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A NEW ADAPTIVE FILTERING TECHNIQUE FOR GNSS MULTIPATH DATA PROCESSING AND MITIGATION

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Abstract

Global satellite based navigation systems such as GPS (US), GLONASS (Russia), Galileo (Europe) and Compass (China) are widely used for precise positioning for several applications. The attainable positional accuracy of these systems is affected by satellite based (satellite clock errors, ephemeris errors, satellite instrumental bias), SIS (Signal in Space) and receiver based errors, clock bias, instrumental bias, multipath and receiver noise. Among the receiver based errors multipath is considered as the major *debilitating factor* that can lead to the degradation of signal strength or complete blockage of the signal in extreme case. Precise estimation and mitigation of multipath error is therefore required to improve positional accuracy of Global Navigation Satellite System (GNSS) systems. The multipath can be estimated precisely using Code minus Carrier (CMC) technique using linear combination of code phase and carrier phase measurements of GNSS signals. There are various multipath mitigation techniques proposed in open literature at signal processing level using hardware (MEDLL, MUSIC etc.) as well as software (Filtering techniques such as RLS, LMS, etc.,) approaches. Filtering techniques for multipath mitigation are superior to hardware approaches in terms of flexibility, adaptability and ability to process signals both in real-time as well as at post processing stages. In this paper, a novel filtering technique 'Block LMS' is proposed for multipath mitigation and its performance is compared with conventional techniques such as LMS and RLS. . The mean multipath error after RLS filtering on L1 and L2 are 1.38 m and 2.09 m, the multipath error reduced by 75.82% for L1 and 73.07% for L2. The mean multipath error on L1 after filtering using HRLS, LMS and NLMS are 1.32 m, 1.67m and1.71m respectively. It is observed that the respective filters multipath error mitigation in terms of percentages are 72.52%, 91.75% and 93.95% respectively. For L2 the mean multipath error using HRLS, LMS and NLMS is 1.98 m, 2.58 m and 2.61 m respectively. BLMS filter performs with significant improvement in multipath mitigation with 95.05% on L1 and 92.30% on L2. It is observed that BLMS filter has reduces multipath error more effectively.

1. Introduction

GPS has 31 operational satellites. The signals are transmitting using three carrier frequencies, L, L2 and L5 at frequencies of 1572.42MHz, 1227.60MHz and 1176.45MHz respectively. Standard positioning service using C/A (coarse-acquisition) is available on L1, L2, and L5 frequencies to all civilian users, while precision positioning service (P-Code) is available only to authorized users[1,3]. Code signals are superimposed on both L1,L2 and L5 frequencies. GPS receivers use these codes to determine the signal propagation time between satellite and receiver. The position estimation in GNSS Receiver is based on pseudo range measurements

to satellite and satellite position estimates using least square or kalman filtering technique. However, a minimum of four satellites are required. GNSS receivers experience positioning errors due to signal propagation delays through the ionosphere and troposphere, receiver clock and satellite errors, biasing, multipath, and some intentional errors. So, the GPS receiver's position accuracy may be degraded. As multipath errors can compromise the performance and accuracy of receiver, they cannot be ignored. Multipath occurs when the same radio signal travels through more than one path to reach the receiving antenna. The main cause is the reflection and diffraction of the original signal by any number of physical phenomena, including the built environment, trees, the ground, and even water[4]. Figure.1depicts typical multipath scenario. Multipath affects both code and carrier phase measurements of GNSS signals. C/A-code and P-code modulations and carrier phase observations are distorted by multipath. Nevertheless, multipath signals are always delayed compared to line-of-sight signals because of the longer travel paths caused by reflection. The carrier phase multipath can reach the maximum value of a quarter of a cycle (4.8cm for the L1 carrier phase) and the pseudo range multipath can reach up to 293m for the C/A code measurement. Although choke ring antennas and antenna selection can effectively mitigate multipath, the residual multipath effect still remains as a major source of error[6].

In general, multipath signal is one that arrives at a receiving antenna in several directions after reflections, diffractions and interfere with a direct signal. As a consequence, there is a distortion in the correlation curve between the received signal and the replica generated by the receiver used for acquisition and tracking. Different methods were proposed to reduce multipath effects based on hardware, software, and hybrid approaches. The fundamental analysis of GPS code and carrier multipath errors using LMS and RLS adaptive filters was reported by Hagerman (1973), Yedukondalu and Sarma (2010, 2013), and Lilin GE (2000). Yedukondalu and Sarma (2013) observed that the multipath error was reduced by 90% and 72% with LMS and RLS filters, respectively. Moreover, in open literature a variety of algorithms were proposed to estimate and mitigate the multipath. Using linear combinations of code and carrier phase measurements of dual frequency signals of GPS, Code minus Carrier (CMC) technique was developed to precisely estimate multipath error independently on L1 and L2. In this paper, using CMC technique multipath on L1 and L2 is estimated and a novel 'Block LMS' filter is used to mitigate multipath effects on L1 and L2 signals.

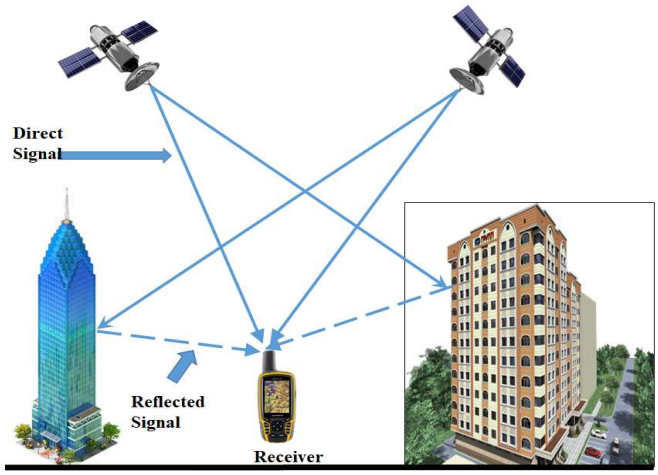

Figure 1: A typical multipath scenario

2. Code minus Carrier Technique:

Direct and indirect signals received at GPS receivers will have relative phase offsets and phase differences between codes and carrier phases measurements Therefore, code and carrier phase measurements can be used to estimate multipath on L1 and L2 using CMC technique[3]. The multipath estimation on L1&L2 expressed as:

$$MP_{L1}=\rho_{L1} - \frac{f_{l1}^2+f_{l2}^2}{f_{l1}^2-f_{l2}^2}\cdot(\emptyset_{L1})+\frac{2f_{l2}^2}{f_{l1}^2-f_{l2}^2}\cdot(\emptyset_{L2})+K_1 \quad (1)$$

$$MP_{L2}=\rho_{L2} - \frac{2f_{l1}^2}{f_{l1}^2-f_{l2}^2}\cdot(\emptyset_{L2})+\frac{f_{l1}^2+f_{l2}^2}{f_{l1}^2-f_{l2}^2}\cdot(\emptyset_{L2})+K_2 \quad (2)$$

Where ρ_{L1} is pseudo range of L1, ρ_{L2} is pseudo range on L2, and corresponds to code phase measurements on L1 and L2 carrier frequencies respectively, K1 and K2 are functions of integer ambiguities and measurement noise, which can be assumed as constant if there is no cycle slip in carrier phase data.

$$MP_{L1}=\rho_{L1} - \frac{9529}{2329}.(\emptyset_{L1})+\frac{7200}{2329}.(\emptyset_{L2})+K_1 \quad (3)$$

$$MP_{L2}=\rho_{L2} - \frac{11858}{2329}.(\emptyset_{L2})+\frac{9529}{2329}.(\emptyset_{L2})+K_2 \quad (4)$$

Where MP_{L1} and MP_{L2} are code multipath on L1 and L2 respectively.

This technique is used widely to estimate multipath and choose a better location for installing GPS receiver as well. Adaptive filters will mitigate multipath error based on the code multipath estimated from Eqs. (3) and (4).

3. Adaptive Filtering techniques

Adaptive filter techniques are widely applied for noise reduction, echo cancellation, interference reduction etc. in signals. Figure 2 illustrates a block diagram of an adaptive filter, using a transverse filter, the filtering process is carried out and the tap weights are controlled by an adaptive weight control mechanism. A self-adjusting adaptive filter performs following tasks to track the optimal behaviour of slowly varying signals (Paulo and Diniz, 2006).

1. calculates the out of filter in response to an applied input signal.
2. Calculates the estimation error by comparing the output to the desired signal.
3. Automatically adjust filter coefficients based on estimation error.

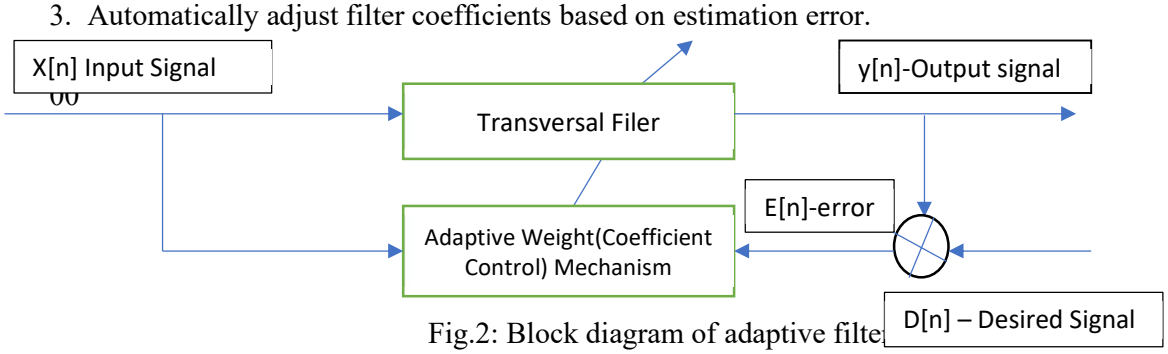

Fig.2: Block diagram of adaptive filte

In general sense, the multipath affect also is dispersed in time and thus adaptive filtering is an optimal choice to track the optimal behaviour of GNSS signals, there by mitigating

multipath. In this section, widely used adaptive filtering techniques RLS, LMS and proposed novel technique 'BLMS' for multipath mitigation are discussed. BLMS technique is not implemented to GNSS before, in this paper work carried out.

3.1 Recursive Least Squares (RLS) filter:

RLS is an adaptive filtering technique that recursively finds coefficients to minimize weighted linear squares relating to input. It provides faster convergence. Furthermore, it produces smaller errors when dealing with unknown systems. The main objective of RLS is to minimize the weighted square error between the desired and output signals. It has infinite memory, and a forgetting factor that allows old data to be de-emphasized compared to new data. RLS methods include simple RLS, House holder RLS (HRLS), QR decomposed RLS (QRDRLS) and House holder sliding window RLS (HSWRLS)[3].

The response of RLS filter is given by:

$$y(n)=\sum_{k=0}^{n-1} w_k u(n-k) \quad (5)$$

$$e[n]=d(n)-y(n) \quad (6)$$

where,

$\boldsymbol{\xi}(w_0, w_1, w_2, \dots \dots . w_n) = \sum_0^{n-1} |e(n)|^2$,

u(n) is input signal

d[n] is desired signal

e(n) is error signal

In the least squares, the sum of squares of errors is minimized. When the weights are adjusted to converge errors to zero, the filter will converge.

3.2 Least Mean Square Filters:

LMS has the ability to learn unknown transfer functions. It uses a gradient-based method, in which the filter coefficients are updated based on instantaneous error. It takes longer time to converge. The purpose of this filter is to minimize the mean square error between the desired signal and the output signal. It does not have a memory. Therefore, previous error is not considered in total error. LMS methods include: 1) Normalized LMS, 2) Variable Step Size LMS, 3) Block LMS, 4) Fast Block LMS

Solo & king(1995) have presented model independence and robust performance of the LMS algorithm. The LMS algorithm is the most widely known and implemented adaptive algorithm. When it comes to implementing an LMS filter, there are two issues during the selection of step size parameter m and filter length M[6].

a) In the least squares, the sum of squares of errors is minimized. When the weights are adjusted to converge errors to zero, the filter will converge.

$$w_i'(n)= w_{i-1}'(n)+me(n)x(n-i) \quad (6)$$

Where m is step size , i=0,1,….M-1, and n=0,1,2,…..,N-1.

The equation above is used to minimize the sum of squared errors(Haykin,1996).

1.The rate of convergence of the LMS algorithm is controlled by m, which must be set appropriately. The higher the value of m, the faster the algorithm converges. In the case of very high values of m, the LMS algorithm may become unstable. In order to achieve better stability, the m value must be selected in the range (Proakis, 1995).

$$0 < \mu < \frac{1}{10MP_X} \quad (7)$$

where,M is the length, and Px is the power of the reference signal, which is given by

$$P_x = \frac{r_{xx(0)}}{M+1} \quad (8)$$

Where $r_{xx(0)}$ is the autocorrelation of the reference signal for zero lag.

2.The filter length should be determined by the input data set. Minimum Description Length (MDL) (Haykin,1996) is defined as

$$MDL(M) = -L(\theta_M) + \frac{1}{2}\text{MlnN} \quad (9)$$

Where M is the filter length, N is the length of the input sequence

In eq.(9), the first term decreases with increasing M, while the second term increases linearly with increasing M, thus MDL can be minimized with M.

3.3 Block Least Mean Square Filters:

The Block LMS Filter implements an adaptive least mean square (LMS) filter, where the weights of the filter are continuously adapted for each block of samples. Filter weights are estimated to minimize the error $E(N)$, between the output signal $Y(N)$, and the desired signal, $D(N)$. Block LMS adaptive filter calculates the filter weights. This algorithm is described by the following equations.

$$\boldsymbol{n = kN + i} \quad (10)$$

$$\boldsymbol{y(n) = w^T(n)} \quad (11)$$

$$\boldsymbol{e(n) = d(n) - y(n)} \quad (12)$$

$$\boldsymbol{w(k) = w(k-1) + f(u(n), e(n), \mu)} \quad (13)$$

The weight update function for block LMS adaptive filter is given by

$$\boldsymbol{f(u(n), e(n), \mu) = \mu \Sigma_{i=0}^{N-1} \mu(kN + i) e(kN + i)} \quad (14)$$

Where n is time index, i is iteration variable in each block ,k is the block number, N is block size, μ(n) is buffered input sample at step n, w(n) is filter-tap estimates at step n, y(n) filtered output, e(n) is estimation error, d(n) is desired response, μ is adaption step size.

4. Data acquisition and processing

The Advanced GNSS Research Laboratory (17.400 N, 78.510 E) at Osmania University, Hyderabad, Telangana, India. State-of-art GNSS receivers including Dual frequency NavIC receivers (make: Accord systems), GPStation6 (make: Novatel) has dual frequency NavIC receivers, Trimble single frequency, and NAVLAN IG3 single-frequency receivers. The GPS data collected from GPS receiver for the analysis. From the pseudo range measurements presented from RINEX observation file.

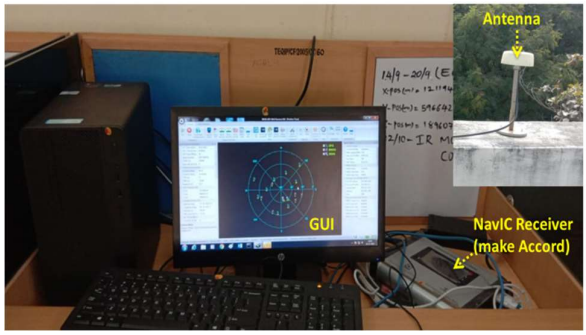

Figure 3. Experimental set-up at Osmania University, Hyderabad

5. Results & discussion:

GPS dual frequency data recorded on 15th March 2020 were used for the analysis of multipath estimation and mitigation. The multipath analysis is done for SV26. The frequency error on L1 and L2 is depicted in Fig4.The minimum multipath error on L1(MP1) is 0.8m and the maximum error is 2.1m. A mean error of 1.82 is observed. A minimum multipath error of 2.0m is observed on L2, and a maximum error of 3.1m is observed. The mean multipath error is 2.86 is observed.

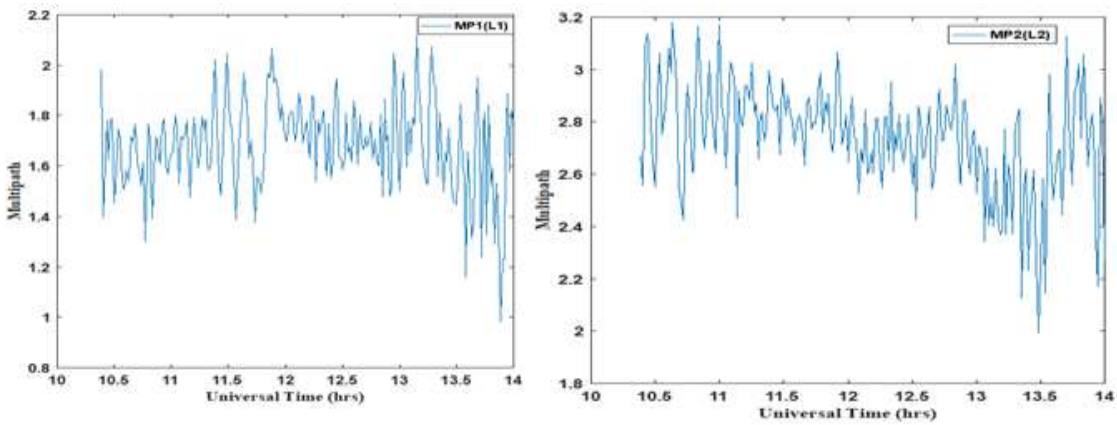

Figure 4: Multipath error on L1 (MP1) and L2 (MP2).

The RLS and HRLS filters have forgetting factor of 0.99 and their correlation matrices are $0.1.[I]_{32x3}$ and $\sqrt{10}.[I]_{32x32}$ respectively. To illustrate the ability of multipath mitigation of the selected and proposed adaptive filters (RLS, HRLS, LMS, NLMS and BLMS), the data corresponding to satellite 'SV 26' is considered. The plots from fig.5 to fig.13 depict a) multipath error (MP1 Signal), b) desired signal, c) filtered signal and d) error signal for MP1 and MP2. The filtered signal and error signal in the plots correspond to RLS (Fig.5 and 6) , HRLS (Fig.7 and 8), LMS (Fig.9 and 10), NLMS (Fig.11 and 12) and BLMS (Fig.13 and 14) filters. The efficiency of the technique depends on how much the input error signal is reduced at its output. Table 2 depicts mean and standard deviation of the adaptive filters considered for the analysis. The reduction in multipath error after filtering is quantified in terms of percentage is estimated as [(Yj)/Xj]*100, where j= 1, 2 that represents L1 and L2. The Xj is the mean multipath error before filtering and and Yj is mean multipath error after filtering. It is observed that X1 and X2 are 1.82 m and 2.86 m, respectively. The mean multipath error after RLS filtering on L1 and L2 are 1.38 m and 2.09 m, the multipath error reduced by 75.82% for L1

and 73.07% for L2. The mean multipath error on L1 after filtering using HRLS, LMS and NLMS are 1.32 m, 1.67m and1.71m respectively. It is observed that the respective filters multipath error mitigation in terms of percentages are 72.52%, 91.75% and 93.95% respectively. For L2 the mean multipath error using HRLS, LMS and NLMS is 1.98 m, 2.58 m and 2.61 m respectively. As depicted in table 2, the corresponding percentage of multipath reduction equals 69.23%, 90.02% and 91.25% respectively. It can be observed from the above data that NLMS filter performs better than RLS, LMS and HRLS filters in mitigating the multipath error. However, above all the BLMS filter out performs with significant improvement in multipath mitigation with 95.05% on L1 and 92.30% on L2. The corresponding mean multipath errors after filtering are 1.73m and 2.64 m.

Table 2. Comparison of various adaptive filter outputs

S.No	Filter type	Signal with minimized multipath error		% of Reduced Multipath error = [(Yj)/Xj]*100, j=1,2..,	
		MP1 (cm)	MP2 (cm)		
		Mean (Y1)	Mean (Y2)	MP1	MP2
1	BLMS	1.73	2.64	95.05	92.30
2	NLMS	1.71	2.61	93.95	91.25
3	LMS	1.67	2.58	91.75	90.2
4	RLS	1.38	2.09	75.82	73.07
5	HRLS	1.32	1.98	72.52	69.23

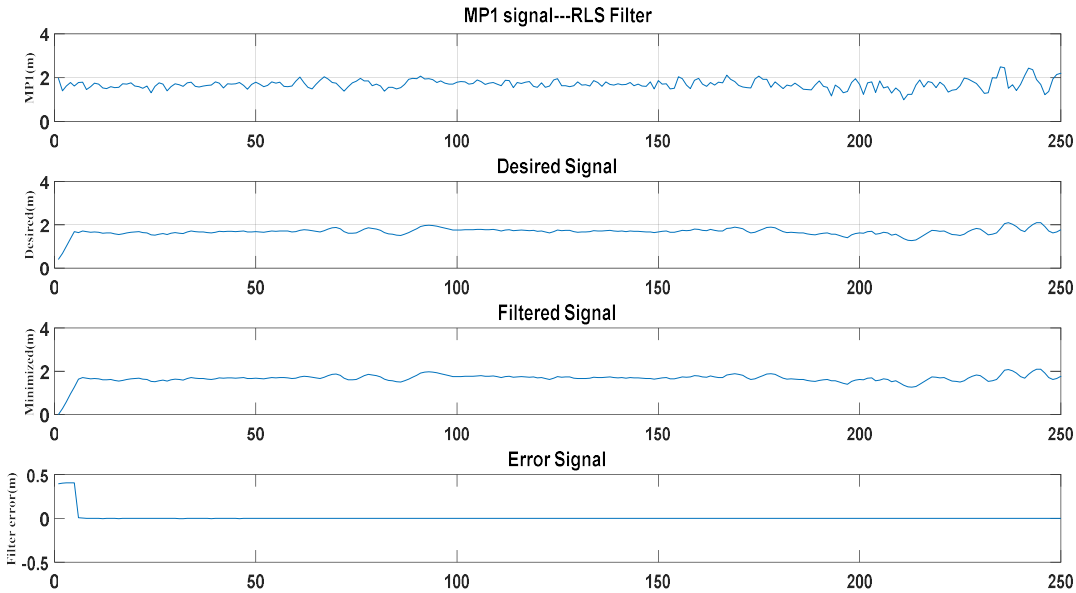

Figure 5: Multipath mitigation using RLS filter on L1 of SV26 (15th March 2020). a) Multipath error (MP1 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

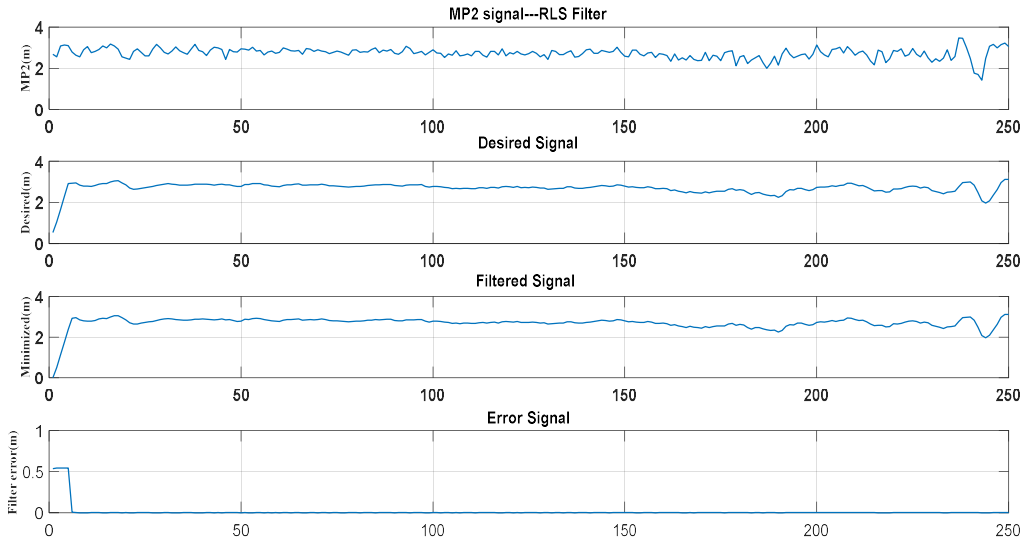

Figure 6: Multipath mitigation using RLS filter on L2 of SV26 (15th March 2020). a) Multipath error (MP2 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

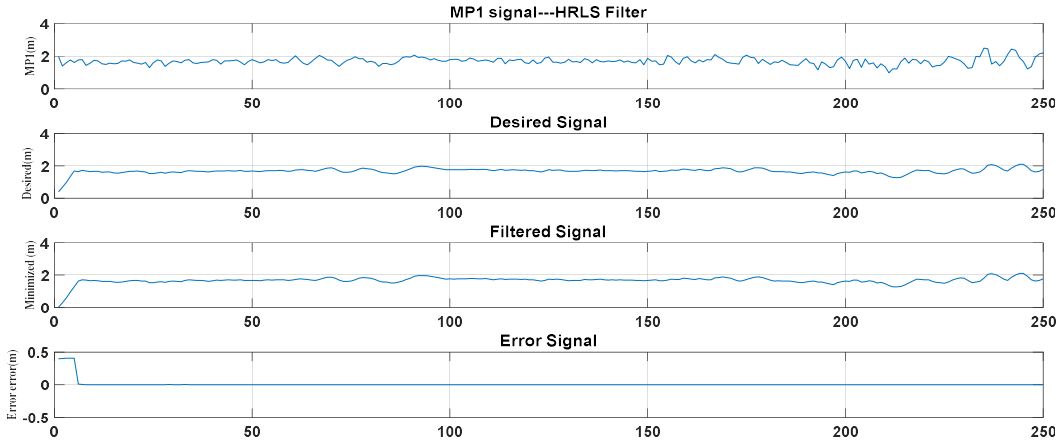

Figure 7: Multipath mitigation using HRLS filter on L1 of SV26 (15th March 2020). a) Multipath error (MP1 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

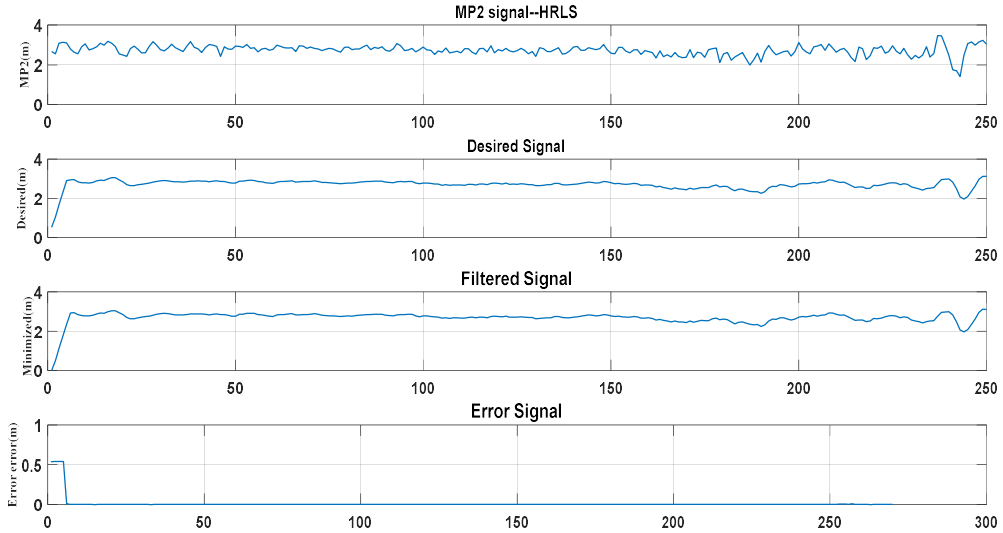

Figure 8: Multipath mitigation using HRLS filter on L2 of SV26 (15th March 2020). a) Multipath error (MP2 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

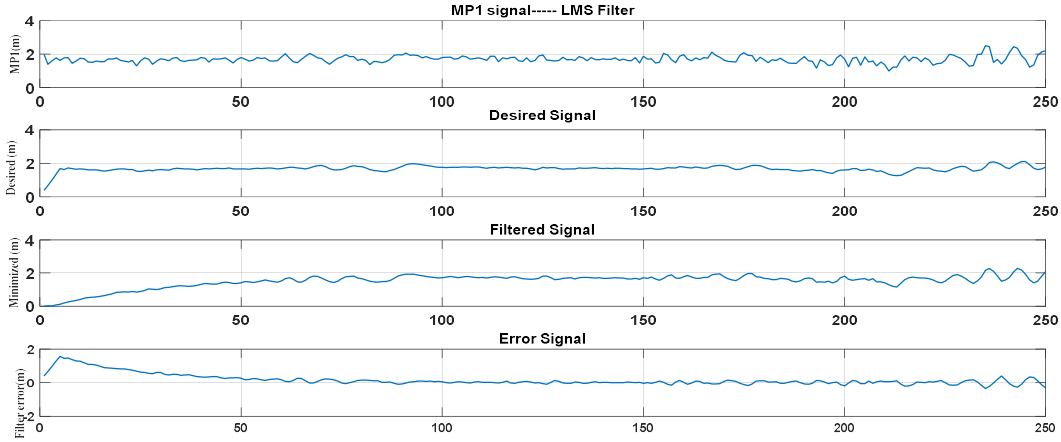

Figure 9: Multipath mitigation using LMS filter on L1 of SV26 (15th March 2020). a) Multipath error (MP1 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

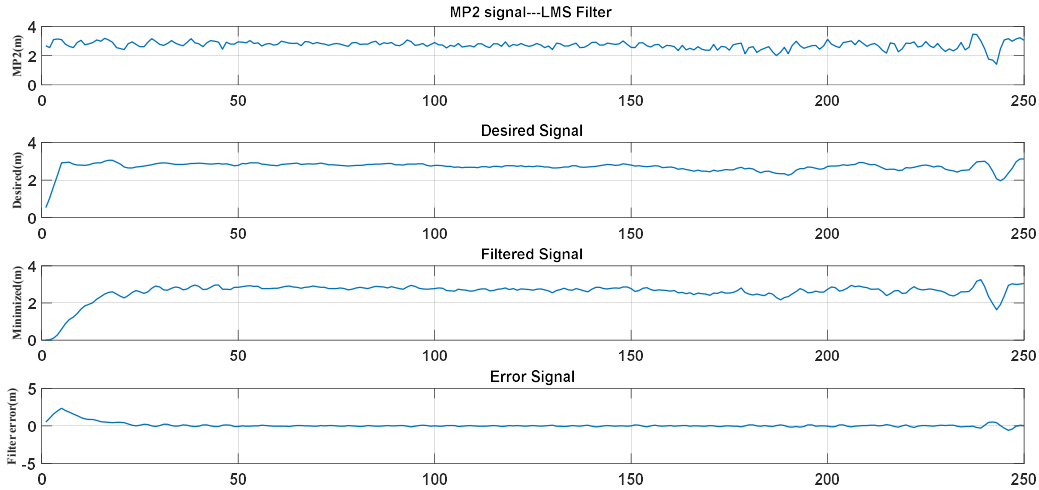

Figure 10: Multipath mitigation using LMS filter on L2 of SV26 (15th March 2020). a) Multipath error (MP2 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

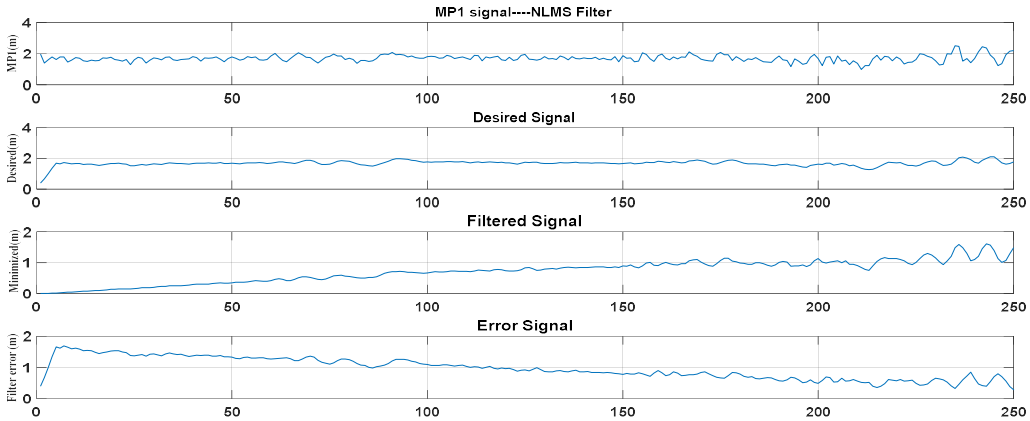

Figure 11: Multipath mitigation using NLMS filter on L1 of SV26 (15th March 2020). a) Multipath error (MP1 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

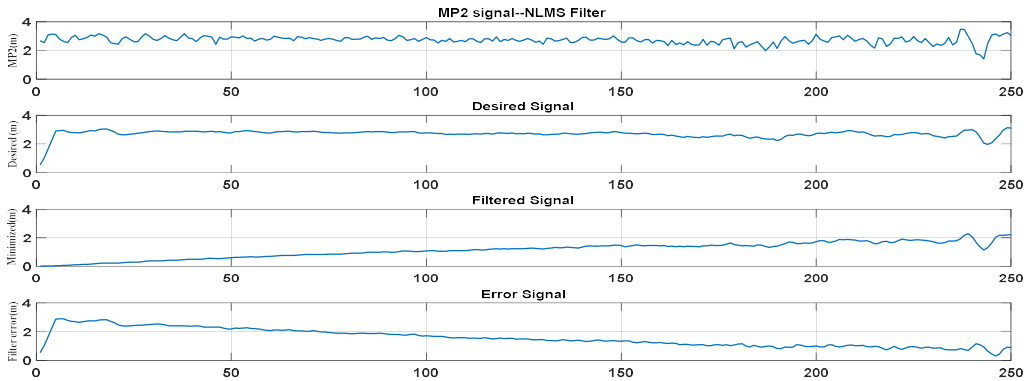

Figure 12: Multipath mitigation using NLMS filter on L2 of SV26 (15th March 2020). a) Multipath error (MP2 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

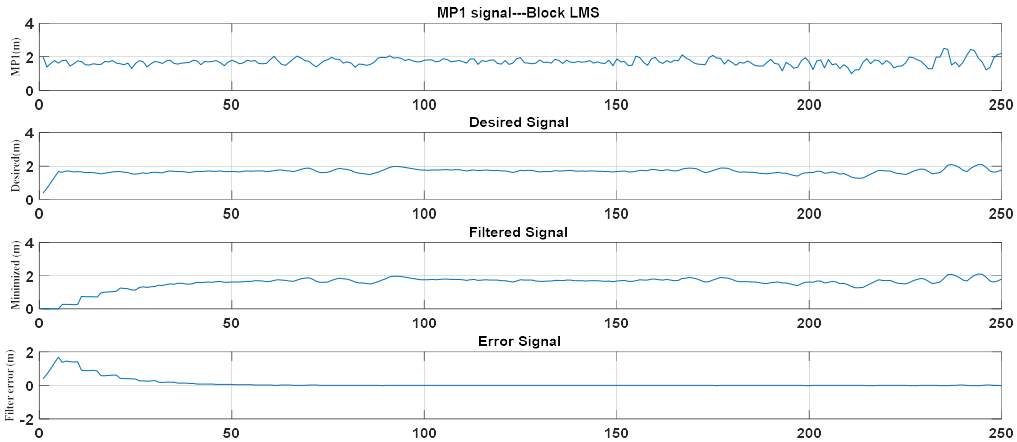

Figure 13: Multipath mitigation using BLMS filter on L1 of SV26 (15th March 2020). a) Multipath error (MP1 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

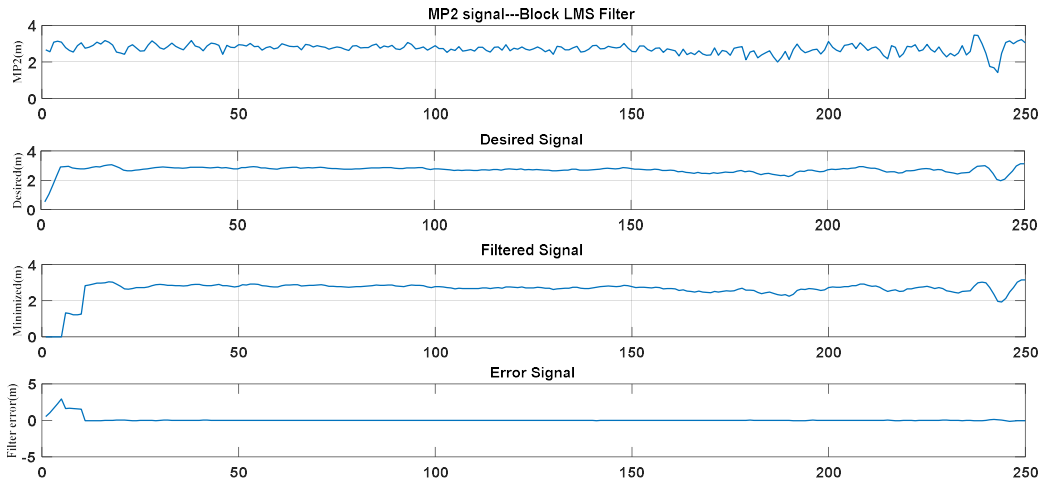

Figure 14: Multipath mitigation using BLMS filter on L2 of SV26 (15th March 2020). a) Multipath error (MP2 Signal). b) Desired Signal. c) Filtered signal. d) Error signal.

6. Conclusions

In this paper, to estimate multipath error CMC method is used. To mitigate the multipath error a new adaptive filtering technique BLMS is proposed and its performance is compared with other conventional adaptive filtering algorithms such as NLMS, LMS, HRLS and RLS. In comparison to the aforesaid filters, the BLMS filter has reduced multipath error more effectively. The percentage of multipath reduction is 95.05% and 92.30% on L1 and L2 respectively. The application of BLMS filter at signal processing level in multi-GNSS receiver will serve the purpose of multipath mitigation with improved performance compared to other conventional approaches.

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