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Smoothing Smartphone GPS Raw Measurements

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Abstract- *This research aims to investigate the smoothing of the pseudo-range raw measurements of the smartphone using a Hatch filter. The measurements of smartphones suffer from high noise generated from low-cost antennas and oscillators, which are designed to work in a certain way. These types of low-cost antennas and oscillators are entirely different from geodetic instruments, which are designed for high accuracy positioning. The GPS measurement data were collected using a Huawei P10 device, 41 minutes and 24 seconds GPS observation time with sampling intervals of 1 second using Geo++ Android application. The GPS measurements are processed using standalone (epoch by epoch) method, by MATLAB software developed by the authors, as a part of a software package for processing smartphone GPS measurements. The errors in raw measurements in the Easting, Northing, and Up (ENU) components when using standalone (epoch by epoch) method are ranging from -50m to 30m, and the errors after applying the Hatch filter are reduced to have ranged from -10m to 5m, the raw data were very noisy and funded it has many cycles slips as a result of low-cost antennas and oscillators of smartphone's. The cycle slips in the measurements were detected and found that it was the result of jumping the errors to 27 m in northing and 43 m in up.*

Keywords- *Hatch filter, GPS smoothing, , GPS Smartphone.*

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1. Introduction

In 2016, Google introduced the Global Navigation Satellite System (GNSS) Analysis Tools. Back in Android nougat, developers implemented application program interfaces (APIs) to retrieve raw measurements of the GNSS from Android devices. The GNSS Analysis Tools are currently ready to process and analyze the measurements. Android runs on over 2 billion devices and Android Phones are produced by many different manufacturers. The main goal of the new tools is to enable device manufacturers to realize in detail how well the GNSS receivers work in each device design and how can improve the GPS/GNSS performances. However, the publicly available tools additionally attach considerable importance to the research and application development [1].
Most of the GPS receivers that provide raw data can measure pseudo-range and carrier-phase, generally, the accuracy of carrier-phase is much more accurate than pseudo-range and the pseudorange data are very noisy so that the non-noisy pseudo-range with high accuracy can be achieved when recalculated depending on the carrier-phase, this recalculation process is called smoothing pseudo-range.

2. The most common smoothing pseudo range that depend on carrier-phase is Hatch filter algorithm. The Hatch filter need only the observation for the current time and the observations of the previous time. They do not need any additional observations and sensors, for that reason the authors used this method because it is most method applicable for GPS Smartphone.

3. GPS Observables

Positioning by a GPS receiver based on the geometrical principles of the predicted satellite positions from the navigation message and the distances between the user antenna position and the GPS satellite transmitter, which is determined by measuring the transit time of the satellite signals. In principle, modern GPS receivers can determine different observation variables. However, not every GPS receiver has the capability of measuring all of the following observables:
1) Pseudo-distance (pseudo-range)
2) The carrier-phase measurement in one or two-frequency.
Besides, the difference in distance between receivers and two orbit positions of the same satellite can be determined by measuring the Doppler shift of the incoming carrier phase in single or dual frequency receivers [2, 3].

4. Smoothing Hatch filter

The pseudo-range measurements generally contain high noise while the carrier-phase contains less noise and having high constancy. The smoothing of the measurements is one of the methods used to reduce the noise of the pseudo range to obtain accurate measurements as much as possible [4-5]. This used to estimate precise positions using single receiving units.

The most common smoothing pseudo range that depends on carrier-phase is the Hatch filter algorithm. Because the Hatch filter needs only the observation for the current time and the observations of the previous time, they do not need any additional observations and sensors [6], for that reason the authors used this method because it is the most method that can be applied for single-phase GPS Smartphone.

Typically used to reduce or smooth the errors of the effect of noise and multipath in pseudo-range measurements by using the corresponding high accuracy carrier phase measurements, the Hatch smoothing filter is represented by the following equation [7]:

$$\bar{R}(s,k) = \frac{n-1}{n}\left[\bar{R}(s,k-1) + \left(\Phi(s,k) - \Phi(s,k-1)\right)\right] + \frac{R(s,k)}{n} \quad (1)$$

Where:

$R(s,k)$: Code measurement for Satellite s at a time n

$\Phi(s,k)$: Carrier phase measurement

s: Satellite.

n: Time

$\bar{R}(s,k-1)$: smoothed code for the previous epoch.

The initial value for the algorithm starts with $\bar{R}(s,1)=R(s,1)$.

Eq. (1) (the Hatch filter) depends on the current epoch measurements and the previous estimate, without any mathematical models or sensors to eliminate errors. Generally, it is used for single frequency low-cost GPS receivers. The filter depends on constancy variations in carrier phase measurement thus if the cycle-slip occurs in carrier phase the filter must be initialized [6, 7].

5. Cycle slips

In the case of phase measurement, the ambiguity value of a given epoch is estimated where the ambiguity represents the main problem, which depends on the continued reception of the signal between the receiver and the satellite. The cycle slips occurs if the receiver losses tracking of the satellite then the satellite reappears again. In other words, a new guessing value will be given and the cycles will be counted from the beginning because of the interruption in the received signal. The result of the cycle slips on the phase measurement is represented as an integer number of cycles. Finding and correcting the cycle slips ensures that the correct ambiguity value is obtained [6].

6. GPS data observations

The data from the GPS receiver was collected using a Huawei P10 device. The specifications of the receiver and antenna that gathered from RINX file are as follows:

Table 1: Specifications for the receiver and antenna.

	Serial Number	Type	Ver.
Receiver	7EX0217923002483	HUAWEI	VTR-L29
Antenna	7EX0217923002483	VTR-L29	

Data were taken for 41 minutes and 24 seconds with sampling interval 1-second using Geo++ Android application and above the building of the department of civil engineering, University of Technology campus without obstructions preventing visibility to the sky and leading to multipath errors.

7. Experimental Results

In the observation time, eleven satellites were obtained (G5, G7, G8, G9, G11, G13, G17, G23, G27, G28, and G30) and represented by elevation angle in degree and epochs in seconds as shown in Figure 1.

The measured pseudo-range observation without smoothing of the eleven satellites is represented by pseudo-range in meters and epochs in seconds as shown in Figure 2.

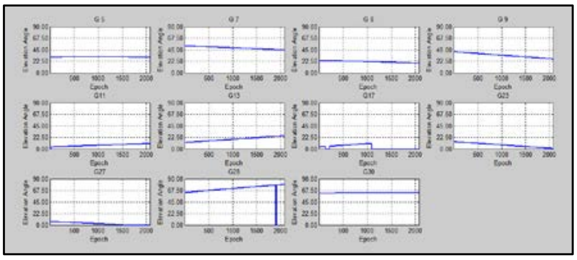

Figure 1: Number of satellite and elevation angles

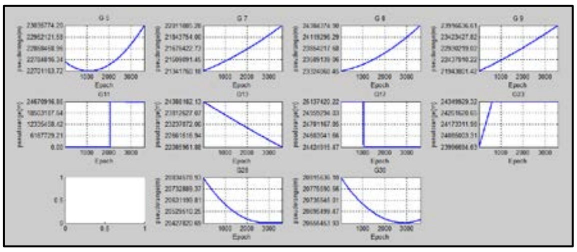

Figure 2: Observations without smoothing

In Figure 2, the satellite number G27 has been dropped because the elevation angle of the satellite is below the elevation mask of 10^{o}.

The raw measurements of the pseudo-range observations were used to estimate the location by the least-squares observation method, using a single point positioning (epoch by epoch) method. The error residuals of the locations estimated from raw data from the most probable value of the local location in (NEU) are illustrated in Figures 3-7. The estimated errors represented by errors in meters and time in seconds.

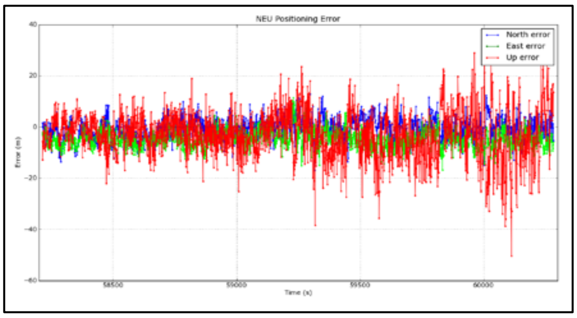

Figure 3: NEU Error of Raw Data

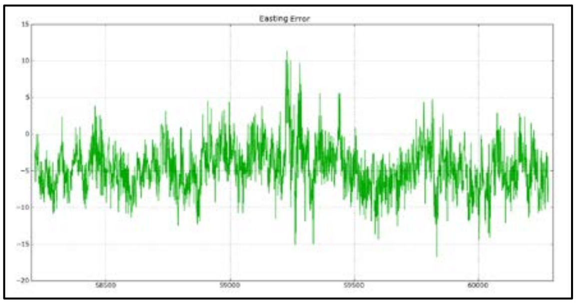

Figure 4: Easting Error of Raw Data

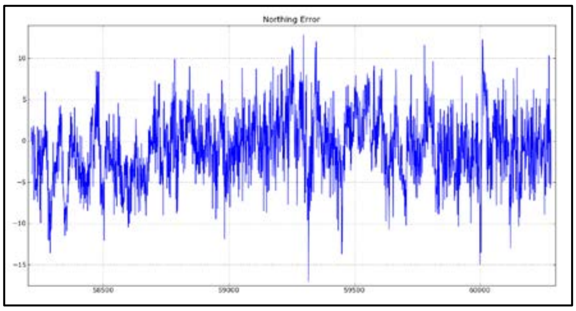

Figure 5: Northing Error of Raw Data

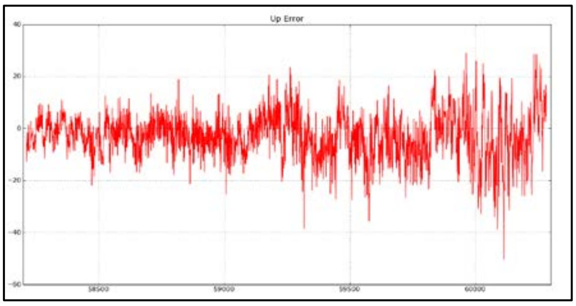

Figure 6: Up Error of Raw Data

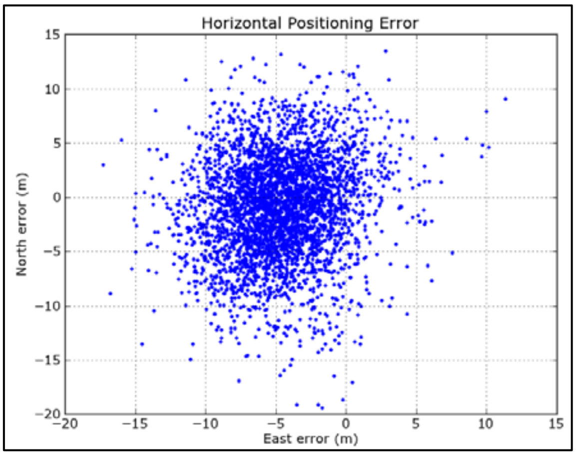

Figure 7: Horizontal Positioning Error of Raw Data

Figure 3 represents all the residuals raw data in the ENU direction with time, Figure 4 illustrates the errors in the easting direction with time. Figure 5 depicts the errors in the northing direction with time. Figure 6 shows the errors in the up direction with time, and Figure 7 represents the horizontal positioning error of raw data in the Easting and North directions.

It is clear that Figure 3,4,5, and Figure 6 have high noisy and errors in the easing direction ranging from -17m to 11m, errors in the northing direction ranging from -17m to 12m, and errors in the up direction ranging from -50 m to 30 m.

The processing of pseudo-range with the Hatch filter, and estimate the positions as in raw pseudo-range epoch by epoch single point positioning the error results as shown in Figures 8-12.

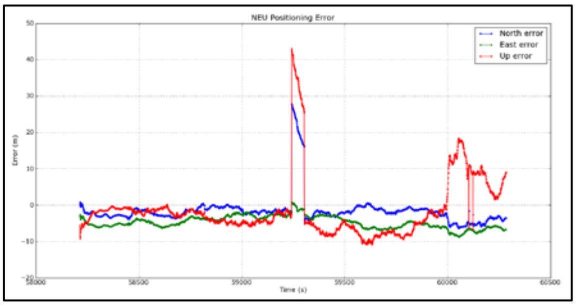

Figure 8: NEU Error of Smoothed Data

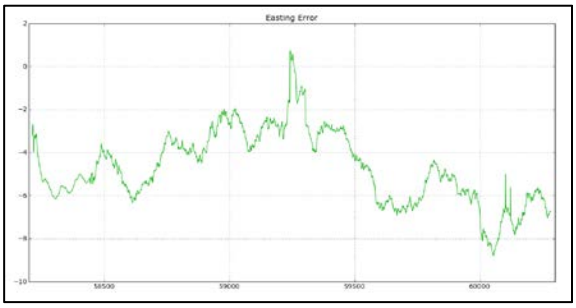

Figure 9: Easting Error of Smoothed Data

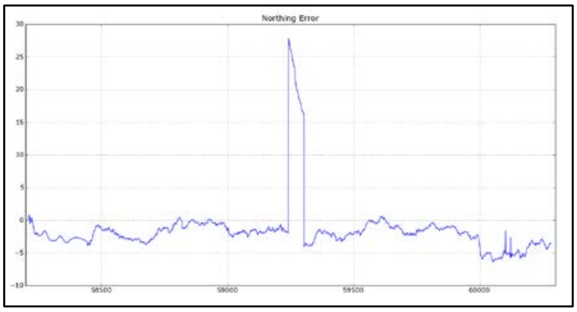

Figure 10: Northing Error of Smoothed Data

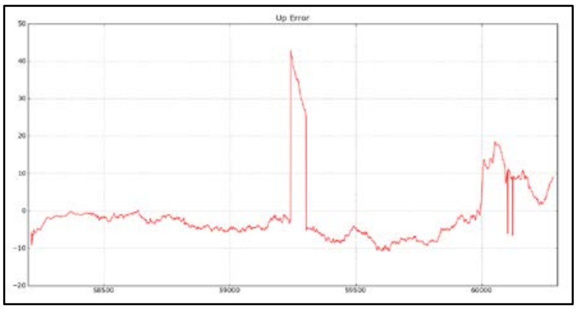

Figure 11: Up Error of Smoothed Data

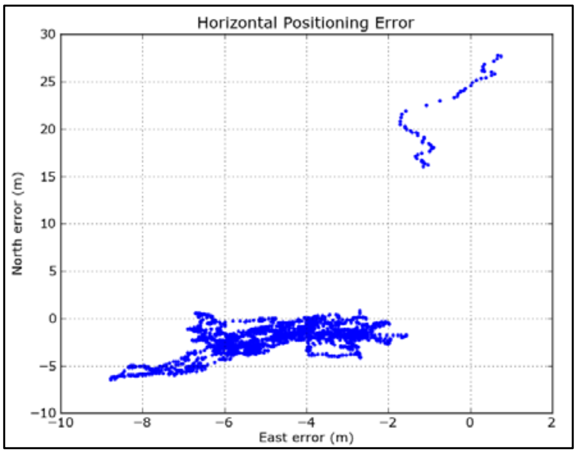

Figure 12: Horizontal Positioning Error of Smoothed Data

Figures 8-12 have the same properties of the Figures 3-7, except that the errors residuals of the locations estimated from smoothed data, and the most probable value of the local location computed depend on smoothed pseudo-range.

Figures 8-12 expresses that the noisy behavior of the raw data have highly reduced after applying smoothening Hatch filter, and the smoothed data having errors in the easing direction ranging from -9m to 0.5 m, errors in the northing direction ranging from -6m to 0.5m, and errors in the up direction ranging from -10 m to 15 m, except the residuals in the northing and up directions, are jumped up to 27 m in northing anord 43 m in up.

After investigating the reasons of the jump in the smoothed data, the authors found that it is the result of cycle-slip, and MATLAB software is used for GPS cycle-slip processing [8], to detect that cycle-slip is shown clearly in Figure 13.

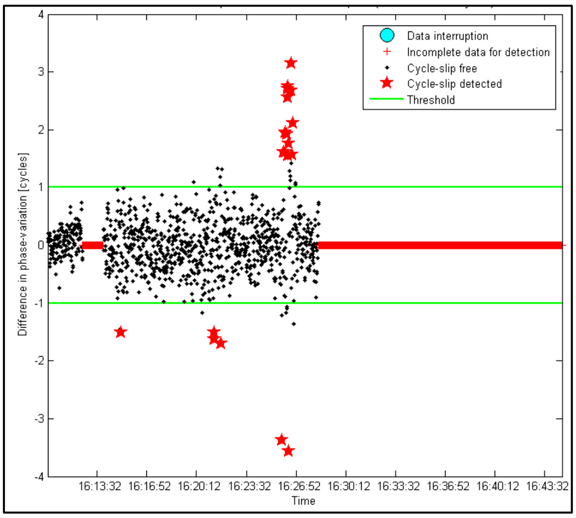

Figure 13: Cycle Slips Detection of SV 17.

As already mentioned earlier, the filter is depending on the constancy variations in carrier phase measurement, so that if the cycle-slip occurs in carrier phase the filter must be initialized when computing smoothed pseudo-range. Figure 1 illustrates that satellite G17 elevation has dropped below the elevation mask, and Figure 13 represents the cycle slips detection of G17, for that reason the initial value for the algorithm in equation (1) must be initialized from start, and the filter at that point will give result worse than raw data.

8. Conclusion

The pseudo-range measurements generally contain high noise when taking measurements while the carrier phase contains less noise and more constant. The raw data are highly noisy and having errors in the easing direction ranging from -17m to 11m, errors in the northing direction ranging from -17m to 12m, and errors in the up direction ranging from -50 m to 30 m.

The noisy behavior of the raw data have highly reduced after applying smoothening Hatch filter, and the smoothed data having errors in the easing direction ranging from -9m to 0.5 m, errors in the northing direction ranging from -6m to 0.5m, and errors in the up direction ranging from -10 m to 15 m, except we have jumped in the residuals in the northing and up directions, that jumps up to 27 m in northing and 43 m in up. The cause of the jumps that satellite G17 elevation has dropped below the elevation mask and that presents cycle slips, the cycle slips will change the initial value for the filter algorithm and must be initialized from start, and the filter at that point will give result worse than raw data. The result also concluded that the Hatch filter can be used to detect and identify the location of cycle slips.

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