AN OPTIMIZATION OF MULTIPLE GATES DELAY FOR UNAMBIGUOUS TRACKING FOR NEW GNSS SIGNALS

TỐI ƯU CẤU TRÚC ĐA TƯƠNG QUAN CHO QUÁ TRÌNH BÁM TÍN HIỆU KHÔNG NHẦM LẪN VỚI CÁC TÍN HIỆU ĐỊNH VỊ GNSS MỚI

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Ngày nhận bài: 17/5/2018
Ngày nhận bài sau phản biện: 26/6/2018
Ngày chấp nhận đăng: 28/6/2018

Abstract

Multipath is one of the main error sources in Global Navigation Satellite Systems (GNSS) such as Global Positioning System (GPS), Russian Global Navigation Satellite System (GLONASS) and European Galileo. In this paper, a novel method of multipath mitigation is proposed. It is based on using six correlators as multiple gate delay structure. This method could be applied to new navigation signals which adopt a new type of modulation called binary offset carrier (BOC). Some variants of BOC have been developed for new navigation signals. These new types of modulation provide some advantage in signal synchronization. However, there are some challenges since there are some side peaks in auto correlation function of signals. These side peaks could raise a risk of wrong peak selection called ambiguity problem. The proposed method in this paper also removes the ambiguity in code tracking. The simulation results show the good performance of this method in code tracking as well as multipath mitigation.

Keywords: BOC signal; multipath mitigation technique; side peaks cancellation; unambiguous tracking; multiple gate delay.

Tóm tắt

Hiện tượng đa đường là một trong những nguyên nhân chính gây ra sai số trong các hệ thống định vị sử dụng vệ tinh như GPS (Mỹ), GLONASS (Nga) và Galileo (Châu Âu). Bài báo này sẽ đề xuất một giải pháp mới để giảm ảnh hưởng của hiện tượng đa đường. Giải pháp đó dựa trên việc sử dụng 06 bộ tương quan theo cấu trúc đa tương quan (MGD). Giải pháp đề xuất có thể được áp dụng với các tín hiệu định vị mới sử dụng kỹ thuật điều chế sóng mang dịch nhị phân (BOC). Các dạng điều chế BOC khác nhau đã được ứng dụng cho các tín hiệu định vị mới. Kỹ thuật điều chế này sẽ mang đến nhiều thuận lợi, ưu điểm cho quá trình đồng bộ tín hiệu định vị. Tuy nhiên, bên cạnh đó, kỹ thuật điều chế này lại gây ra những khó khăn do hiện tượng tạo đỉnh phụ trong hàm tự tương quan của tín hiệu định vị. Các đỉnh phụ này sẽ gây ra hiện tượng bám tín hiệu nhầm vào các đỉnh phụ và do đó gây ra sai lệch trong quá trình bám mã. Vì vậy, giải pháp đề xuất cũng sẽ có cơ chế để loại bỏ các đỉnh phụ này. Các kết quả mô phỏng đã cho thấy hiệu năng hoạt động của giải pháp đề xuất trong cấu trúc bám mã cũng như khả năng giảm ảnh hưởng hiệu ứng đa đường.

Từ khóa: Tín hiệu BOC; kỹ thuật giảm nhiễu đa đường; kỹ thuật triệt đỉnh phụ; bám không nhầm lẫn; đa tương quan.

1. INTRODUCTION

Recently, the Global navigation satellite systems (GNSS) play an important role in almost sectors of life. The navigation services have been used in aviation, marine navigation, environment surveying and disaster warning system. However, the performance of GNSS is suffered from some error sources such as ionosphere delay, tropospheric delay, ephemeris error, receiver noise and multipath. While other errors could be removed by differential technology, multipath is still the main error since its impact is dependent on the location of each receiver. Multipath mitigation techniques could be classed as three approaches [1]: pre-receiver techniques applied before the GNSS signals entering the antenna; receiver signal processing techniques applied in code and carrier phase tracking loops and post-processing techniques used after the pseudo-range have been achieved. The approach in this paper is focus on the second class. This approach is correlation-based technique. In typical GNSS receivers, the tracking loops include phase lock loop

(PLL) for carrier phase tracking and delay lock loop (DLL) for code delay tracking. The conventional DLL uses 03 correlators named as Early (E), Prompt (P) and Late (L) with early-late spacing is one chip to create a discriminator function based on Early-Minus-Late (EML) form. However, this classical DLL fails to mitigate multipath impact. Therefore, many EML-based multipath mitigation techniques have been proposed in literature recent years. One of the first method for enhancing multipath mitigation, called Narrow Correlator (NC), is proposed in [2] based on the narrowing the early-late spacing to $0.1 chips$. However, the correlator spacing depends on the frontend filter bandwidth, thus, it could not be reduced too much. Another approach called Double Delta Correlator (DDC) based on using five correlators instead of three correlators as NC. The multipath mitigating performance of DDC is better than NC for medium-to-long multipath delays. One other method which could be a generalization of DDC is Multi Gate Delay (MGD) [3]. In MGD, there are more than three correlators using to create the discriminator function. The performance of MGD may be worse than DDC and NC. However, it could eliminate the risk of wrong peak selection when applied to binary offset carrier (BOC) modulated signals.

In this paper, a new method of code tracking is proposed in order to improve the code tracking performance of MGD. The structure of the proposed method based on six correlators and the weight coefficients of each correlator are optimized in order to get the unambiguous tracking. Moreover, the performance in multipath mitigation is also improved according to some criteria such as multipath error envelope (MEE).

The rest of the paper is organized as follows. The characteristics of BOC modulated signals is described in Section 2. After that, section 3 illustrates the principle of our proposed method. The numerical results and discussion are presented in Section 4. Finally, some conclusions is drawn in Section 5.

2. THE CHARACTERISTICS OF BOC MODULATED SIGNALS

While the traditional navigation signal, GPS L1 C/A, using binary phase shift keying (BPSK) as its modulation, many new navigation signals such as Galileo E1, GPS L1C use new type modulation of BOC in order to co-exist with each other signal on the same carrier frequency. According to [4], the baseband BOC modulated signal is the result of multiplied the pseudorandom noise (PRN) code with a rectangular subcarrier of frequency f_s. Typically, the BOC modulated signals is denoted as $BOC(m,n)$, in which $m = f_s/f_{ref}$ and $m = f_c/f_{ref}$ where f_c is code rate and $f_{ref} = 1.023MHz$ is the reference frequency. Depending on the initial phase of subcarrier, the $BOC(m,n)$modulated signal could be sine-phased $BOC(m,n)$ ($BOCs(m,n)$) or cosine-phased $BOC(m,n)$ ($BOCc(m,n)$) if the initial phase of subcarrier is 0 radian or $\pi/2$ radian, respectively.

The important characteristics of $BOC(m,n)$ modulated signals could be considered is autocorrelation function (ACF). The ACFs of of $BOCs(n,n)$ as well as $BOCc(n,n)$ modulated signals are shown in **Fig. 1**. As shown in the figure, besides the main lobe, the ACF of BOC modulated signal also introduces some side lobes. The number of the side lobes depends on the modulation order of N_B and the initial phase of subcarrier. The side lobes of the ACF will raise the risk of false lock in code tracking because the tracking loop may lock on one of the side lobes instead of the main lobe. This phenomenon is called ambiguous problem.

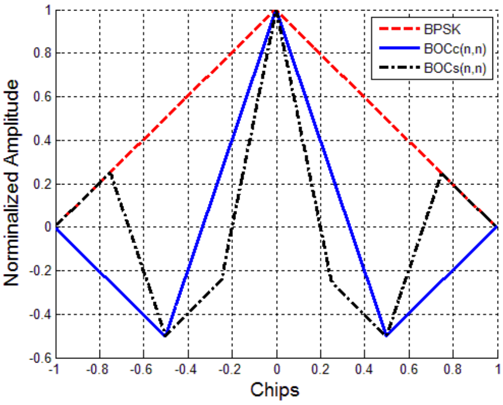

Fig. 1. BPSK, $BOCs(n,n)$ and $BOCc(n,n)$ normalized ACFs

3. PROPOSED DELAY TRACKING LOOP IN GNSS RECEIVERS

3.1. Proposed MGD Structure

Typically, in GNSS receiver, the code delay tracking loop is based on feedback delay lock loop (DLL), which is an implementation of maximum likehood Estimation (MLE) of time delay of PRN code of a navigation signal of a visible satellite. The zero crossings of discriminator function (S-curve) defines the path delay of received navigation signal. There are several variants of discriminator function as in [5].

The proposed structure of DLL includes three pairs of early and late correlators ($N = 3$). Therefore, the discriminator function of the proposed MGD is expressed as

$$D_{p-MGD}(\tau) = \sum_{i=1}^{N} a_i (E_i^2 - L_i^2) = \sum_{i=1}^{3} a_i \left(\left(R\left(\tau - \frac{\delta_i}{2}\right)\right)^2 - \left(R\left(\tau + \frac{\delta_i}{2}\right)\right)^2 \right) \quad (1)$$

where a_i are weighting factors; E_i, L_i are the outputs of Early and Late correlators, respectively; δ_i are spacing (in chips) between the i^{th} Early and the i^{th} Late correlator ($\delta_i = i\delta_1$).

Without loss of generality, the first weighting coefficient of a_1 should be chosen as $a_1 = 1$. In Equation (1), there are two weighting coefficients of a_2, a_3 being optimized according to the early-late spacing and other criterions.

3.2. Optimization of the proposed structure

The optimization includes two phases. Firstly, the weighting coefficients are optimized in order to get the discriminator function in which there is no false lock point. Secondly, among the achieved set of weighting coefficients, finding out which set of them provide the best multipath mitigation. It means that the main peak of ACF is still tracked even if the initial tracking error is larger than chip period.

In the first phase of optimization, the channel model only includes LOS signal. In order to get the unambiguous discriminator function, the following characteristic has been obtained: in both side of correct zero crossing point, the discriminator function must not change the sign. It means that

$$\begin{aligned} D_{p-MGD}(\tau) &< 0, for\ 0 \le \tau \le 1 \\ D_{p-MGD}(\tau) &> 0, for -1 \le \tau \le 0 \end{aligned} \quad (2)$$

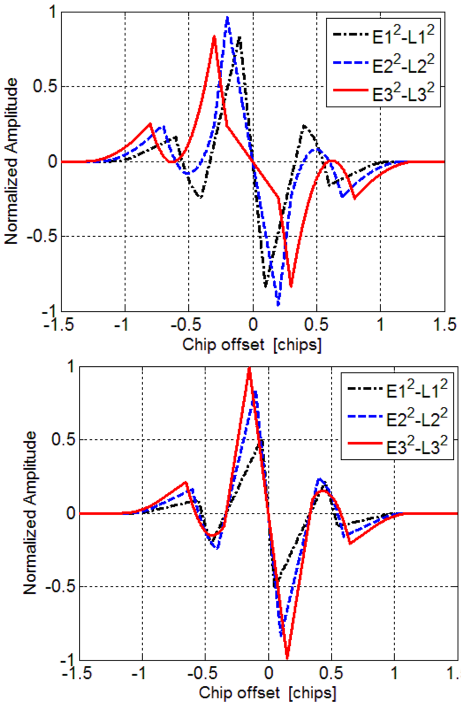

Fig. 2. S-curves of 3 pairs of correlator for $\delta_1 = 0.2chips$ (top) and $\delta_1 = 0.1chips$ (bottom)

The characteristic of the discriminator function as in Equation (3) depends on the early-late spacing and S-curves of each pair of correlators. **Fig. 2 (left)** and **Fig. 2 (right)** show the S-curves of 3 pairs of correlators, they are $E_1^2 - L_1^2, E_2^2 - L_2^2, E_3^2 - L_3^2$ curves, with early-late spacing $\delta_1 = 0.2chips$ and $\delta_1 = 0.1chips$, respectively. From these figures, it could be concluded that one of half of early – late spacing $\delta_i/2$ must be larger than half of the width of the ACF main lobe. For the proposed MGD structure with $N = 3$, the weighting coefficients for unambiguous discriminator function is found out unless δ_1 is not smaller than $0.1chips$. With the range of coefficient values of $[-1; 1]$ (normalized according to the value of a_1) with the step of 0.1, for the first phase of optimization, the number of pairs of optimized coefficients as shown in Table 1 with several values of early-late spacing.

TABLE I. THE NUMBER OF OFTIMUM COEFFICIENTS OF MGD

Chip spacing	Number of pairs of coefficients $(a_2; a_3)$
$\delta_1 = 0.2$	25
$\delta_1 = 0.25$	112
$\delta_1 = 0.4$	124

In the second phase of optimization, among the resulting set of coefficients achieving in the first phase, the finally optimized coefficients should be found in order to provide the best multipath mitigation. In order to assess the performance of code tracking delay loop of GNSS receivers in multipath environment, the typical criteria is multipath error envelope (MEE). In MEE, there are only two paths of receiving GNSS signals entering the antenna of receivers, one line-of-sight (LOS) signal and one multipath signal. The multipath signal is either in-phase or out-phase in comparison to LOS signal. Moreover, the multipath signal should be delay-invariant. It means that for all delays amplitude, phase of multipath signal are constant. Using MEE, the multipath mitigation of delay tracking structure is good if there are small average errors, small worst errors in MEE and small maximum multipath delay after that MEE reaches to zero. The values of optimum coefficients are shown in Table 2 with several values of early-late spacing.

TABLE II. OPTIMUM COEFFCIENTS OF MGD BASED ON MEE

Chip spacing	a_2	a_3
$\delta_1 = 0.2$	-0.5	0.6

$\delta_1 = 0.25$	-0.5	0.4
$\delta_1 = 0.4$	-0.1	0.8

From these tables, it can be seen that the weighting coefficients could be chosen in order to get the minimum multipath errors as well as provide an unambiguous discriminator function.

4. SIMULATION RESULTS AND DISCUSSION

4.1. The S-curve of the proposed MGD structure

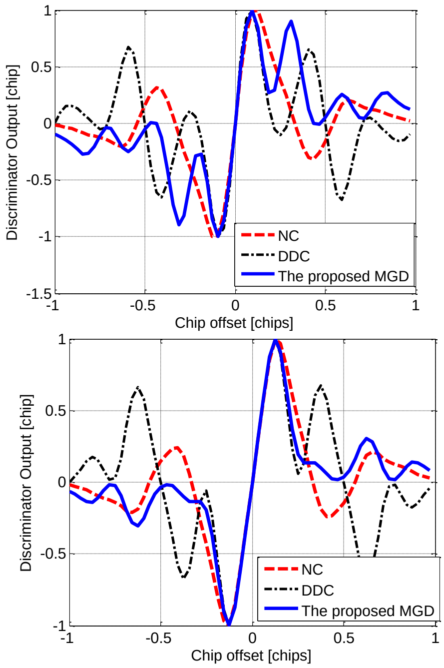

Fig. 3. S-curves for NC, DDC, proposed MGD ($[a_2; a_3] = [-0.5; 0.6]$) with $\delta_1 = 0.2chips$ (top) and ($[a_2; a_3] = [-0.5; 0.4]$) with $\delta_1 = 0.25chips$ (bottom) for $BOCs(n, n)$ signal.

For verifying the characteristic of the discriminator functions (S-curve), the received GNSS signal only includes a single LOS component. **Fig. 3** illustrates the shapes of discriminator functions with NC, DDC and the proposed MGD for $BOCs(n, n)$ signal. The spacing of the first pair of early-late correlators is $\delta_1 = 0.2chips$ (left) and $\delta_1 = 0.25chips$ (right). As seen in the figure, there is only one zero crossing point for the proposed MGD. This zero crossing point locates at zero code delay (in case of multipath – free). It means that the tracking loop could lock at the main peak of ACF. Therefore, the ambiguity problem is resolved. In the same case, the NC and DDC create more than one crossing point. Thus, they suffer from ambiguity problem in code tracking loop.

4.2. The effects of multipath

As above mentioned, MEE criteria could be used for assessing the multipath mitigation performance in code tracking loop. The amplitudes of LOS signal and multipath signal are 1 and 0.8, respectively. The MEE is shown in **Fig. 4**. As shown in the figure, the performance of the proposed MGD is better than NC but worse than DDC. Although the performance of MGD is not good as DDC, the difference is very small. Moreover, in case of multipath environment, the proposed MGD could eliminate the ambiguity problem, the DDC could not. Therefore, the ranging error of DDC under the effect of multipath signal maybe larger than the proposed MGD.

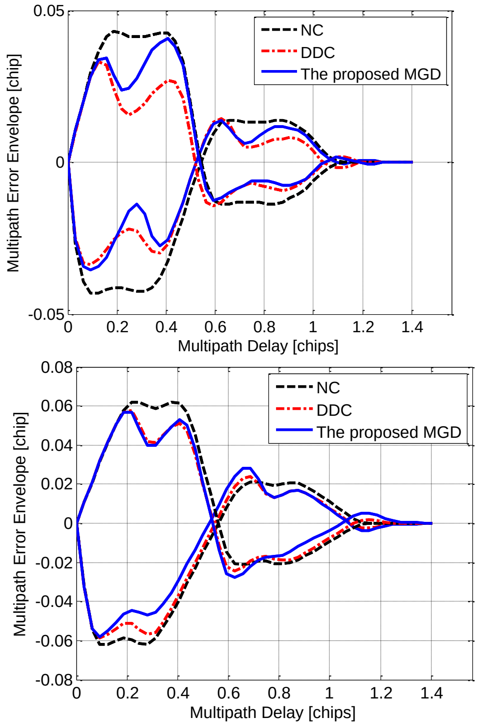

Fig. 4. MEE for NC, DDC, proposed MGD ($[a_2; a_3] = [-0.5; 0.6]$) with $\delta_1 = 0.2chips$ (top) and ($[a_2; a_3] = [-0.5; 0.4]$) with $\delta_1 = 0.25chips$ (bottom) for $BOCs(n, n)$ signal.

5. CONCLUSIONS

In this paper, an unambiguous BOC tracking technique based on MGD structure is presented. The weighting coefficients of the proposed structure are optimized in two steps in order to get an unambiguous discriminator function and to achieve the best multipath mitigation. Moreover, the proposed method is also compared to NC and DDC. Although the multipath mitigation performance of the proposed method is worse than DD, this method achieves an unambiguous BOC tracking.

REFERENCES

[1]. Nunes, F. D., Sousa F. M. G., and Leitao J. M. N., "Gating Functions for Multipath Mitigation in GNSS BOC Signals," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 43, pp. 951-964, 2007.

[2]. Dierendonck, A. J. V., Fenton P., and Ford T., "Theory and Performance of Narrow Correlator Spacing in a GNSS Receiver," *Journal of the Institute of Navigation,* vol. Vol. 39, Fall 1992.

[3]. Bello, P. A. and Fante R. L., "Code tracking performance for novel unambiguous M-code time discriminators," in *Proceedings of the 2005 National Technical Meeting of The Institute of Navigation*, San Diego, CA 2005, pp. 293 - 298.

[4]. Lohan, E. S., Lakhzouri A., and Renfors M., "Binary-offset-carrier modulation techniques with applications in satellite navigation systems," *Wireless Communications and Mobile Computing,* vol. 7, pp. 767-779, 2007.

[5]. Borre, K., Akos D. M.*, et al.*, *A Software-Defined GPS and Galileo Receiver - A Single-Frequency Approach*. Berlin: Birkhäuser, 2007.