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# Research on Correlation Peak Distortion Detection Method of Satellite Navigation Signal

**Hongxiao Li***

*Civil Aviation Air Traffic Control Technology Equipment Development Co. Ltd. Beijing, China*
**Corresponding author: lihongxiao.1988@163.com*

***Abstract:*** *Correlation peak distortion is an important part of signal quality monitoring (SQM) correlation domain research, in which correlation peak distortion detection plays an important role in the traceability of abnormal satellite navigation signals. In this paper, the GPS navigation signal data is processed, and the actual correlation peak distortion range is obtained by using the idea of multi-correlator accumulation and averaging, and the detection of the navigation signal correlation peak distortion is realized by comparing the ideal correlation peak. The correlation peak distortion detection method proposed in this paper can realize the rapid detection of correlation peak distortion, and provide a new idea for the research of correlation peak distortion detection.*

***Keywords:*** *Correlation peak distortion, Signal Quality Monitoring, Abnormal navigation signal, Global Positioning System*

## 1. Introduction

With the continuous iterative upgrade of the global satellite navigation system (GNSS), the service performance of the satellite navigation system has been comprehensively improved, and the application scenarios and scope have been deepened, playing a pivotal role in the national economy and military fields [1]. During the entire transmission process from generation, broadcast to reception of satellite navigation signals, problems in any part will lead to abnormalities in the navigation signals received on the ground, resulting in a reduction in ranging accuracy and ranging deviations. In serious cases, it may even cause immeasurable consequences [2]. Since the abnormality of GPS satellite navigation signals in the United States in 1993, the research on the quality monitoring of navigation signals has gradually attracted extensive attention of researchers in the field of international satellite navigation [3-4].

At present, there are two main ways to monitor the quality of navigation signals: fault detection and identification of multi-satellite navigation signals based on omnidirectional antennas, and refined analysis of navigation signals based on high-gain and large-aperture directional antennas. The two navigation signal quality monitoring methods have their own advantages and disadvantages. Among them, due to the low gain of the omnidirectional antenna, the received navigation signal is usually overwhelmed by noise, and it is impossible to directly observe and analyze the navigation signal. The relevant information can only be obtained through the correlation domain and the measurement domain, but the omnidirectional antenna can simultaneously complete the monitoring and reception of multiple satellites within the visible range; high-gain directional antennas, due to their high gain, can not only complete the analysis of information in the correlation domain and measurement domain, but also directly observe and analyze the time domain, frequency domain and other information of the signal. Only one satellite can be tracked directionally at a time, and the evaluation of navigation and positioning service indicators cannot be completed. It can be seen from the above analysis that the two signal quality monitoring methods can complete the monitoring of the correlation domain of the navigation signal, and the distortion detection of the correlation peak in the correlation domain monitoring index is an important research content. Therefore, starting from the perspective of correlation peak distortion detection, the monitoring of signal anomalies can be completed without being restricted by the signal quality monitoring method.

This paper first analyzes the existing methods of correlation peak distortion detection, and then obtains the original observation data of GPS satellite navigation signals through omnidirectional antennas. Taking GPS L1C/A code signal as an example, the data length of 36s is selected, and 8 pairs of lead-lag correlators are set. The actual correlation peak distortion range is obtained by averaging the multi-correlator lead and lag accumulation results, and compared with the ideal correlation peak, the rapid identification and detection of the correlation peak distortion of the navigation signal is completed.

## 2. Existing Correlation Peak Distortion Detection Methods and Analysis

### *2.1. Multiple Correlator Detection*

The basic idea of multi-correlator detection is to introduce a pair of lead-lag correlators with a narrow correlation interval in the signal tracking process, and other correlators are based on the pair of correlators for fixed interval expansion. To obtain the correlation value at different chip positions of the correlation peak, so as to realize the purpose of monitoring the shape of the correlation peak in real time [5-6].

The detection value obtained by linear combination of the output result of the correlator is compared with the standard correlation peak, which can reflect the slope and symmetry of the correlation peak, so as to realize the detection of the distortion of the correlation peak. Commonly used assays include:

$$\Delta Detection\text{:}\quad \Delta_{\pm d_1/2,\pm d_2/2} = \Delta_{\pm d_1/2} - \Delta_{\pm d_2/2} = \frac{I_{-d_1/2} - I_{+d_1/2}}{I_O} - \frac{I_{-d_2/2} - I_{+d_2/2}}{I_O} \tag{1}$$

$$Ratio\ Detection\text{:}\quad R_{\pm d_i/2,O} = \frac{R_{-d_i/2,O} - R_{+d_i/2,O}}{2} = \frac{I_{-d_i/2} - I_{+d_i/2}}{2\cdot I_O} \tag{2}$$

Among them, $I_{-d_1/2}$ represents the correlation peak amplitude corresponding to the leading $d_1$ chip, $I_{+d_1/2}$ represents the correlation peak amplitude corresponding to the lagging $d_1$ chip, and similarly $I_{-d_2/2}$ and $I_{+d_2/2}$. $I_0$ represents the amplitude of the correlation peak and the road tracking output in time.

The multi-correlator detection algorithm uses a pair of trackers and 11 detection values composed of two pairs of subordinate correlators to complete the distortion detection of correlation peaks. The multi-correlator monitoring algorithm has many detection variables, and each variable needs to set a corresponding threshold according to its noise distribution, and it is necessary to determine whether the correlation peak is distorted according to the detection results of multiple variables; in addition, the multi-correlator detection algorithm has high hardware complexity, which brings a burden to the design of the hardware receiver.

### *2.2. E-L Detection*

The so-called E-L detection algorithm is to use the correlation value between the leading and lagging correlation peaks to make a difference, and establish a Gaussian distribution model of each correlation value to detect the distortion of the correlation peak [7]. The E-L detection algorithm model is as follows:

$$T\left(r\left(t\right)\right) = H_i^E\left(t\right) - H_i^L\left(t\right) \tag{3}$$

Among them, $H_i^E\left(t\right)$ represents the leading coherent integral value of the local signal and the actual signal in each code loop plus the local signal and the interference signal, and $H_i^{\mathrm{L}}\left(t\right)$ represents the local signal and the actual signal in each code loop plus the lag coherent integral value of the local signal and the interference signal.

In the case of no interference, the correlation value of each code loop can be regarded as a Gaussian distribution model, and the mean values of E and L are considered to be the same [8]. Therefore, the E-L detection algorithm conforms to a Gaussian distribution with zero mean and unknown variance $\sigma_{\mathrm{o}}^2$ under the undisturbed condition ( $F_o$ represents the undisturbed condition):

$$F_o : T\left(r\left(t\right)\right) \sim N\left(0,\sigma_o^2\right) \tag{4}$$

In the symmetrical time of the two branches E and L, the detection value of E-L conforms to $\sigma_1^2$ Gaussian distribution with zero mean and different variance ( $F_1$ represents the interference condition):

$$F_1 : T\left(r\left(t\right)\right) \sim N\left(0, \sigma_1^2\right) \tag{5}$$

Equations (4) and (5) show that the premise of the correlation peak distortion detection is to know $\sigma_o^2$ and $\sigma_1^2$, otherwise the detection value of E-L under the conditions of $F_o$ and $F_1$ cannot be distinguished, and the correlation peak distortion detection cannot be realized.

### *2.3. Ratio Detection*

The basic idea of the Ratio detection method is to use the ratio of the sum of the leading and lagging correlation values to the immediate road correlation value as the basic detection quantity to judge and evaluate the degree of correlation peak distortion [9-10]. Model for Ratio detection method:

$$T_1\left(r\left(t\right)\right) = \left(H_i^E\left(t\right) + H_i^L\left(t\right)\right) \Big/ H_i^O\left(t\right) \tag{6}$$

Among them, a, b and c represent the lead, lag and immediate related output values of the i-th branch, respectively. Since Equation (6) introduces random variable division, Ratio detection will not conform to a Gaussian distribution with zero mean like E-L detection, so it will bring the following problems:

(1) The mathematical form of the Gaussian distribution with non-zero mean is complex, the calculation is difficult, and it is difficult to accurately calculate the performance of the detection quantity. And the test threshold and test probability still need prior information to be determined.

(2) The essence of the Ration algorithm is to check the "dead zone" at the top of the correlation peak, but it is powerless to detect the distortion on both sides of the correlation peak.

## 3. A Novel Correlation Peak Distortion Detection Method

Aiming at the shortcomings of the above three correlation peak distortion detection methods, a software multi-correlator post-processing is proposed in this paper, and the correlation peak distortion is detected by using the mean value of the accumulative error tracked by the correlator as the distortion detection range. The original data of GPS satellite navigation signal processed in this paper is obtained by omnidirectional antenna. Taking the L1 C/A signal of BPSK modulation as an example, the data length of 36s is selected for the PRN10 satellite for processing. The correlation peak distortion detection method in this paper is as follows:

The mean and ideal correlation accumulation mean of PRN10 satellite 36s data are respectively expressed as:

$$\overline{R}_F = \sum_{i=1}^{n} R_i^F \Big/ n \tag{7}$$

$$\overline{R}_I = \sum_{i=1}^{n} R_i^I \Big/ n \tag{8}$$

Among them, $\overline{R}_F$ and $\overline{R}_I$ respectively represent the actual average value and the ideal average value after the relevant accumulation of 36s data; n is equal to 36000, which means that the 36s data is accumulated 36000 times (1ms cycle accumulation); $R_i^F$ and $R_i^I$ respectively represent the actual correlation value and ideal correlation value after a single accumulation of the correlator, which can be expressed as:

$$R_i^F = R_i^{FE} + R_i^{FP} + R_i^{FL} \tag{9}$$

$$R_i^I = R_i^{IE} + R_i^{IP} + R_i^{IL} \tag{10}$$

Among them, $R_i^{FE}$, $R_i^{FP}$ and $R_i^{FL}$ represent the actual correlation accumulated value of each leading, immediate and lag, respectively; $R_i^{IE}$, $R_i^{IP}$ and $R_i^{IL}$ respectively represent the ideal correlation accumulated value of each leading, immediate and lag.

Normalize the cumulative mean of the actual and ideal correlations, and then do the difference to get the correlation peak distortion range:

$$r_{F-I} = \left(\bar{R}_F / \max\left(\bar{R}_F\right) - \bar{R}_I / \max\left(\bar{R}_I\right)\right) \big/ m \tag{11}$$

Among them, m represents the number of correlators, and the correlator interval set in this paper is 0.125 chips, so m=8.

Finally, the final correlation peak distortion degree is determined by the ideal correlation cumulative mean and the correlation peak distortion range:

$$J_{F-I} = \bar{R}_I \pm r_{F-I} \tag{12}$$

If the mean value of a correlator after the actual correlation accumulation is greater than $J_{F-I}$, it means that the mean value of the correlator exceeds the allowable maximum correlation distortion range, and the correlation distortion occurs at the mean value of the correlator; if the mean value of a correlator after the actual correlation accumulation is less than or equal to $J_{F-I}$, indicating that the mean value of the correlator is within the allowable range of distortion, the correlation peak can be considered available, and the correlation peak is not distorted.

## 4. Analysis of measured results

According to the new correlation peak distortion detection method, the actual GPS satellite navigation signal is processed and analyzed, and the normalized actual and ideal correlation peaks are obtained, as shown in Figure 1. It can be seen from Figure 1 that the actual correlation peak curve deviates significantly from the ideal correlation peak curve, indicating that the actual correlation peak is distorted. The ideal GPS satellite navigation signal correlation peak is symmetrical with the zero chip as the center, and the maximum value of the correlation peak is located at the center of the zero chip, with a value of 1; however, the correlation curve of the actual correlation peak is not a smooth straight line, but a left-right asymmetrical curve, and the closer the position is to the center of the zero chip, the more serious the distortion of the correlation peak.

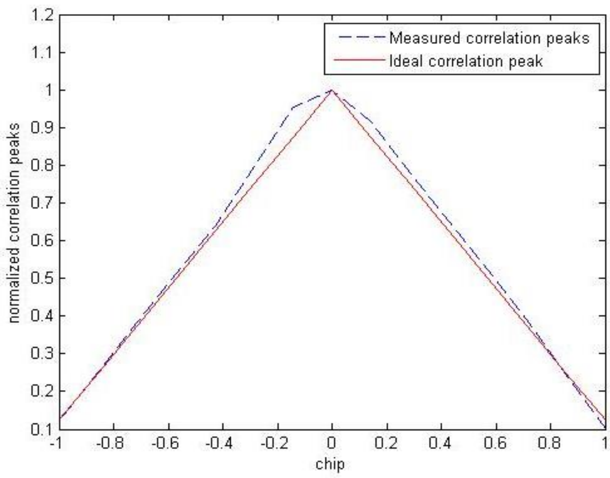
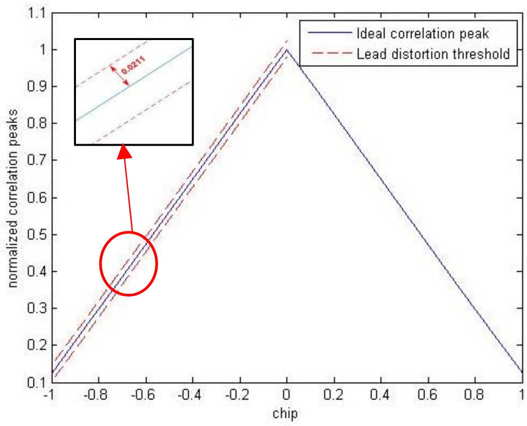
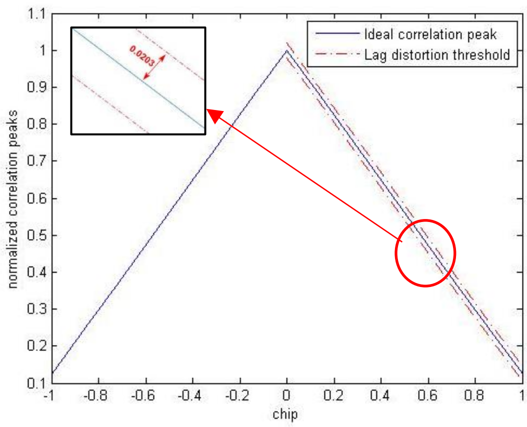



*Figure 1: Actual and ideal correlation peaks*

According to formulas (11) ~ (12), taking the ideal correlation peak as the benchmark, by calculating the difference between the actual lead and lag correlation cumulative mean and the ideal correlation cumulative mean, the lead and lag distortion ranges and local magnifications relative to the ideal correlation peak are obtained, as shown in picture 2. As shown in Figure 2 (a), the leading distortion range of the correlation peak and its local magnification, the distortion range is ±0.0211 relative to the ideal correlation peak; Figure 2 (b) shows the correlation peak lag distortion range and local magnification, the range of the correlation peak distortion is ±0.0203. The lead distortion range of the correlation peak is larger than the lag distortion range, which verifies that the actual correlation peak shown in Figure 1 is left-right asymmetric and the left-side distortion is larger than the right-side distortion.




*(a) Correlation peak lead distortion range and local magnification*




*(b) Correlation peak lag distortion range and local magnification*

*Figure 2: The leading and lagging distortion range and local magnification of the correlation peak of GPS L1 C/A code signal*

Figure 3 shows the actual correlation peak distortion detection results. The dotted lines in the figure represent the lead and lag distortion ranges of the correlation peak. For the actual satellite navigation signal, the multi-correlation cumulative mean is obtained after tracking processing. If the correlation mean is within the distortion range, it means that the point is not distorted, and if the correlation mean jumps out of the distortion range, it means that the point is distorted. As shown in Figure 3, two correlation points at the leading top and the lagging top of the correlation peak jump out of the distortion range, indicating that the top region is severely distorted, and rapid detection of the correlation peak distortion can be achieved.

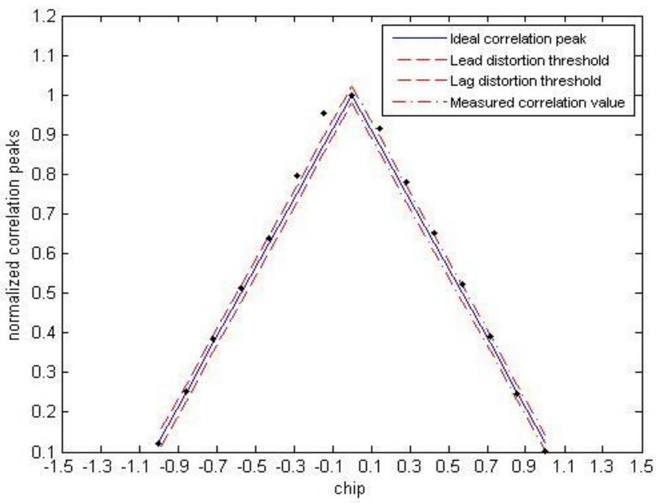



*Figure 3: Actual correlation peak distortion detection results*

## 5. Conclusion

Aiming at the correlation peak distortion problem of GPS L1 C/A code signal, this paper studies and analyzes the existing correlation peak distortion detection methods, and proposes a new correlation peak distortion detection method. The method determines the distortion detection range by calculating the cumulative average of the actual correlation peaks leading and lag and the cumulative average of the

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ideal correlation peaks. Compared with several existing methods for detection of correlation peak distortion, this method has specific advantages. Compared with multi-correlator detection, the new method requires less detection variables and does not require more hardware cost; compared with EL detection, the new method has low computational complexity and does not need to determine prior information; compared with Ratio detection, the new method enables the detection of distortions on both sides of the correlation peak. The correlation peak distortion detection method in this paper has certain value for the rapid detection and identification of correlation peak distortion.

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