Proceedings of the World Congress on Engineering 2010 Vol I
WCE 2010, June 30 - July 2, 2010, London, U.K.

Total Electron Content (TEC) and Estimation of Positioning Error Using Malaysia Data

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Abstract— **This paper studied the TEC value for Malaysia regions, based on location of the receivers (latitude, longitude, height). The 13 location of GPS receiver stations across east and west Malaysia were chosen and their TEC values were compared. The determination of the TEC value in ionosphere is done using leveling process. In the process, the error translated from code-delay to the carrier-phase is assessed to reduce carrier phase ambiguities from the data. The positioning error can be calculated as one unit of TEC introduces a range error of approximately 0.16 meters at the L1 (1.6 GHz) frequency of GPS. From the results, the calculated TEC range errors were from -3.1 meters to 7.2 meters at different receiver locations.**

Index Terms— **GPS, ionosphere, leveling process, Total electron content (TEC), Positioning**

I. INTRODUCTION

Global Positioning System (GPS) is space-based radio navigation system operated by the US Air Force for the United States Government. GPS is a satellite-based navigation system made up of a network of 24 satellites, which are distributed in six orbital planes around the globe at an altitude of about 20,162.61 km. The total signal for each satellite in GPS comprises of two transmission signals: the L1 signal having carrier frequency of 1575.42 MHz and the L2 signal of 1227.60 MHz [1]. After the turn off of the Standard Positioning Service (SPS) known as Selective Availability (SA) in May 2000, the ionosphere represents the largest source of positioning error for GPS users [2]. In addition, the effects of the ionosphere can cause range-rate errors for GPS satellite users who require high accuracy measurements [3]. The parameter of the ionosphere that affects the radio signals that propagate through this layer is known as Total Electron Content (TEC). TEC is an integral of electron density along the path between the GPS satellite and the receiver.

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TEC is measured in a unit called TECU where 1 TECU = 1 x 10^{16} electrons/m^2. Various methods have been developed for extracting TEC information from the amplitude and phase of GPS signal [4]. Researches in Malaysia have also embarked in TEC studies around the equatorial region. The studied on TEC parameters and comparing the data observed at Fraser Hill and compare result with the one at Parit Raja, Johor [5]. The locations chosen were based on fountains effect and magnetic equator to study the scintillation effect. Other research on TEC distribution estimation using Bent, IRI and Klobucher modeling was conducted by [6] using GPS MASS station network. Another study was done on Malaysia's quiet ionosphere [7, 8].

This paper describes the study of TEC over Malaysia's ionosphere base on geographical location. From this calculated TEC, range error can be estimated base on 1 TECU approximately equivalent to 0.16m for the L1 GPS frequency [9].

II. METHODOLOGY

A. Data Collection

Data collection is carried out using GPS receiver networks from Malaysia Department of Survey and Mapping, JUPEM in a RINEX (Receiver Independent Exchange Format) data format. The GPS data (RTK and MASS) consists of observation and navigation data. A total of 13 sets of GPS data were collected by receiver stations across east and west Malaysia on 8th of November 2005, with 24 hours observation in 15 seconds interval.

GPS data from satellites include ephemeris data in the signals they transmit to GPS receiver stations. Ephemeris data is a set of parameter that can be used to accurately calculate the location of a GPS satellite at a particular point in time. It gives the description of the path taken by the satellite as it orbits the Earth. Base on the location of a receiver; in terms of latitude, longitude and height, the elevation angle between the receiver and the satellite is determined. The GPS stations are as identified by KUKP, TGPG, UTMJ, BANT, UPMS, KTPK, KUAN, IPOH, BKPL, USMP, RTPJ, GETI and ARAU. The flow chart for data processing using Matlab is as Fig. 1:

ISBN: 978-988-17012-9-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

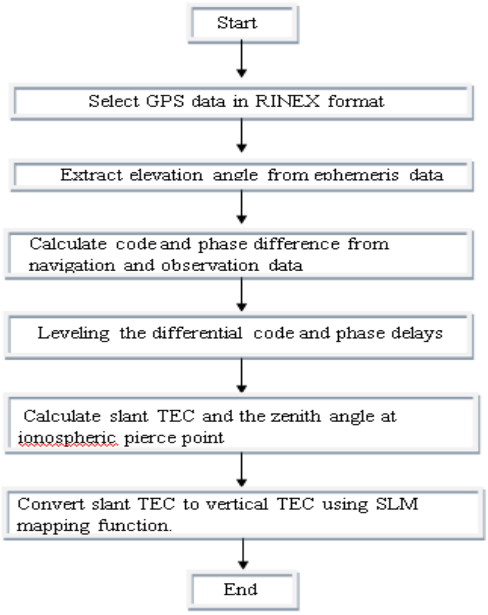

Fig. 1 Flow Process for TEC Calculation

B. TEC calculation using levelling process

Each satellite used for GPS positioning, transmits two carrier electromagnetic waves in L-band frequencies; namely L1 and L2. L1 frequency is 1575.42 MHz and L2 frequency is 1227.60 MHz with a fundamental frequency (f_o) of 10.23MHz. ($f1 = 154f_o$, $f2 = 120f_o$). These carrier frequencies contain codes modulation so that by comparing them to the reference code, we can measure the travelling time of the codes and the carrier between the satellite and the receiver. Information from both, code and phase measurements of L1 and L2, is used to study TEC with the absolute value of group delay as follows:

$$I_{\phi,g} = \int \frac{x}{2} ds = \frac{80.6}{sf^2} \int N_e ds \qquad (1)$$

where $\int N_e ds$ is define as the integral of electron density, TEC.

Use of TEC in (1) yields two delays which can be expressed as representation in units distance (2) or representation in units of time (3)

$$I_{\phi,g} = \frac{40.3}{f^2} TEC[m] \text{ or} \qquad (2)$$

$$\Delta t = \frac{40.3}{cf^2} TEC[s] \qquad (3)$$

A dual-frequency GPS receiver measures the difference in ionospheric delay between the L1 and L2 signal. The group delay for dual-frequency GPS receiver can be written as:

$$P_2 - P_1 = 40.3 TEC \left(\frac{1}{f_2^2} - \frac{1}{f_1^2} \right) \qquad (4)$$

where P_1 and P_2 are the group path lengths, f_1 and f_2 are the corresponding high and low GPS frequency respectively. From (4), TEC can also be obtained by writing as:

$$TEC = \frac{1}{40.3} \left[\frac{f_1^2 f_2^2}{f_1^2 - f_2^2} \right] \left(P_2 - P_1 \right) \qquad (5)$$

The TEC data derived from pseudorange measurement contained large noise level as compare to the carrier phase measurement. In order to reduce the noise effect, pseudorange data is smoothed by using carrier phase measurement technique known as carrier phase leveling written as (6) [10].

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$$B = \frac{1}{N} \sqrt{\sum_{i=1}^{N} \left\{ \left(P_{1i} - P_{2i} \right) - \left(L_{2i} - L_{1i} \right) \right\}^2} \qquad (6)$$

Let N be the number of measurements in a phase-connected arc of data for a given receiver and satellite. For each datum i, the pseudorange delay are denoted by P_{1i} and P_{2i} for *f1* and *f2* respectively, and the corresponding phase delays are L_{1i} and L_{2i} . The leveling bias, B is computed so as to minimize the root-sum-square difference between pseudorange and phase differential delay computed over the arc. The TEC observable for measurement i is the carrier phase difference $L_{2i} - L_{1i}$ added to the bias B. After adjustment for the bias, the root-mean-square difference between the pseudorange and earlier phase delays is dominated by pseudorange noise [11].

III. RESULTS AND DISCUSSION

The location of 13 GPS station which is used in this research as illustrated in Table 1. Fig. 2 to 4 shows TECv for ARAU, BANT and BKPL station. The elevation angle for reference station using PRN 1 is 38.5º and 47.5º was determined at ARAU station from 1:00- 2:00 UTC, BANT station is -3.7º and -3.6º using PRN 3 and BKPL station is -0.1º and -2.8º using PRN 1. Single Layer Model (SLM) model is used to convert slant TEC (TECs) to vertical TEC (TECv) as shown in Fig. 2 to Fig 4. The analysis at an equatorial region used SLM mapping function where the peak altitude ranges from 350 to 500 km. The resulted vertical TEC are precise, accurate and without multipath, unless the multipath environment is really terrible, in which case a small, residual amount of multipath can even be seen in the differential carrier phase.

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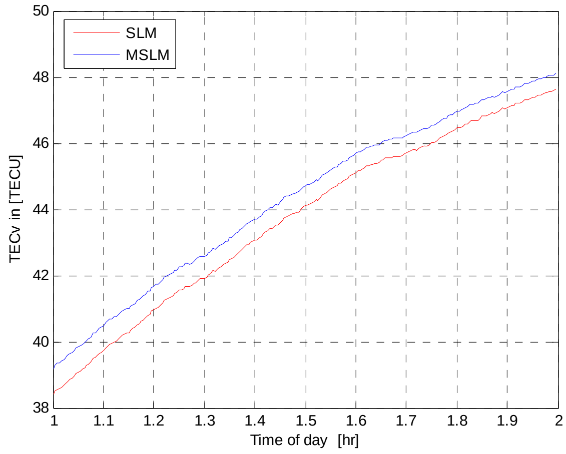

Fig. 2 Vertical TEC for PRN 1 at ARAU station (1:00-2:00 UT)

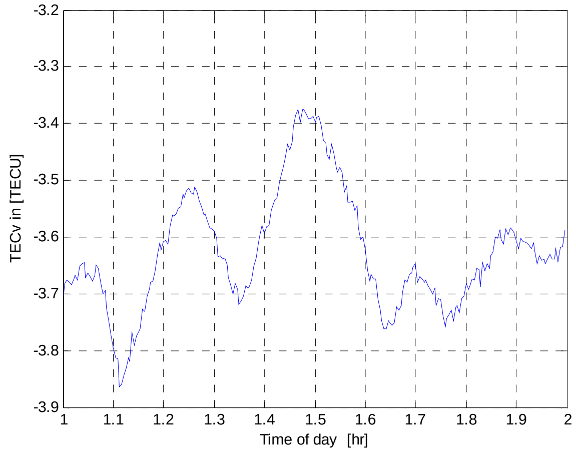

Fig. 3 Vertical TEC for PRN 3 at BANT (1:00-2:00 UT)

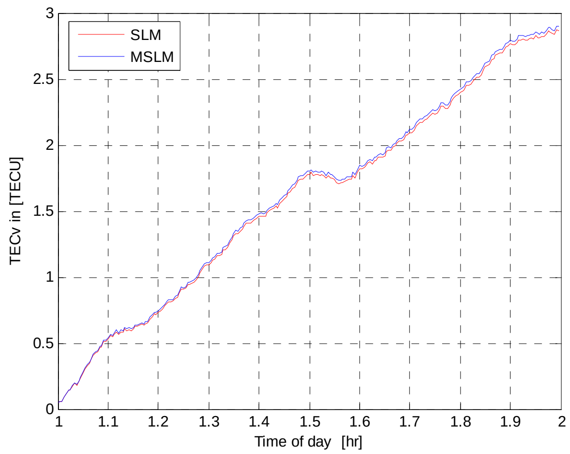

Fig. 4 Vertical TEC for PRN 1 at BKPL (1:00-2:00 UT)

A. *Calculate TEC base on stations location*

The levelling process was carried out at 13 GPS stations to study the effect of the location (latitude, longitude and heights) to the TEC values. The time parameter was set at 1:00-2:00 UTC at all 13 stations, so that the calculated TEC for all the receiver stations can be compared. The results are plotted in Fig. 5 to 8 as below:

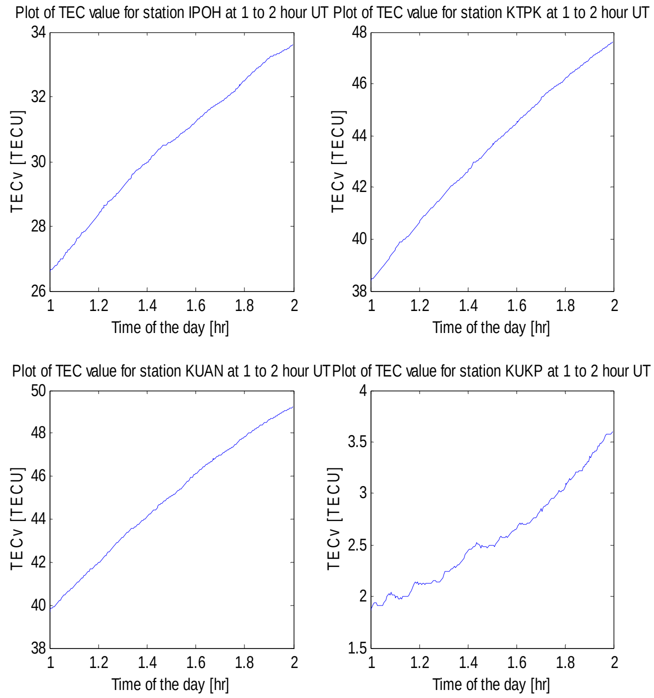

Fig. 5 TEC at IPOH, KTPK, KUAN and KUKP stations at 1:00- 2:00 UTC

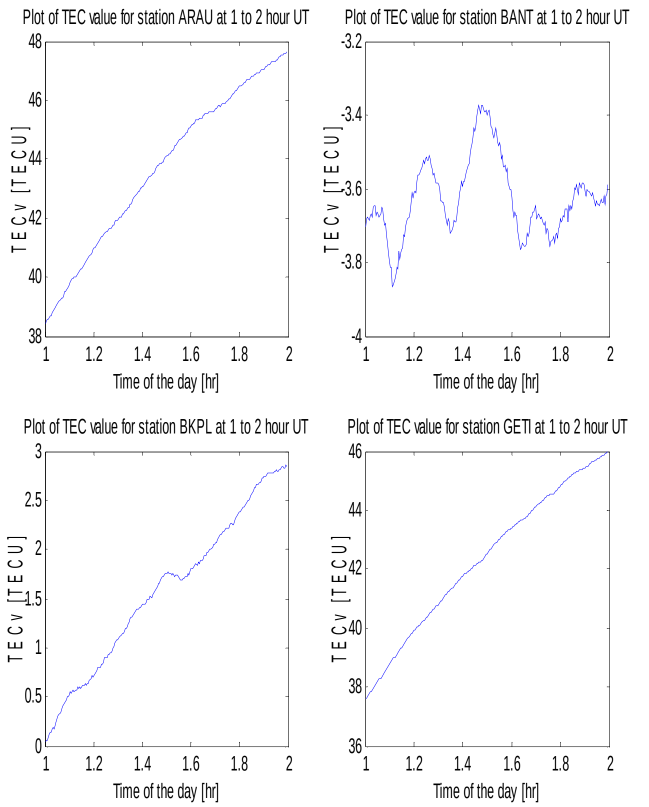

Fig. 6 TEC at ARAU, BANT, BKPL and GETI stations (1:00- 2:00 UTC)

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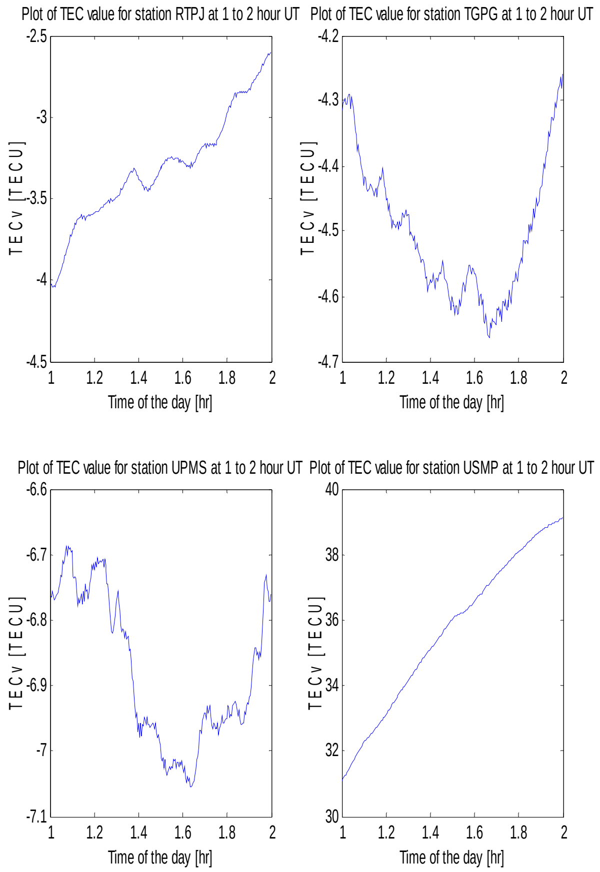

Fig. 7 TEC at RTPJ, TGPG, UPMS and USMP stations at 1:00- 2:00 UTC

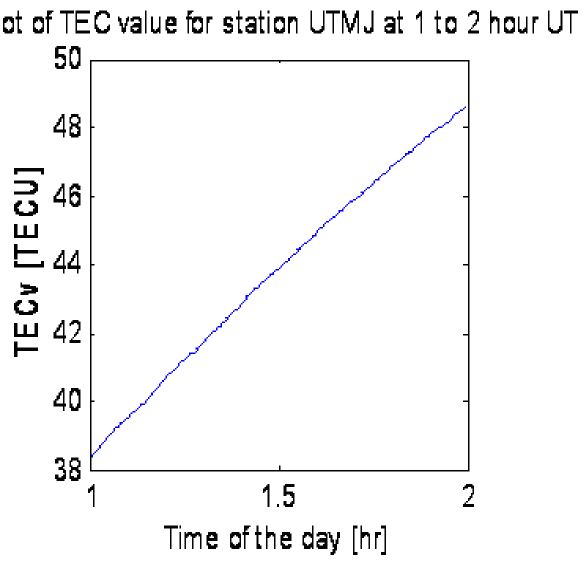

Fig. 8 TEC at UTMJ station at 1:00- 2:00 UTC

The mean TEC value at respective stations were calculated and presented in the Table 1. From this value, positioning error can be estimated based on 1 TECU = 0.16 meter range error. The calculated range errors observed were from -3.1 meters to 7.2 meters at different receiver locations. It is observed that 5 stations; namely UTMJ, KTPK, KUAN, GETI and ARAU station have recorded mean TEC more than 40 TECU while other four stations have negatively TEC values. The 5 stations (UTMJ, KTPK, KUAN, GETI and ARAU station) are MASS data while others are RTK data. It is important to further investigate on these irregularities.

TABLE 1
LIST OF GPS STATION, LOCATION, MEAN AND RANGE ERROR

No	Station ID	Latitude	Longitude	Height	Mean TEC value (TECU)	Range Error (Meter)
1	KUKP	1.333275	103.453432	15.429	2.5818	0.413088
2	TGPG	1.367411	104.108258	18.107	-4.5006	-0.720096
3	UTMJ	1.565815	103.639564	80.44	43.7413	6.998608
4	BANT	2.825956	101.53735	8.832	-19.5841	-3.133456
5	UPMS	2.993396	101.723509	100.385	-6.8787	-1.100592
6	KTPK	3.170944	101.717608	99.79	43.3995	6.94392
7	KUAN	3.834378	103.350352	25.426	44.9138	7.186208
8	IPOH	4.588471	101.126176	41.854	30.442	4.87072
9	BKPL	5.338986	100.21836	-0.062	1.5815	0.25304
10	USMP	5.357788	100.304036	19.907	35.6407	5.702512
11	RTPJ	6.003363	101.991465	23.948	-3.3129	-0.530064
12	GETI	6.226192	102.105462	-0.477	42.3241	6.771856
13	ARAU	6.450158	100.279736	18.078	43.7009	6.992144

IV. CONCLUSION

The aim of this project is to describe the leveling process use in dual-frequency GPS signal to calculate TEC and to estimate positioning error from this value. At different latitudes and longitudes within Peninsular Malaysia where latitudes are ranging from 1º 19’ 59.8”N to 6º 27’ 0.57”N and longitudes varies from 100º 13’ 6.1”E to 104º 6’ 29.73”E the positioning errors are ranging from -3.13 meter to 7.18 meter. It is about 10.3 meters error range due to the present of TEC with respect to the receiver locations.

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