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A Multipath Mitigation Algorithm for vehicle with Smart Antenna

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Abstract. In this paper, the antenna array adaptive method is used to eliminate the multipath interference in the environment of GPS L1 frequency. Combined with the power inversion (PI) algorithm and the minimum variance no distortion response (MVDR) algorithm, the anti-Simulation and verification of the antenna array, and the program into the FPGA, the actual test on the CBD road, the theoretical analysis of the LCMV criteria and PI and MVDR algorithm principles and characteristics of MVDR algorithm to verify anti-multipath interference performance is better than PI algorithm , The satellite navigation in the field of vehicle engineering practice has some guidance and reference.

1. Introduction

GNSS, global satellite navigation system. Four active systems are existed as: US-led GPS, Russia-led GLONASS, China-led BDS and European-led GALILEO. With the development of satellite navigation applications, GPS has become the world's most trusted users, the most important spatial information infrastructure, GPS system to provide users with the whole period, all-weather positioning, navigation and timing (PNT) service capabilities have become the most important national capacity in the United States. In recent years, the deteriorating electromagnetic environment and man-made threats have caused signal transparency and interface to open the GNSS system to further increase the vulnerability, making the receiver facing difficult to meet the military needs, homeland security, economic development, infrastructure and people's daily life on the positioning, Navigation and timing requirements of the dilemma, the urgent need to strengthen the receiver anti-jamming and interference cancellation research.

The most common interference scenarios for GNSS receivers in civil applications are multipath disturbances, which occur in urban canyons and tall mountains, and the GNSS receivers receive signals that are formed by mixing the direct and reflected portions, In extreme cases, only the reflected part of the received signal, multi-path interference caused by the GPS positioning accuracy of the maximum error even up to 150 meters. According to the principle of division, in the receiver section of anti-jamming technology has three: antenna technology, receiver technology, post-processing technology [1]. The basic principle of the antenna technology is to compare the desired line of sight signal direction vector and the actual signal direction vector difference to carry out multi-path detection [2]. It has the advantage that the adjustment factor can be used to suppress multi-path interference accuracy, but the cost is higher; receiver technology is through pre-detection bandwidth,

narrowed signal code tracking loop filter and carrier tracking loop filter bandwidth approach to improve Anti-jamming performance, the advantage is that the external navigation system can provide accurate speed to make up for the loss of the dynamic range, the disadvantage is that the code / carrier tracking ring can not be long lost [3]. The post-processing technology is also called fusion technology, mainly through the Kalman filter algorithm and other related algorithms to integrate multi-sensor, multi-system solution data to correct the positioning error caused by multipath interference, which has the advantage of achieving high precision positioning of the receiver , The disadvantage is that real-time elimination of interference can not be achieved [4].
The antenna array is composed of multiple antennas, and its essence is to use the spatial array of sensor arrays and multi-channel reception to obtain the multi-dimensional information such as time domain and airspace of the signal source to achieve the purpose of detecting the signal and extracting its parameters. in fact. Present form of adaptive antenna technology, antenna array beam formation of the satellite signal to enhance the receiving technology, zero antenna technology, vector antenna technology. These methods can not only inhibit the influence of multipath signals. And can suppress narrowband or broadband interference. To achieve the signal to the wave direction identification and signal polarization diversity reception.
The rest of this paper is organized as follows. Section 2 introduces the signal model and Section 3 the mitigation algorithm is compared for the vehicle. In section 4, some results are presented to evaluate in the vehicle test, and conclusions are drawn in Section 5.

2. Signal Model

2.1. Multipath Inference

Improvements due to GNSS augmentations and GNSS modernization are reducing many sources of error, leaving multipath and shadowing as significant and sometimes dominant contributors to error, as shown in Figure 1.This section discusses these sources of error, their effects, and ways to mitigate their effects [5].

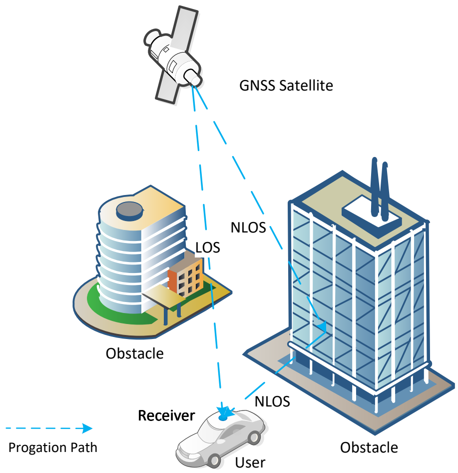

Figure 1. Multipath Effect

Let’s assume we receive total combined signal $x(t)$, it can be decomposed into three distinct components: desired signal, interference signal, and the noise. Thus, $x(t)$ can also is described in three components form as

$$x(t) = x_d(t) + x_i(t) + x_n(t) \qquad (1)$$

Where the subscripts *d*, *i* denote the desired signal, interference, and $x_n(t)$ is the thermal noise of propagation.
For the desired signal $x_d(t)$ with no multipath and noise is given by

$$x_d(t) = A_0 C(t - \tau_0) e^{-j\phi_0} e^{j2\pi f_c \tau_0} \quad (2)$$

Where A_0 is the received amplitude of the desired signal, $C(t)$ is the complex envelope of the transmitted signal, τ_0 and ϕ_0 are the propagation delay and carrier phase of the desired signal from satellite to receiver, and f_c is the carrier frequency. Then the multipath interference with the same form is expressed as

$$x_i(t) = \sum_{i=1}^{L} A_i C(t - \tau_i) e^{-j\phi_i} e^{j2\pi f_i \tau_i} \quad (3)$$

Where there are L multipath, A_i is the receiver amplitude of the ith multipath interference, τ_i is the propation delays of the ith multipath returns, ϕ_i is the carrier phases of ith multipath returns. and f_i is the received frequencies of the ith multipath return relative to the carrier frequency.
The expression (1) can be rewritten using parameters with neglecting noise $x_n(t)$ after sampling as

$$x(t) = A_0 e^{-j\phi_0}\left[C(t - \tau_0) + \sum_{i=1}^{L} \widetilde{A_i} e^{-j\widetilde{\phi_i}} C(t - \tau_0 - \widetilde{\tau_i})\right] \quad (4)$$

Where $\widetilde{A_i}$ denote the ith interference to desired ratio of amplitude, $\widetilde{\tau_i}$ is the relative delay of the ith multipath returns, and $\widetilde{\phi_i} = \phi_i - \phi_0$ is the relative carrier phases with ith multipath returns.
The expression (4) implies that the receive signal consist of a relatively stable direct signal(neglect shadowing occurs) and multipath interference drastically with changes in circumstance reflections. The change in the received signal is more dependent on the relative variable. Theoretical analysis, the desirable signal can be captured and tracked by technique with relative amplitude weights, relative delays and relative phases, such as DLL(Delay Lock Loop) and PLL(Phase Lock Loop), and similarly, the interference can be eliminated with waveform distortionless algorithm in delay and phase [6] .

2.2. Adaptive Antenna Array

Adaptive antenna array, also known as Smart antenna, is composed of the antenna array, ADC (Analog to Digital Converter) and baseband processing part. According to the array structure arrangement, it can be divided into: ULA (Uniform Linear Array), UPA (Uniform Planar Array), UCA (Uniform Circular Array) and spherical array.
The intelligent antenna can adaptively adjust the maximum radiation direction of the beam, and track the desired signal dynamically, and align the main signal with the desired signal, the null point to the interference signal, and the maximum suppression of the interference, using the signal antenna and the phase difference signal[7].

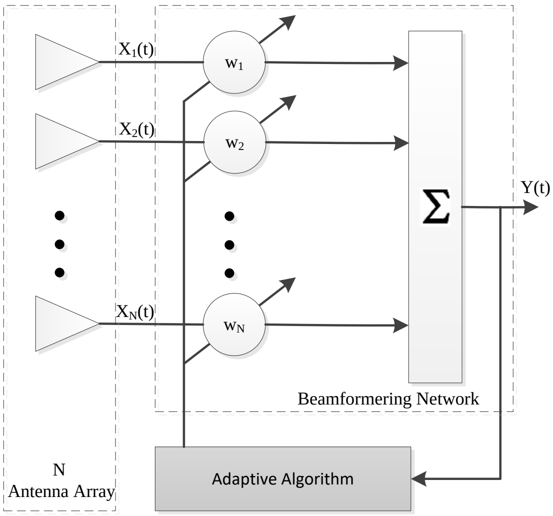

Figure 2. Adaptive Antenna Arrays Model

For a uniform array with N elements, d is denoted the spacing between adjacent elements, the signal received by each array through the adaptive processing module, get the N-way weight, the signal data and the corresponding right Value is weighted to get the combined output [8], as shown in Figure 2. The angle of incidence of the expected signal is θ and the elevation angle is φ. It can be expressed as

$$y_n(\theta,\phi) = \vec{W}^H \cdot \vec{X}(n) \tag{5}$$

The received signals array

$$X(t) = AS(t) + N(t) \tag{6}$$

$X(t) = [X_1(t), \cdots, X_N(t)]^T$ is data vector with N elements array, $N(t) = [N_1(t), \cdots, N_N(t)]^T$ denote noise vector, $S(t) = [S_1(t), \cdots, S_N(t)]^T$ is the received signal complex envelope vector, $S_p(t)$ is the complex of the pth signal source Envelope. $A = [a(\theta_1), \cdots, a(\theta_m)]$ denote steering matrix, $a(\theta_p)$ denote the steering vector with pth source, and $a(\theta_p) = [1, e^{j\beta_p}, \cdots, e^{(N-1)j\beta_p}]$, (P=1,2, ⋯m)

$$\beta_p = \frac{2\pi}{\lambda} d\sin\theta_p \tag{7}$$

Define the array covariance matrix

$$R = E[X(t)X^H(t)] \tag{8}$$

The weight is denoted by

$$W = [W_1, \cdots, W_N] \tag{9}$$

Then the array signal is weighted after the synthesized power output as

$$P_{out} = E\{|y(n)|^2\} = E\left\{\left(W^H X(n)\right)\left(W^H X(n)\right)^*\right\} E\{W^H R_{xx} W\} \tag{10}$$

3. Beamforming algorithm

3.1. PI

PI(Power Inversion) algorithm based on the LCMV criterion, so that the response vector g is constant 1, Constraint matrix $C = S = [1,0, \cdots ,0]^T$, the linear constraint condition as follow

$$W^H S = 1 \tag{11}$$

That is, the constraint factor for the first branch of the weighting factor is always 1, so that the output power is minimum, PI algorithm optimal weight vector is calculated as

$$W_{PI} = R_{XX}^{-1} S \left(S^H R_{XX}^{-1} S\right)^{-1} \tag{12}$$

The signal after interference suppression is

$$S_{PI}(n) = W_{PI}^H a(\theta_p) s(n) \tag{13}$$

3.2. MVDR

MVDR (Minimum Variance Distortionless Response) algorithm was first proposed by Capon in 1967, also known as Capon algorithm, which is an adaptive spatial beam spectrum estimation algorithm. Based on the linear minimum criterion, that is, under certain linear constraints, the signal power can be minimized. Based on the LCMV criterion, the response vector in the constraint direction is constant 1, while the constraint matrix is the desired signal direction vector,

$$\begin{cases} \text{s.t.} W^H a(\theta_p) = 1 \\ \min P_{out} = E\{|y(n)|^2\} \end{cases} \tag{14}$$

MVDR algorithm optimal weight vector is calculated as

$$W_{MVDR} = R_{XX}^{-1} a(\theta_p) \left(\alpha^H(\theta_p) R_{XX}^{-1} a(\theta_p)\right)^{-1} \tag{15}$$

The signal after interference mitigation is

$$S_{MVDR}(n) = W_{MVDR}^{H}\, a(\theta_p) s(n) \tag{16}$$

4. Simulation results

With Matlab simulation, the basic parameters are set: RF frequency f = 1575.42 MHz, the signal-to-noise ratio of the signal arriving at the antenna segment is about -28 dB, the spreading code rate is 1.023 MHz, the sampling rate is 1 MHz, the interference intensity is obviously stronger than the noise, The Jamming Signal Rate (JSR) is set in the range of 30 dB to 80 dB depending on the scene. In the case of most satellite navigation interference environments, the array model uses a typical 8-element linear array, Spacing d is 1/2 RF signal wavelength, interference for broadband Gaussian interference, bandwidth of 1.023 MHz, the center frequency and signal frequency of the same, as shown in Figure 3. The two algorithms pour into the hardware, the Central Business District in Beijing for the actual road test, we set the sampling rate of 1hz, positioning results shown in Figure 4. The yellow line represents the use of receiving RTK (Real - time kinematic) high precision , the red line represents the position data obtained using the MVDR algorithm with multi-antenna arrays, and the green line represents the position data obtained using the PI algorithm with multi-antenna arrays.
Figure 4 and Figure 5 show that the MVDR algorithm has a certain advantage over the RTK, but it has more obvious advantages than the PI algorithm. The anti-multipath interference ability is obvious and the contribution to the positioning accuracy is greater.

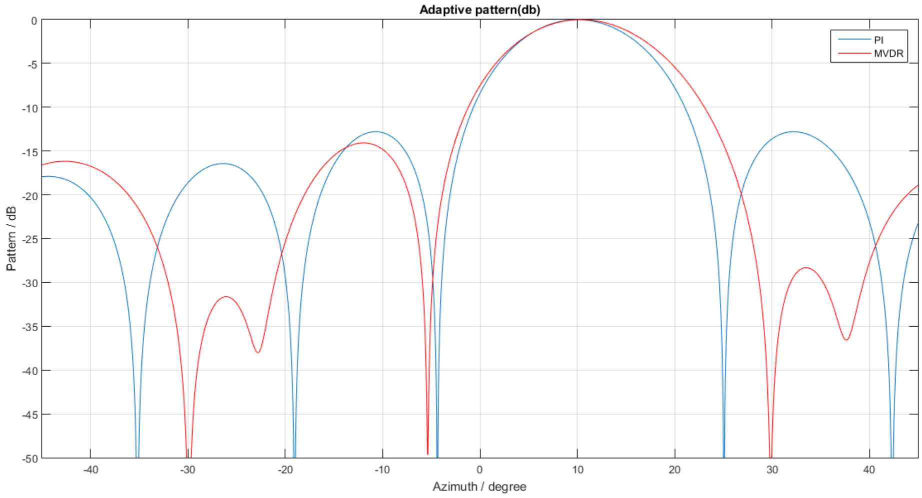

Figure 3. Adaptive Pattern

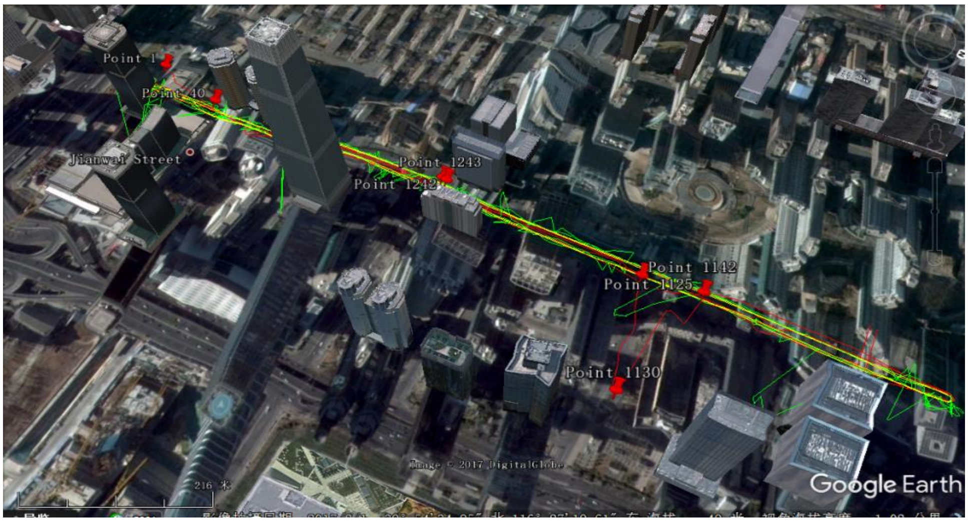

Figure 4. Comparison positioning data between PI and MVDR in vehicle test

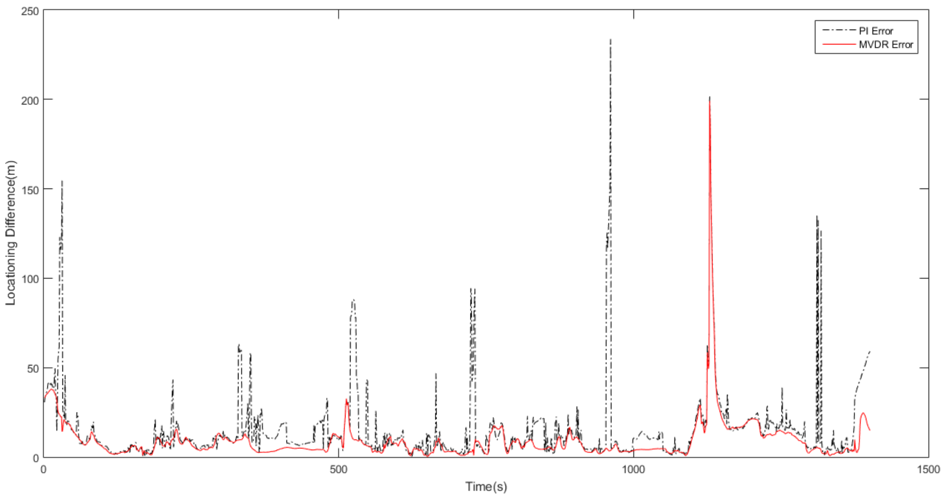

Figure 5 Comparison Error between PI and MVDR in the vehicle test

Figure 4 and Figure 5 show that the MVDR algorithm has a certain advantage over the RTK, but it has more obvious advantages than the PI algorithm. The anti-multipath interference ability is obvious and the contribution to the positioning accuracy is greater.

5. Conclusion

In this paper, two algorithms are proposed based on adaptive antenna array, the simulation results show that the MVDR algorithm is better than the classical PI algorithm in the application of the vehicle terminal, and it is better than the multi - path interference. The validity of the application of MVDR algorithm in vehicle high precision receiver is verified by on-the-road test, which lays the foundation for the application of multi-antenna array antenna in the vehicle.

6. References

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