Low-cost Ionospheric Scintillation Detector using Software-based GNSS Receiver

La The Vinh
Hanoi University of Science and Technology, No. 1, Dai Co Viet, Hai Ba Trung, Hanoi, Viet Nam
Received: May 19, 2016; Accepted: November 03, 2017

Abstract

In this study, we investigate in the use of software-based GNSS receiver to detect ionospheric scintillation in Vietnam. Ionospheric scintillation is well-known for its bad effect on the precision of GNSS receivers. Vietnam locates at a low-lattitude region which is one of the most-affected region if any scintillation occurs. Therefore, it is important to be able detect and store the data of the receiver during scintillation periods for later analysis and mitigation. However, professional ionospheric scintillation monitoring machin are often expensive and not easy to access. The main goal of this work is to propose a low-cost method to detect the scintillation and to save its data for later use by utilizing a software-based GNSS receiver.

Keywords: Ionosphere, Scintillation, GNSS, GPS

1. Introduction

In Global Navigation Satellite Systems (GNSS), it is well-known that the ionosphere layer strongly influences on the precision of the GNSS receivers, especially at low-lattitude regions due to the high value of the total electron content (TEC). In particular, once a strong ionosphere scintillation happens, it may totally disrupt GNSS signal's phase and amplitude making the receiver unable to perform satellite aquisition and tracking. A number of publications has shown that strong ionosphere scintillations often happen at the time of strong solar activity, and at near-equator regions, including Vietnam [1-4].

Therefore, ionosphere-related research is gaining more attention from the researchers . Most popular research topics include characterizing TEC [2, 4], modeling the ionosphere layer [5-8], monitoring inosphere scintillations [9-12], etc. It can be seen that, those studies of the ionosphere are typically conducted with precision navigation receivers tracking both the multi-frequency carrier and code phase. However, the carrier and code measurements may not be available when the receiver is not able to accquire any satellite in a seriously strong scintillation. Some commercial GNSS logging equipments are available for capturing raw data in such a situation. Nevertherless, GNSS raw data takes a huge amount of storage space (approximately 16 MB/s). Hence it is not pratical to keep the data logger running continuously for hours or days.

Motivated by the need of a continuosly operating GNSS raw data logger for ionospheric scintillation monitoing, we propose in this work a monitoring systemwhich is capable of: (1) computing scintillation index in realtime, (2) activating data logger if and only if there is a scintillation (the index is over a predefined threshold), and (3) capturing raw GNSS data even if a strong scintialltion disabling the receiver from satellite accquision and tracking.

The remaining of our paper is organized as following: in section 2, we give a detail description of our method and preliminary result; our conclusion is drawn in section 3.

2. The proposed methodand results

Fig. 1 describes our system architecture which include four main parts:

- A low-cost hardware front-end for receiving raw GNSS I/Q samples from satellites
- A software-based receiver which is responsible for acquiring satellite and extracting S4 scintillation index of trackable satellites.
- An online software ephemeris analyzer to calculate satellites' position in real-time from IGS (International GNSS Service) data stream.
- A software logger to record raw GNSS data to storage for later analysis.

* Corresponding author: Tel.: (+84) 985.290.681
Email: vinh.lathe@hust.edu.vn

For the receiving front-end, we decide to choose a low-cost one from Sparkfun† which is illustrated in Fig. 2 with the below features:

- Operating frequency: L1 (1.575 GHz)
- Intermediate Frequency: 4.092 MHz
- Bandwidth: 2.5 MHz

Bit per sample: 2 bits

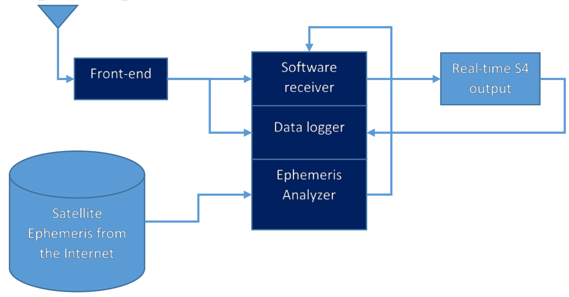

Fig. 1. Block diagram of the proposed monitoring system

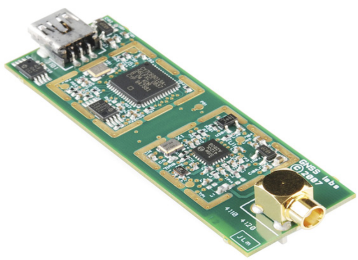

Fig. 2. SIGE front-end

For the software receiver, we use our existing one [13]. What we focus on (in this work) is to develop and integrate the S4 scintillation index computing algorithm into the software engine. Although phase scintillation is another index, we are not using this value because to precisely compute the phase measurement, an expensive oscillator is required, which obviously conflicts with our purpose of a low-cost system.

To compute the S4 scintillation index, we directly utilize the output (I/Q samples) from the tracking phase of our software-based receiver. We first compute the narrow band and wide band power of every 20-millisecond period (M=20) from 1kHz I/Q samples (I_i and Q_i):

$$WBP = \sum_{i=1}^{M} (I_i^2 + Q_i^2) \quad (1)$$

and $NBP = (\sum_{i=1}^{M} I_i)^2 + (\sum_{i=1}^{M} Q_i)^2$ (2)

Then we compute S4 index using the below equation:

$$S_4 = \sqrt{\frac{\langle SI^2 \rangle - \langle SI \rangle^2}{\langle SI \rangle^2}} \quad (3)$$

where $\langle . \rangle$ denotes the average value over a period of 60 seconds. Finally, we detrend the S4 values using a low-pass filter as suggested in [14]. Fig. 3 illustrates S_4 values calculated from a period of I/Q data with a scintillation observed (about 50 minutes at the beginning of the period).

It should be noted that when a scintillation affects the amplitude of I/Q samples, the S_4 values are significantly higher than those of the period without a scintillation. Before integrating the above algorithm into our real-time software receiver, we validate the algorithm by comparing our S4 values with those of recorded by a commercial-grade GNSS receiver (Septentrio Rx3). The data for the validation was recorded on March, 18th, 2013. Fig. 4 shows the C/N_0 of satellites for validating.

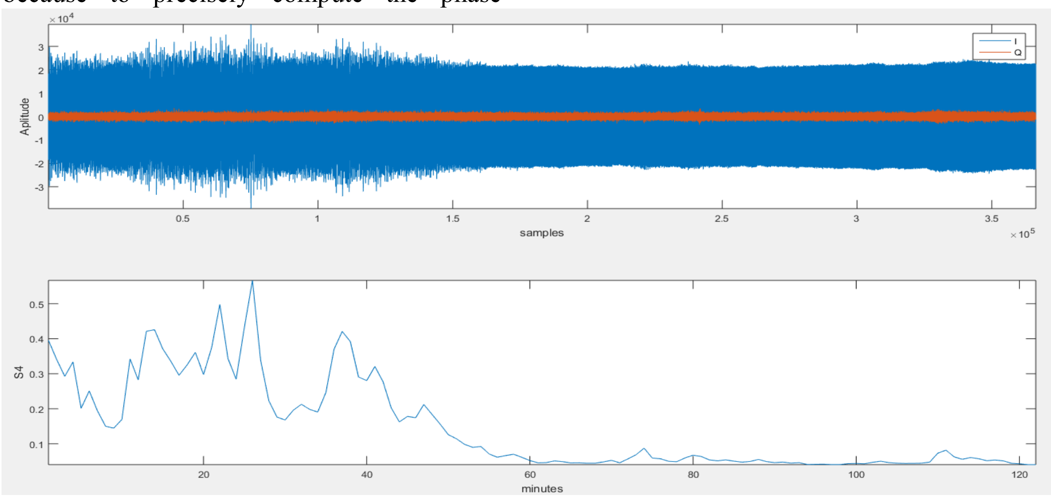

Fig. 3. I/Q samples and S_4 calculated values in 120 minutes

† https://www.sparkfun.com/ products/retired/10981

In the comparison, three satellites (PRN 7, 11, 19) are selected to demonstrate different ionospheric scenarios: no scintillation, strong scintillation and partially scintillation. The comparisions are illustrated in Fig. 8. As can be seen, S4 values computed by our post-processing algorithm, software receiver and the professional Septentrio receiver reflect similar trends; though the absolute values are somewhat different due to the detrending strategies of each method. Detrending is used to filter out high-frequency changes and to keep only low-frequency changes probably caused by inospheric scintillation.

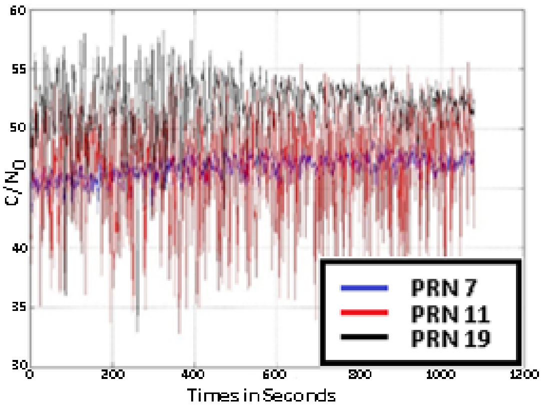

Fig. 4. C/N$_0$ of satellites (7 – blue, 11 – red, and 19 – black)

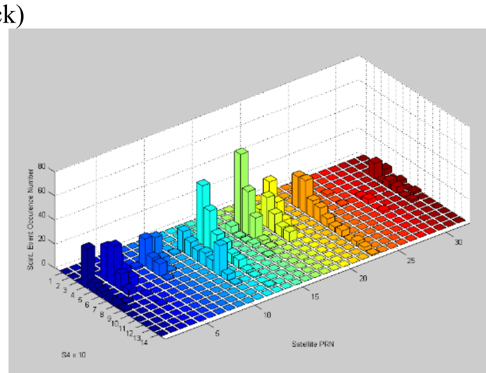

Fig. 5. Number of scintillations accumulated by satellites and S$_4$ values (x10)

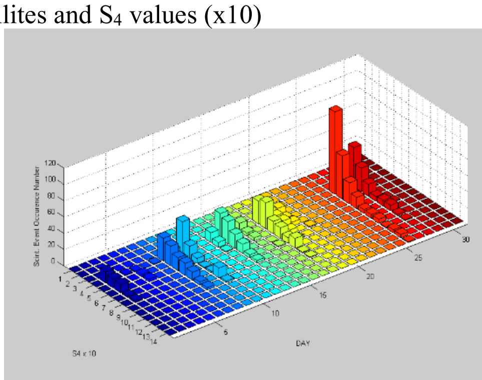

Fig. 6. Number of scintillations accumulated by day and S$_4$ values (x10)

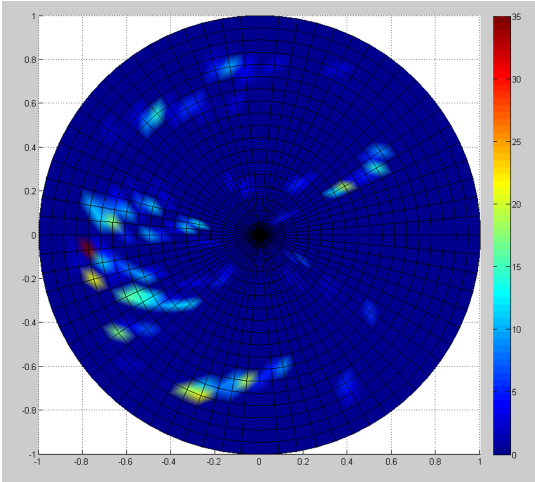

Fig. 7. Skyplot of scintillations over a month

In addition to validating the calculation algorithm, we have developed a simple visualization tools to analyse the scintillation characteristics from the collected dataset. Fig. 5, 6, and 7 demonstrate useful characteristics of scintillation data collected at Hanoi in March, 2013.

In Fig. 5 and Fig. 6, we count the total occurrence number of the scintillations in March, 2013 accumulated by satellites and days. It can be seen that March 26 and 28 have the highest numbers of scintillations. This fact can be explained as the effect of the March Equinox. Fig. 7 gives another aspect of the scintillation in March, 2013, where we can see some regions on the sky with a high probability of scintillation.

3. Conclusions

In this paper, we have shown that S$_4$ is a good index for detecting ionosphere scintillation and we have completed a properly implementation of S$_4$ calculation algorithmusing raw I/Q samples.

This approach does not require high-cost, specific-designed hardware; therefore it can be easily deployed on any personal computer. However, the biggest disadvantage of this approach is the calculation speed since the software-based receiver has to process millions of samples to compute one S$_4$ value for each satellite. To overcome this limitation, we propose to calculate s$_4$ sequentially satellite-by-satellite. Obviously there is a probability of missing short scintialltions if they happend with the satellites which are not currenly processed by the software receiver.

The proposed automatic logger system is used in our EU-granted ERICA project in 12 months and has provided a database of more than 4 TB raw GNSS measurement (I/Q samples), which helps finding interesting ionospheric events such as the so-called Saint Patrick magnetic storm [14].

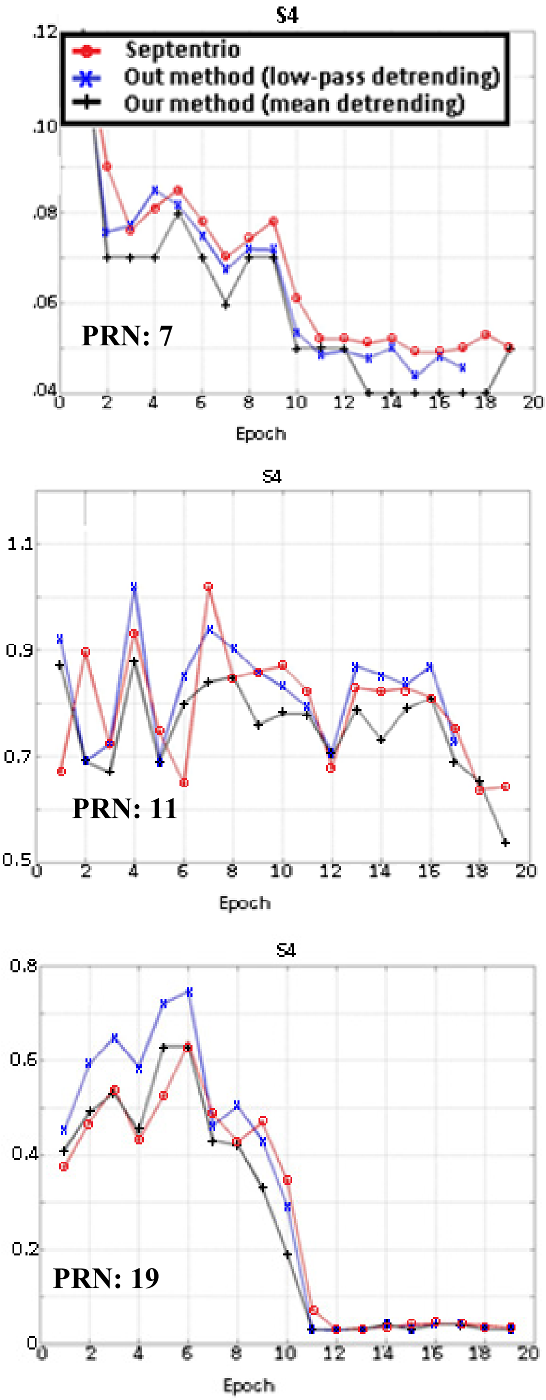

Fig. 8. S_4 values of our method (+ black – mean detrending and x blue – lowpass detrending), and Septentrio receiver (o red)

Acknowledgement

This research was supported by Hanoi University of Science and Technology under the contract number T2016-PC_010.

References

[1]. Lê Huy Minh, A. Bourdillon, P. Lasudrie Duchesne, R. Fleury, Nguyễn Chiến Thắng, Trần Thị Lan, Ngô Văn Quân, Lê Trường Thanh, Hoàng Thái Lan, Trần Ngọc Nam, "Xác định hàm lượng điện tử tổng cộng tầng điện ly ở Việt Nam qua số liệu các trạm thu tín hiệu vệ tinh GPS", Tạp chí Địa Chất, Số 296, (2006) 54-62.

[2]. Le Huy Minh, Tran Thi Lan, R. Fleury, Le Truong Thanh, Nguyen Chien Thang, Nguyen Ha Thanh, "TEC variations and ionospheric disturbances during the magnetic storm in March 2015 observed from continuous GPS data in the Southeast Asia region", Vietnam Journal of Earth Sciences, vol. 38(3), (2016) 287-305.

[3]. Le Huy Minh, Tran Thi Lan, C. Amory-Mazaudier, R. Fleury, A. Bourdillon, J. Hu, Vu Tuan Hung, Nguyen Chien Thang, Le Truong Thanh, Nguyen Ha Thanh, "Continuous GPS network in Vietnam and results of study on the total electron content in the South East Asian region", Vietnam Journal of Earth Sciences, vol. 38(2), (2016) 153-165.

[4]. M. Le Huy, C. Amory-Mazaudier, R. Fleury, A. Bourdillon, P. Lassudrie-Duchesne, L. Tran Thi, T. Nguyen Chien, T. Nguyen Ha, P. Vila, "Time variations of the total electron content in the Southeast Asian equatorial ionization anomaly for the period 2006–2011", Journal of Advances in Space Research, vol. 54, (2014) 355–368.

[5]. Deshpande, K. B., Bust, G. S., Clauer, C. R., Scales, W. A., Frissell, N. A., Ruohoniemi, J. M., and Weatherwax, A. T., "Satellite-beacon Ionospheric-scintillation Global Model of the upper Atmosphere (SIGMA) II: Inverse modeling with high-latitude observations to deduce irregularity physics". Journal of Geophysical Research: Space Physics, vol. 121(9), (2016) 9188-9203.

[6]. L.T. Vinh, P. X. Quang, A. Garcia-Rigo, A. Rovira-Garcia and D. Ibañez-Segura, 2013, "Experiments on the Ionospheric Models in GNSS", IEICE Technical Report, vol. 113, no. 335, ISSN 0913-5685.

[7]. Oliveira Moraes, A., Paula, E. R., Muella, A. H., Tadeu, M., and Perrella, W. J., "On the second order statistics for GPS ionospheric scintillation modeling". Radio Science, 49(2), (2014) 94-105.

[8]. Priyadarshi, S., "A review of ionospheric scintillation models". Surveys in geophysics, vol. 36(2), (2015) 295-324.

[9]. Povero, Gabriella; Alfonsi, Lucilla; Spogli, Luca; Di Mauro, Domenico; Cesaroni, Claudio; Dovis, Fabio; Romero, Rodrigo; Abadi, Prayitno; Le, Minh; La, Vinh; Floury, Nicolas, 2017, "Ionosphere Monitoring in South East Asia in the ERICA study", Accepted on the Journal of the Institute of Navigation (NAVIGATION), ISSN 0028-1522.

[10]. Sridhar, M., Rao, C. S., Raju, K. P., and Ratnam, D. V., "Ionospheric scintillation monitoring at a low

latitude Indian station during geo-magnetic storm”. In Proceedings of the International Conference on Electronics and Communication Systems (ICECS), (2014) 1-6.

[11]. Trần Thị Lan, Lê Huy Minh, R. Fleury, Trần Việt Phương, Nguyễn Hà Thành, “Đặc trưng xuất hiện nhấp nháy điện ly ở Việt Nam trong giai đoạn 2009 – 2012”, Tạp chí Các Khoa học về Trái đất, Số 37(3), (2015) 264-274.

[12]. Van Dierendonck, A. J., Klobuchar, J., & Hua, Q., “Ionospheric scintillation monitoring using commercial single frequency C/A code receivers”. In Proceedings of ION GPS, vol. 93, (1993) 1333-1342.

[13]. Hai Ta, T., Minh Truong, D., Thanh Thi Nguyen, T., Trung Tran, H., Dinh Nguyen, T., and Belforte, G., “Multi-GNSS positioning campaign in South-East Asia”, Coordinates, vol. 9(11), (2013) 11-20.

[14]. Spogli, Luca and Cesaroni, Claudio and Di Mauro, Domenico and Pezzopane, Michael and Alfonsi, Lucilla and Musicò, Elvira and Povero, Gabriella and Pini, Marco and Dovis, Fabio and Romero, Rodrigo and Linty, Nicola and Abadi, Prayitno and Nuraeni, Fitri and Husin, Asnawi and Le Huy, Minh and Lan, Tran Thi and La, The Vinh and Pillat, Valdir Gil and Floury, Nicolas, “Formation of ionospheric irregularities over Southeast Asia during the 2015 St. Patrick's Day storm”, Journal of Geophysical Research: Space Physics, vol. 121, issue 12, (2016) 12211-12233.