential corrections broadcast by the DGPS reference station depends on the tracking capability and the nature of its surrounding environment. Also, for real-time applications, the validity of the corrections estimated and broadcast by the DGPS reference station is restricted to specific local users. The larger separation of distances between the reference and the rover, errors estimated at the reference site become de-correlated with those errors effected at the rover location due to the spatial difference between the error sources. These logistical, economic and technical limitations have primarily contributed to the evolution of multi-reference (or network) DGPS techniques. To provide nationwide multi-reference DGPS coverage, however, a multitude of differential base stations are required with all sorts of GNSS and communication equipment. This would obviously be overly expensive and uneconomical. Therefore, wide area differential GPS (WADGPS) techniques have been adopted for such a purpose.

1.1 Satellite-Based Augmentation Systems (SBAS)

Satellite-Based Augmentation Systems (SBAS) are being developed worldwide due to their unique advantage of wide area coverage to use as wide area differential GPS (WADGPS) technique to improve the accuracy of GNSS observations over a large spatial region. The US Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay system (EGNOS) and the Japanese Multi-functional Satellite Augmentation System (MSAS) are good examples.
A typical WADGPS mathematical algorithm combines the various WADGPS corrections received from the difference reference stations to produce locally-valid single set of DGPS corrections. The algorithm accounts for spatial decorrelation of GPS error sources at the different reference stations due to the large separation distances involved [Ashkenazi et al.,1993]. All the WADGPS algorithms used can be classified into three groups: measurement domain, position domain and state-space domain algorithms [Abousalem, 1996]. Measurement domain WADGPS algorithms provide DGPS network corrections computed as the weighted mean of the various DGPS base station corrections. A possible disadvantage of such algorithms, however, is the degradation of the correction accuracy with the distance from the network centroid. Position domain WADGPS algorithms, on the other hand, provide DGPS position solutions computed as the weighted mean of the different DGPS position solutions resulting from using each of the available DGPS corrections independently. In other words, each of the incoming set of DGPS corrections is used separately to produce an independent position fix for the remote receiver. The resulting position fixes are then weighted and averaged to produce the final solution.
Finally, state-space domain WADGPS algorithms, as used by WAAS and EGNOS, provide highly accurate baseline-independent corrections using a number of DGPS reference stations equipped with GPS receivers (usually of the dual frequency type) and complex software. The algorithm models the involved GPS error sources including satellite clocks and orbits, the ionosphere, the troposphere and the reference station clocks. The principle behind the various state-space models developed so far is to use the available multiple sets of WADGPS corrections to estimate the different error components involved, and thus be able to estimate local measurement errors. Therefore, the majority of state-space WADGPS reference networks employ dual-frequency GPS receivers for real-time dual-frequency ionospheric modeling. Users typically receive their differential corrections in multiple components to be integrated within their equipment with the locally measured GPS data. In the case of WAAS and EGNOS, the users receive their corrections in the RTCA DO-229 format which provides satellite clock corrections, satellite orbital corrections and ionospheric corrections all in separate components [FAA, 1997].

1.2 GPS Aided Geo Augmented Navigation (GAGAN)

GPS Aided Geo Augmented Navigation (GAGAN) is an Indian implementation of SBAS, developed jointly by Airports Authority of India (AAI) and Indian Space Research Organization (ISRO). The Directorate General of Civil Aviation (DGCA) in India certified GAGAN's full operation potential by December, 2013 with three (03) geo stationary satellites in space covering a huge area beyond Indian Territory, extending from Africa to Australia. In the GAGAN system, location-specific ionosphere induced signal propagation delay is mapped onto multiple grid points of 5° by 5° latitudes and longitudes as shown in figure 01. Each grid point is called an ionospheric grid point (IGP). Ionospheric delay is estimated for each of these IGPs by utilizing the observations of precisely surveyed network of 15 ground reference stations called Indian Reference Stations (INRES) established throughout India.
According to the GAGAN system architecture illustrated in figure 2, Indian Master Control Centers (INMCC) located at Bangalore receives the data collected by all the reference stations and uses this data to calculate the differential corrections and the ionospheric delay estimates for each of the observed GNSS Satellites and the IGPs respectively. The compiled corrections for each monitored GNSS satellite are then uplinked to geostationary satellites GSAT-8 and GSAT-10 as SBAS messages and which then broadcast the same messages on the same GNSS frequency, but with different data rate and PRN code allowing SBAS compatible receivers to identify these satellites and receive,

decode and process the correction and integrity data. GSAT-8 and GSAT-10 transmit the data with codes 127 and 128, respectively, and will appear on some SBAS-compatible GNSS receivers as satellites 40 and 41. A third satellite, GSAT-15 will serve as an "in-orbit spare", to be switched on if either GSAT-8 or GSTA-10 fail.

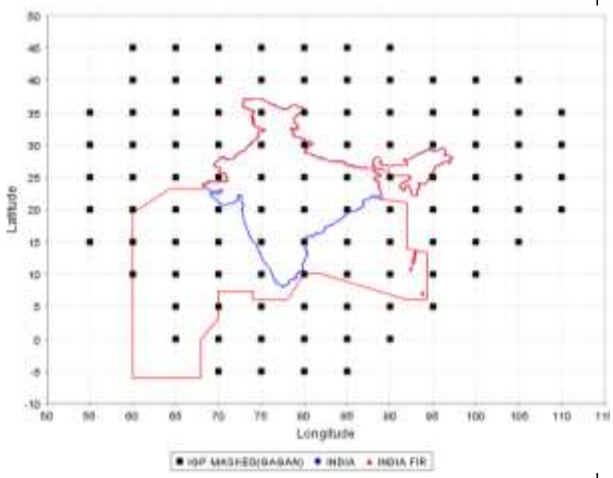

Figure 1: Ionospheric Grid Points (IGP) of GAGAN

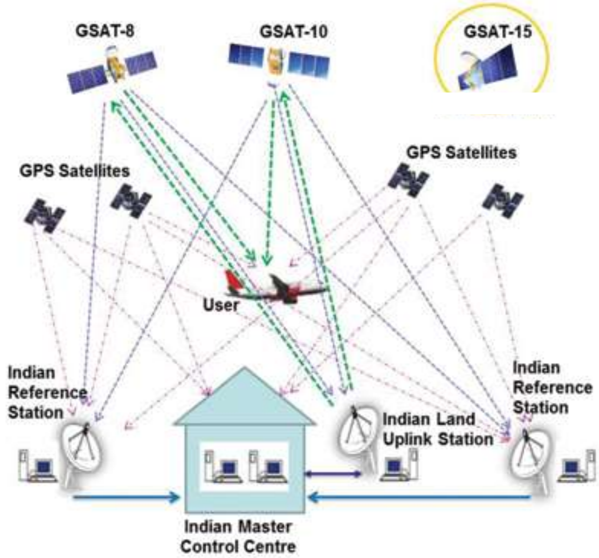

Figure 2: GAGAN system architecture

2. PERFORMANCE ANALYSIS

There are many GPS users in Sri Lanka in different fields such as surveying, geodesy, GIS professionals, security agencies, intelligent transportation, maritime, highways, railways, telecom industry, personal users with location based applications and etc. For any of these professional work; accurate, reliable, continuously available and cost effective correction services are essential. However, due to the limited availability of free DGPS services and cost of utilizing personal DGPS; most of the GPS/GNSS users in Sri Lanka, except professional land surveyors, work with L1 or L1/L2 GPS or GNSS receivers as standalone observations without any real-time or post-processing differential corrections. However, GAGAN is a satellite based augmentation service (SBAS), freely available over Indian region including Sri Lanka, and it is operated to reduce ionospheric, satellite clock and ephemeris errors from the GPS/GNSS satellites to improve the accuracy of positioning and navigation. Unfortunately, SBAS technology is a new experience for GPS/GNSS users in Sri Lanka and yet not many of them even know about the availability of GAGAN over Sri Lanka. However, GAGAN service is freely available since early 2014; hence, the general standalone GPS/GNSS users in Sri Lanka can get the benefit of real-time positional accuracy enhancement with the utilization of SBAS capable GPS/GNSS. Therefore, the primary objective of this study is to test the availability of GAGAN satellite based augmentation service over Sri Lanka and to analyses its operational accuracy with compare to general stand alone L1 and L1/L2 observations. Moreover, majority of GIS professionals use L1 GPS/GNSS receives to collect point, line, and polygon spatial feature for various decision making GIS and remote sensing applications. Hence, this study also focused to assess the GAGAN service capability to improve the accuracy of point, line, and polygon feature collection over Sri Lanka.

2.1 Study area and instruments used

For this study only seven GPS observation locations were selected in six districts of three provinces in Sri Lanka for this initial experiment. The control stations of national geodetic network were selected for the observations. 24-hour observation is conducted over a temporally established known station. Garmin Etrex 10 –GPS L1 Receiver, SXBLUE-IIB receiver with GPS L1 + GAGAN + SBAS capability, PENTAX GPS+ GLONASS L1/L2 receiver and Kolida Total Station with 2'' angle accuracy and 2mm distance accuracy were used for the observations and testing. In order to test the performances of GAGAN service the single frequency SXBLUE-IIB receiver is configured as a SBAS receiver and others were kept as GPS stand-alone receivers.

2.2 Analysis method

In order to analysis the performance of GAGAN active receiver in point feature collection, 10 minutes of observations in static mode is performed at all the 7 known points and compare the achievable accuracy with respect to L1 and L1/L2 standalone observations. For the study of linear and area feature observation accuracies the three sample line and area features collected with GAGAN active receiver are compared with Total Station measurements of the same. Moreover, observations were carried out for 24 hours to validate the availability of GAGAN corrections throughout the day.

3. RESULTS AND ANALYSIS

Table 1 shows the average values of positional error for 10 minutes of observations at the selected 7 known points over Sri Lanka. According to the resulted positional accuracies, GAGAN active L1 receiver always shown significant accuracy improvement over L1 uncorrected observations. Further, except at two locations all the other stations it has shown improved accuracy even over L1/L2 uncorrected observations. Five out of the 7 observation locations the calculated average 3D positional errors are lower than 1m.

Table 1: 3D positional accuracy comparison at deferent locations over Sri Lanaka

Observation location	Average 3D positional error (m)			
	L1 receiver	L1/L2 receiver	GAGAN active L1 receiver	Highest accuracy with GAGAN
1. Narammala	4.589	1.747	1.595	**YES**
2. Athugala	3.351	1.579	0.622	**YES**
3. Gannoruwa	1.754	0.780	0.906	NO
4. Kegalle	6.867	0.839	1.361	NO
5. Homagama	4.015	1.059	0.932	**YES**
6. Ambalangoda	3.437	1.008	0.346	**YES**
7. Mathara	2.139	1.394	0.899	**YES**

Three line features were observed as a combination of different number of points and compared the distance difference between the total station observed distance and the distance calculated with GAGAN receiver observed points. As shown in table 2, the distance difference is well within centimeter level and the accuracy is not significantly influenced by the number of points included for each line.

Table 2: Line feature accuracy assessment

Feature	No of Observed points		Total Distance (m)		Distance difference (m)
	GAGAN Receiver	Total Station	GAGAN Receiver	Total Station	
Road center line	29	29	560.044	560.000	0.044
Edge of a road	15	15	299.435	300.000	0.565
Line on a play ground	3	3	64.422	64.230	0.192

In order to test the accuracy of area features a playground with a clear boundary is selected and the area is calculated with GAGAN active L1 receiver with observing 11 points to compare it with total station surveyed area. Table 3 shows that quantitative results of accuracy assessment. Accordingly, the area measurement difference is $43m^2$ and 1.68 perches. This accuracy is sufficient for GIS applications with medium or small scale mapping. Area measurements are very important for cadastral surveying which mainly deals with measurements of land plots. According to Sri Lanka Survey Department regulations the acceptable difference for cadastral surveying is calculated based on following equation. Based on which the acceptable difference for the tested observation as in table 3 is $7.79m^2$ and 0.31 perches. Therefore, accuracy is not according to the requirement of cadastral surveying.

∆€= +-0.04 [P sin(360/N)]1/2

∆€- Acceptable difference in Perches, P - Area computed in perches, N - Number of Observed points

Table 3: Area feature accuracy assessment

	GAGAN Receiver	Total Station
No of Observed points	11	11
Areas (A. R. P)	0 A 2 R 29.86 P	0 A 2R 31.54 P
Areas (Ha)	0.2779	0.2821
Area Difference	$43\ m^2$ (1.68 P)	

Further analyses were carried out to test the GAGAN 3D positional accuracy over 24 hours of continuous observations. The accuracy is compared with uncorrected and differentially corrected coordinates obtained from L1 GPS receiver as illustrated in figure 3.

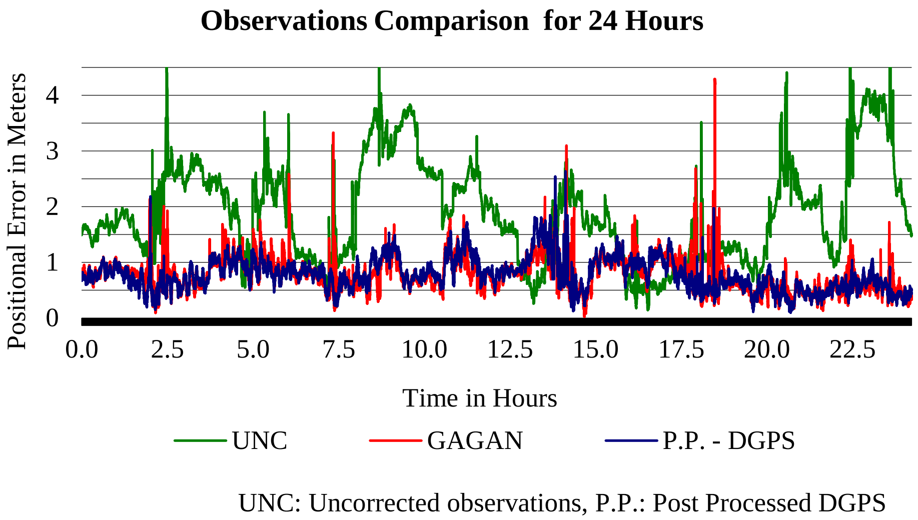

Figure 3: 3D positional accuracy for a continuous observation of 24 hours for L1 GPS receiver

The percentage of 3D positional accuracy, for the same 24 hours of observations, according to less than 0.5m, 1.0m and greater than 1.0m is calculated and presented in table 4.

Table 4: Percentage of 3D positional accuracy for 24 hours of observations

Observation mode	Percentage of observations		
	< 0.5m	< 1.0m	>1.0m
UNC	0.00%	7.50%	92.50%
GAGAN	18.90%	78.90%	21.10%
P.P. -DGPS	23.50%	85.00%	15.00%

4. Conclusion

According to system architecture of GAGAN, only two satellites PRN 127 and 128 are currently available for GAGAN users. Also according to all observations done in different areas the GAGAN active L1 GPS receiver only tracked PRN 128 (GSAT-10). For this initial study, GPS observations were done at only 7 locations in 6 districts, at each point the GAGAN satellite signal was tracked without any problem. Less than 1-meter accuracy can be achieved by stand-alone GPS observation in real time with using GAGAN signal by GPS L1/GAGAN capable receiver. The 24 hour observations confirmed the accuracy and reliability of the GAGAN service and it has higher potential to use in various applications from LBS to spatial data collection.

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