Design Engineering

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

The Optimized Power Inversion Algorithm Applied in the Environment of Strong Interference and Weak Interference in Beidou Navigation System

Guoping Lei*, Xiuying Luo, Hongliang He, Minlu Dai
Chongqing Key Laboratory Geological Environment Monitoring and Disaster Early-warming in Three Gorges Reservoir Area, Chongqing Three Gorges University, Wanzhou, Chongqing, China
*Corresponding Author: Guoping Lei

Abstract:

The Beidou satellite signal of Beidou navigation positioning system is constantly changing, receiving signal processing before a priori information is not easy to judge the satellite signal. Therefore, the choice of the received signal power inversion algorithm of interference suppression effect is good under the condition of the environment. However, under a weak interference signal, the power strength is similar to the navigation signal, terminal receiving antenna sank in the position of jamming signal form zero with the navigation signal of zero in the same. It can't be differentiated! Therefore, this paper adopts the idea of matrix decomposition to extract the sub-matrix eigenvector values of interference and noise respectively, and then the algorithm is optimized by the judgment processing of the matrix. At the same time, the antenna adaptive interference power inversion method framework and process are designed, and the code was written and simulated with MATLAB software. The simulation results show that the optimization algorithm can eliminate the signal in the case of strong interference and weak interference.

Keywords*: Beidou navigation system, Power inversion, Interference.*

I. INTRODUCTION

The global satellite navigation system has the characteristics of precise timing, high positioning accuracy and strong real-time performance. Therefore, it is widely used in scientific research, agriculture, military and other fields [1,2]. However, the satellite is far away from the earth's surface, the signal transmission power is weak, at the same time, Human intentional or unintentional interference is increasing day by day, which makes the navigation signal received by the user segment poor and cannot be accurately positioned, Aiming at this situation, building

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

a complete scheme of anti-jamming satellite signals the user segment, finding a method to realize the high efficiency, low cost, strong stability, designing a even in the case of electromagnetic interference environment is relatively poor, still can restrain interference, capture navigation signal, normal precise positioning of anti-jamming product is very important [3-5].

By analyzing the signal characteristics of Beidou navigation messages, the power inversion algorithm based on multi-linear constrained minimum variance criterion to suppress the interference signal was decided to us [6,7]. However, on the Power Inversion (PI) iterative algorithm principle analysis, formula deduction, the traditional PI algorithm of strong interference signal suppression effect was found obvious and the weak interference signal suppression was found not good [8]. For this kind of situation, this paper presents a matrix decomposition to extract noise interference of matrix and matrix method to the judgment matrix, and thus made under the condition of weak interference of the signal by PI algorithm can weaken the filter [9,10].

II. POWER IINVERSION ALGORITHM

PI algorithm is an easy to implement algorithm in adaptive anti-interference algorithm. According to the LCMV standard, for the purpose of obtain the minimum output power of the array, the obtained power signal should be inverted and used as the error signal. Formula (1) is a constraint condition, where $\mathbf{s} = [1, 0, \ldots, 0]^T$ is the direction vector of the desired signal [11].

$$\begin{cases} Min \quad P_{out} = \left[|\mathbf{y}(\mathrm{n})|^2 \right] \\ s.t. \qquad \boldsymbol{\omega}^H \mathbf{s} = 1 \end{cases} \tag{1}$$

The idea of PI algorithm is to first acquire and suppress stronger signals, and then suppress weaker signals. In other words, the algorithm suppresses both the navigation signal and the interference signal, but the suppression effect is different. Therefore, when receiving different signals from different azimuths, zero depression will be generated in the beam pattern.

The stronger the power intensity of the interference signal and the useful signal, the deeper the zero trap formed on the beam forming diagram. Since the power intensity of the interference signal in the Beidou satellite navigation system far exceeds the navigation signal, the zero depression caused by the interference signal is deeper than other signals [12]. From another perspective, the interference signals at the deeper trap have been suppressed, that is, the s/n ratio at the output of the navigation receiver has been improved.

PI algorithm based on uniform linear array is also a simple structure of spatial filter, as shown in Fig 1 [13].

The input vector of the M elements in the graph is $x_1, x_2, \cdots, x_M$, which means that each time can capture useful signals. Assume that:

$$\mathbf{X} = [x_1, x_2, \cdots, x_M]^T = \mathbf{a}(\theta, \varphi) \cdot \mathbf{s} \tag{2}$$

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

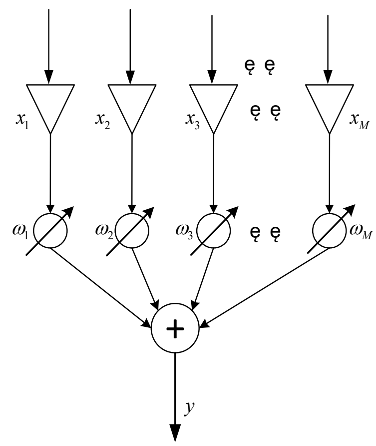


Fig 1: Power inversion matrix diagram

Where: $\mathbf{a}(\theta,\varphi)$ is the manipulating vector of antenna array elements (guide vector), $\mathbf{s}$ is the vector of the incoming signal (including interference signals and useful signals). For a uniform linear array, the steering vector is:

$$\mathbf{a}(\theta,\varphi)=[1,\mathrm{e}^{jkd\sin\theta\cos\varphi},\cdots,\mathrm{e}^{j(M\text{-}1)kd\sin\theta\cos\varphi}] \tag{3}$$

Expression 3 is the guide factor of the antenna array element (that is matrix factor). $w_1,w_2,\cdots,w_M$ represents the adaptive weighting factor of each time, and the array output is y. Take the input signal of the first array element as the reference signal $d=x_1$, assume that:

$$\mathbf{XX}=[x_2,\cdots,x_M]^T \tag{4}$$

The correlation matrix between X and the reference signal is:

$$\mathbf{r}_{xd}=E\{\mathbf{X}\bullet x_1^T\} \tag{5}$$

The auto-correlation matrix of X is:

$$\mathbf{R}_{XX}=E\{\mathbf{X}\bullet\mathbf{X}^T\} \tag{6}$$

The weighting coefficients of each antenna array element are as follows:

$$\boldsymbol{\omega}=[1,\boldsymbol{\omega}_{opt}]^T \tag{7}$$

Which $\boldsymbol{\omega}_{opt}=[w_2,w_3,\cdots,w_M]^T$, The weighted output and reference signals of the element 2~M obey the minimum mean square error (LMS) criterion. Here, the output of the array is:

$$y=x_1-\boldsymbol{\omega}^H\mathbf{X} \tag{8}$$

Based on the LCMV criterion, the performance functions of the signal output power can be obtained as follows:

$$P_{out}=E[|\mathbf{e}|^2]=E[|\mathbf{d}|^2]-2\,\mathrm{Re}[\boldsymbol{\omega}^H\mathbf{r}_{xd}]+\boldsymbol{\omega}^H\mathbf{R}_{xx}\boldsymbol{\omega} \tag{9}$$

The weighted vector from element 2 to element M can be expressed as:

$$\boldsymbol{\omega}_{opt}=\mathbf{p}_{out}\mathbf{R}_{XX}^{-1}\mathbf{r}_{xd} \tag{10}$$

$$\mathbf{p}_{out}=(\mathbf{s}^T\mathbf{R}_{xx}^{-1}\mathbf{s})^{-1} \tag{11}$$

The gradient estimates of power are also obtained as follows:

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

$$\nabla_{\omega}\mathbf{P}_{out} = 2\mathbf{R}_{xx}\boldsymbol{\omega} \tag{12}$$

In this case, the gradient method is used to make the performance function decrease most rapidly in the direction of the power function, so that the input signal reduces the matrix inversion operation, and then the recursive formula can be obtained [14].

$$\boldsymbol{\omega}(k+1) = \boldsymbol{\omega}(k) - \mu\nabla_{\omega}\mathbf{P}_{out} + \mu\frac{\mathbf{s}\mathbf{s}^{T}}{\mathbf{s}^{T}\mathbf{s}}\nabla_{\omega}\mathbf{P}_{out} \tag{13}$$

Taking the formula 11 into 12, the iterative relation of the power inversion algorithm based on LMS can be obtained as follows:

$$\boldsymbol{\omega}(k+1) = \boldsymbol{\omega}(k) - 2\mu(1-\frac{\mathbf{s}\mathbf{s}^{T}}{\mathbf{s}^{T}\mathbf{s}})\nabla_{\omega}\mathbf{P}_{out} = \boldsymbol{\omega}(k) - 2\mu(1-\frac{\mathbf{s}\mathbf{s}^{T}}{\mathbf{s}^{T}\mathbf{s}})\mathbf{X}\bullet\mathbf{X}^{T}\boldsymbol{\omega}(k) \tag{14}$$

In the adaptive nulling array element antenna, all array elements are adjustable except that the weighting factor of the first array element is a fixed value of 1. The output power can be minimized by adjusting the weighting factor, so that the trap generated by the interference signal direction on the factor beam pattern is deeper.

The PI algorithm follows the LCMV guidelines, so the system signal can maintain a certain fixed value in the constraint direction, but it will suppress the signal in the system to some extent. Since the interference signal has the highest power and the signal has the deepest zero depression on the beam pattern, the interference signal can obtain a higher signal-to-noise ratio.

III. IMPROVED ALGORITHM OPTIMTIZATION

The conventional PI algorithm does not need to care about or know the information of the target signal instead of it directly to interfere with the suppression. PI algorithm, however, there is inadequate: when the power strength of the weaker interference signal is similar to the navigation signal strength, terminal receiving antenna in the direction of jamming signal form zero trapped and navigation signal of zero phase at the same time, it is impossible to distinguish between filter. Therefore, the optimization of the algorithm is improved.

3.1 Receive Weak Interference and Enhance Suppression Signal

Separating the interference subspace and the noise subspace in the covariance matrix of the input signal relies on the matrix space decomposition method, so that interference signals of different intensities can be suppressed.

Firstly, the covariance vector array of array signal reception is processed by eigen decomposition method, such as formula (15):

$$R_{xx} = \sum_{i=1}^{N}\lambda_{i}p_{i}p_{i}^{H} = \sum_{i=1}^{q}\lambda_{i}p_{i}p_{i}^{H} + \sum_{i=q+1}^{N}\delta_{n}^{2}p_{i}p_{i}^{H} \tag{15}$$

Then it can be obtained:

$$R_{xx}^{-1} = \sum_{i=1}^{q}\lambda_{i}^{-1}p_{i}p_{i}^{H} + \sum_{i=q+1}^{N}\delta_{n}^{-2}p_{i}p_{i}^{H} \tag{16}$$

Then, taking the formula 16 into formula 12, we can get:

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

$$\omega_{opt} = \mathbf{p}_{out}[\sum_{i=1}^{q} \lambda_i^{-1} p_i p_i^H + \sum_{i=q+1}^{N} \delta_n^{-2} p_i p_i^H]\mathbf{r}_{xd} \tag{17}$$

$$\mathbf{p}_{out} = \frac{1}{\mathbf{s}^T[\sum_{i=1}^{q} \lambda_i^{-1} p_i p_i^H + \sum_{i=q+1}^{N} \delta_n^{-2} p_i p_i^H]\mathbf{s}} \tag{18}$$

The above equation is explained as follows:

λ is the eigenvalue of the Q-th order sub-array of the captured signal matrix R_{xx}, and δ^2 is the eigenvalue of the N-Q-th order sub-array of matrix R_{xx}, and these eigenvalues are called white noise.

The optimal value of the weight of the PI algorithm refers to the addition of the weight of the characteristic value of the interference signal and the useful signal. In equation (17), it can be seen that the first term and the second term correspond to the eigenvalue vector values of the interference and noise signals. Under strong interference, the eigenvalue of the first term is relatively large, which has a small impact on the optimal value, and can form a zero valley in the interference direction, thereby improving the output signal-to-noise ratio. When the power of the interference signal is close to the power of the noise, the eigenvalues of the two items are close. The measure taken at this time is to keep the second item and use it to calculate the best value. The zero depression formed in the interference direction will be deeper.

In the algorithm design, for increasing the judgment function. The first step is to input signal covariance matrix, eigenvalue extraction for noise signal and interference signal eigenvalue, the discriminant. Use the following formula to compare with the threshold, and the threshold is e^2.

$$\tau = \frac{\lambda}{\delta^2} \tag{19}$$

If $\tau < e^2$, it means that the power of interference signal and the noise signal are similar.Therefore, the forward element space array in the direct equation (17) is carried out directly for subsequent calculation. If $\tau < e^2$, it means that the interference signal is strong and it can be distinguished from the noise signal,the first item is retained, which can suppress the signal strongly. The whole algorithm flow is shown in Fig 2. If $\tau < e^2$, it means that the interference signal can be well distinguished from the noise signal, and the first item needs to be kept. Fig 2 shows the flow of the algorithm.

The optimization part is embedded in the PI algorithm as a sub-process to update the iteration, so that the algorithm is intelligent and adaptive. No matter the input interference signal is strong or weak, it can form a deep zero depression in the interference direction in the beam pattern.

3.2 The Framework and Process of the Optimization Algorithm

3.2.1 Optimization of PI Algorithm Framework

The algorithm framework is shown in Fig 3. In the design, the first step is to generate signal source, including satellite useful signal and interference noise signal, the second step is to select the antenna array model (linear array, rectangular array, circle array), the third step is to capture

Design Engineering
ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

the signal under the weighted synthesis, orthogonal frequency conversion process, then carries on the pretreatment of sampling and adopted the digital signal processing, the fourth step of PI algorithm related operations. In the correlation operation of PI algorithm, the optimization algorithm is added, and then the signal of the adaptive array output anti-interference processing is performed after the weighted synthesis.

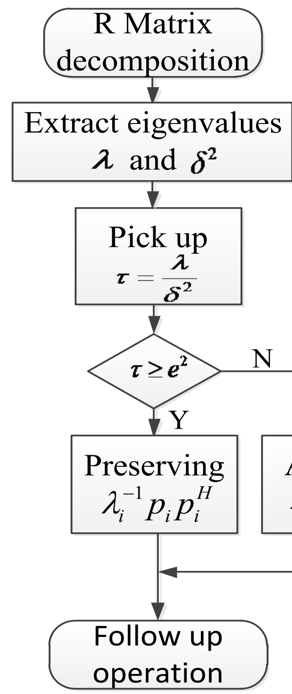


Fig 2: Optimization part of the flowchart

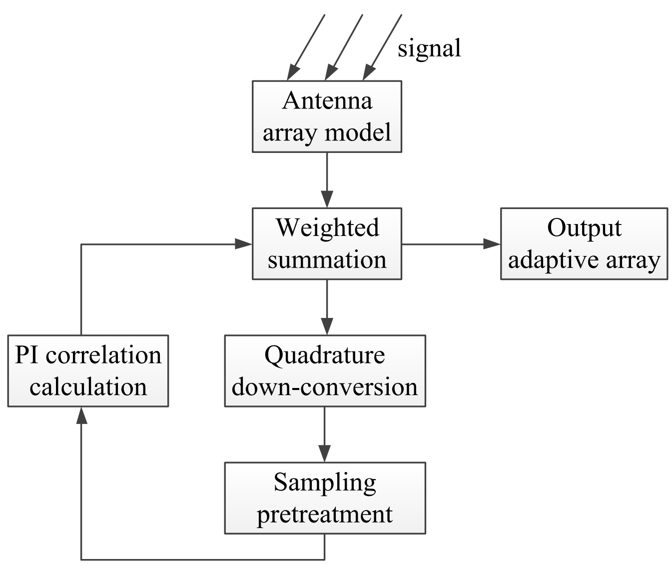


Fig 3: Optimized block diagram of PI algorithm

3.2.2 The Design Process of Optimized the PI Algorithm

Design Engineering

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

Process steps of adaptive anti-interference PI algorithm:

1) When N=0, the antenna is initialized, and the weight value of the reference signal path is assigned to 0 respectively.

2) N= 1,2, start the following cycle iteration:

a) Filtering process: in the chip in the weight parameter setting, the weights of N-1 time is used to generate the weights of the output of the next moment, and then after frequency conversion module and the ADC sampling and digital pretreatment process of the error signal is generated;

b) Adaptive updating calculation: based on the array input data and error data, the relevant data operation is performed to calculate the relevant amount of the updated weight value and generate the new weight. Then, the weight of each channel signal is weighted, and the data signal of noise reduction processing is output.

The flowchart is shown in Fig 4.

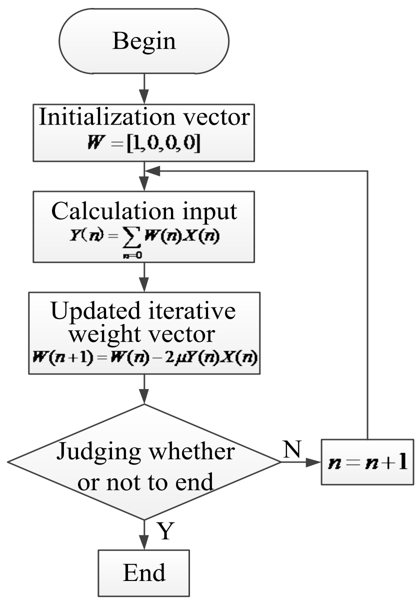


Fig 4: Optimized block diagram of PI algorithm

3.3 The Simulation of the Optimization Algorithm

The simulation conditions are as follows:

1) Uniforming linear Array with 4 Array elements;

2) The central frequency of array antenna array elements is 1268.52 mhz;

3) The spacing of the array is the half wavelength (0.5λ);

4) Noise selection Gaussian white noise, power is $\delta^2 = 1$;

5) The signal-to-noise ratio of the input signal is always -30db;

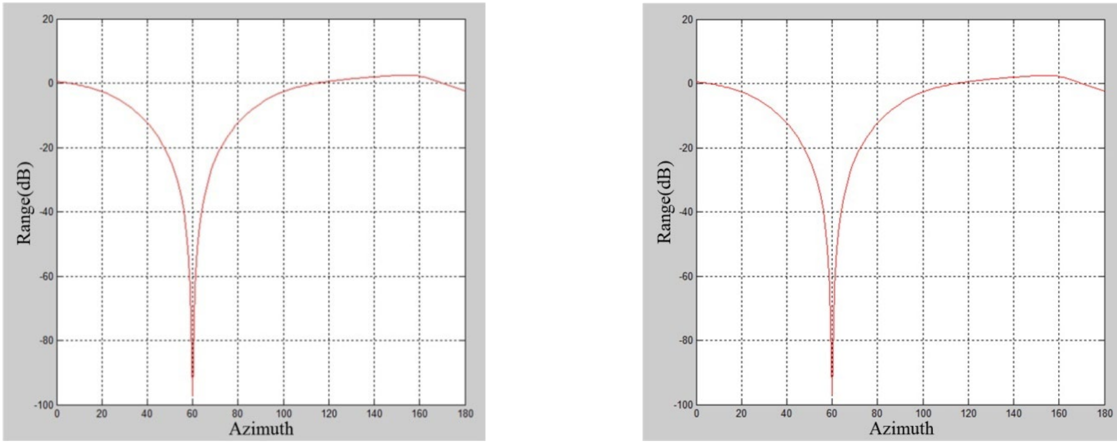
6) The incident azimuth Angle of the useful signal is 160, and the azimuth of the interference signal is 60.

3.3.1 Simulation in the Strong Interference Environment

Under strong jamming, the input signal is -50db. At this time, by comparing and analyzing

Design Engineering
ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

the simulation results of whether the PI algorithm is optimized, which can obtain the interference suppression zero depression.



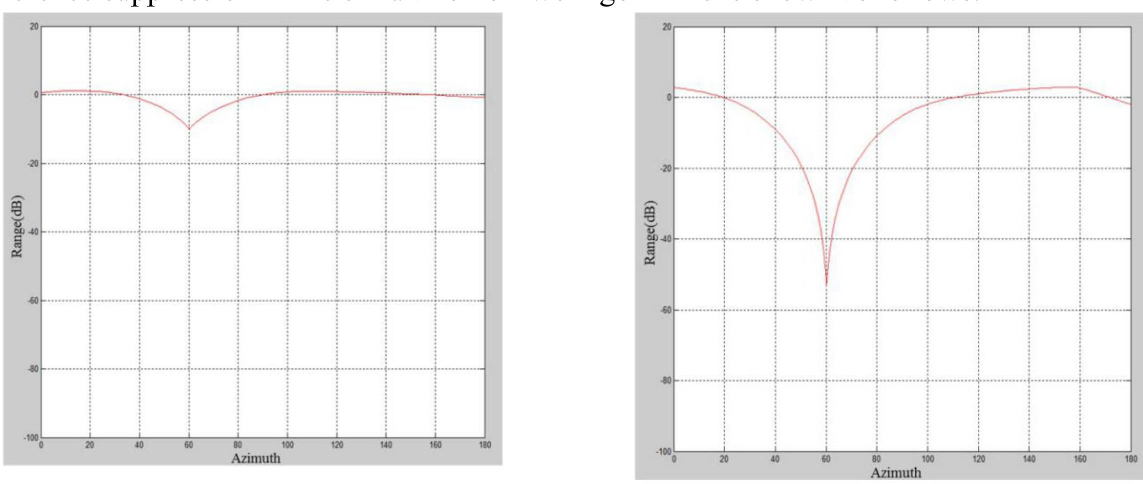
(a) (b)

Fig 5: Algorithm simulation in strong interference environment

The Fig 5 shows that both the not optimized PI algorithm and the optimized PI algorithm have a zero depression with a depth of -98.56dB, with good anti-interference performance, under strong interference. In the strong interference environment, the optimization of PI algorithm and the un-optimized result did not change significantly.

3.3.2 Simulation in a Weak Interference Environment

Under the condition of weak interference, the input signal is -70db. In the same way, the interference suppression in the simulation of two algorithms is shown as follows.



(a) (b)

Fig 6: Algorithm simulation in weak interference environment

The simulation diagram shows the azimuth Angle of 60° (jamming signal to wave direction), the Fig 6(a) shows that the zero depth of 10.23 dB, the Fig 6(b) shows that the zero depth is 55.12 dB. It can be concluded that the optimized PI algorithm has very good anti-interference performance in the weak interference condition environment.

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

IV. CONCLUSIONS

In this paper, the adaptive interference suppression performance of the PI algorithm is compared and analyzed.

Firstly, the principle of PI algorithm is theoretically analyzed and inferred. Secondly, in view of the low resolution of the PI algorithm in a weak interference environment, the interference subspace and the noise subspace are separated, so that the interference signal can be processed in a targeted manner. Therefore, it can be used to suppress both strong and weak interference. Then, the optimized PI algorithm is designed and described. Finally, the simulation results show that the optimized PI algorithm can eliminate the signal in the case of strong interference and weak interference.

ACKNOWLEDGEMENTS

This work was supported by Natural Science Foundation Project of CQ CSTC (Grant No. cstc2018jcyjAX0038, cstc2018jcyjAX0812), the Youth project of science and technology research program of Chongqing Education Commission of China (No. KJQN201801212), the Major Scientific and Technological Research Project of Chongqing Education Commission of China (KJZD-M201901201).

REFERENCES

[1] Ye T, Cheng H U, Chao D X, et al. (2017) Atmosphere effects on geosynchronous SAR: Theoretical Analysis and Compensation Method. Journal of Signal Processing

[2] Jun X, Jianjun Z (2018) Design of Space-based PNT System Based on BeiDou Navigation Satellite System. Aerospace China 19(04): 22-30

[3] Gross J N, Kilic C, Humphreys T E (2019) Maximum-Likelihood Power-Distortion Monitoring for GNSS-Signal Authentication. IEEE Transactions on Aerospace and Electronic Systems 55(1): 469-475

[4] Jung H, Nguyen B V, Song I, et al. (2020) Design of Anti-Jamming Waveforms for Time-Hopping Spread Spectrum Systems in Tone Jamming Environments. IEEE Transactions on Vehicular Technology 69(1): 728-737

[5] Qiao J, Xu G, Liu W, et al. (2020) Comparison of Beidou autonomous navigation performance using the SRP model and onboard accelerometers. Acta Astronautica

[6] Zhang Y, Kubo N, Chen J, et al. (2020) Apparent clock and TGD biases between BDS-2 and BDS-3. GPS Solutions 24(1)

[7] Cui, Gao, Cai (2019) A Quad-Constellation GNSS Navigation Algorithm with Colored Noise Mitigation. Sensors 19(24): 5563

[8] Fan L, Tu R, Zhang R, et al. (2019) An improved method for detecting BeiDou signal-in-space anomalies from precise ephemerides. Acta Geodaetica et Geophysica 54(4): 567-581

[9] Huang G, Cui B, Xu Y, et al. (2018) Characteristics and performance evaluation of Galileo on-orbit satellites atomic clocks during 2014–2017. Advances in Space Research 63(9): 2899-2911

[10] Tian Yanan (2017) Research on the Application of Beidou Two Generation Navigation and Positioning System in Logistics

[11] Guo S.X. (2013) Anti-jamming Performance Test System Building Method of Beidou Satellite

ISSN: 0011-9342
Issue: 1 | Pages: 42 - 51

Navigation Receiver. Computer Science 40(7): 28-31

[12] Yongqian H E, Xinrong L, Plant Z R (2017) Research and implementation of beidou satellite navigation system anti-jamming technology. Ship Electronic Engineering

[13] Ronglei K (2017) Cooperative Location Method of Beidou Interference Sources under Complicated Electromagnetic Environment. Computer & Digital Engineering

[14] Xin-Feng C, De-Feng Z, Zhong-Guo W U, Jin-Long H E (2013) Research into the injected hardware-in-the-loop simulation test methods of radar reconnaissance equipment. Shipboard Electronic Countermeasure