The innovational method to locate the transponder interference based on the single GEO satellite

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Abstract

In this paper, the basic principle, technical essentials and the realization method has been deeply analyzed firstly. Then the Doppler frequency shift caused by the satellite transponder movement has been accurately estimated. Using the external high precision reference source, the frequency error caused by the instability of the receiver LO, satellite transponder LO and others error all can be exactly separated. Finally, the total frequency shift caused from uplink transmitter and Doppler frequency. The Geo Location algorithm realized by particle filter technology was designed based on the long time frequency date. In order to test and verify the effectiveness of the algorithm, a real system had been constructed. The result shows that the location accuracy is far better than traditional 2D searching algorithm. The realization of the location technology based on only one satellite greatly improve the radio monitoring efficiency and promote the radio management level.

1. Introduction

Satellite communication becomes more and more important in the field of the national security, information security, economics construction, national defense construction, etc. It offers commonly service to all the country as the scare resource. Meanwhile the satellite transponder suffers more and more stolen interference and attacked interference because of its transparent property. How to quickly and effectively locate and eliminate the interference is the one of the most important duty of the radio management department. GEO location technology to locate the transponder interference is the indispensable technology method to protect Nowadays, most of the countries mainly use the FDOA and TDOA location technology to locate transponder interference, where the FDOA and TDOA are the arriving frequency and time difference the signal propagate through the two adjacent satellites. But there are many limitations to the two satellites location method. More and more interference can't be located by method mentioned above. So there is the urgent need to develop a total new system solving this deficiency. This kind of technology can be the effective supplement in the national strategic deployment and future development , and also be the national economy escort。

Based on the requirement of the project, the mesh searching algorithm had been adopted firstly. The mainly work in locating algorithm is to calculate the longitude and latitude of the interference source. In mesh searching algorithm, the longitude and latitude is nonlinear to the Doppler frequency shift. The measured and calculated Doppler frequency complies with non-Gauss Distribution. The key point to solve the interference is to probably estimate the position of the interference source on the condition of the known measured Doppler frequency. While the particle filter technology can be effective to estimate the nonlinear and non-Gauss parameters. So the particle filter technology was used in the Single Satellite Location algorithm.

In this algorithm, the range of the searched longitude and latitude can be converted to coordinates. Based on the principle of the particle filter, the particles are produced where the coordinates are the random variables. Then the state equation was established according the parameters of the coordinate particles and calculated Doppler frequency and its differentials. Finally the particle filter technology resulted to the location of the satellite interference source through the transponder.

2. The location technology based on the change rate of the Doppler frequency

According to the practical movement of the astrophysics, combining with the requirement of researching artificial satellite, the satellite can be supposed to be carried by the earth. Mechanics problem involved in the satellite is not included in this movement of the earth. The geocentric coordinate system is used all the way. In order to express the space position of the satellite, the topocentric coordinate system should also be used. In this paper, only the GEO satellite was discussed, so the earth-fixed coordinates system was adopted. In other words, the earth is deemed to be stable.

In satellite communication systems, orbit position of the GEO satellite is marked with longitude and latitude. In this

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system, zhongxing 10 satellite is the object satellite to locate the interference. The orbit of the zhongxing 10 satellite is E110.5° . Based on the position of the orbit, the longitude and latitude of the satellite can be calculated in Geographic Frame Coordinate System. In this paper, the zero meridian of the coordinate system is set to the Greenwich meridian. If there is any difference in definition, all the parameters in formula should be converted to Greenwich meridian.

Here, a is the semi major axis of ellipsoid, b is the semi minor axis of ellipsoid, 1/f is the Reciprocal of the change rate, so,

$$X=(\mathrm{v}+h)\cos\varphi\cos\lambda,\quad Y=(\mathrm{v}+h)\cos\varphi\sin\lambda,\quad Z=((1-e^2)\mathrm{v}+h)\sin\varphi\sin\lambda.$$

where: v is the Prime circle radius of curvature at the latitude φ, $v=a/(1-e^2\sin^2\varphi)^{0.5}$, φ and λ is the latitude and longitude separately, h is the height of the relative ellipsoid, e is the First eccentricity of the ellipsoid, and

$$e^2=(a^2-b^2)/a^2=2f-f^2, \tag{1}$$

In this project, the longitude of the ZhongXing 10 satellite is E110.5. So the relative position of the satellite in earth fixed coordinate system can be calculated:

X=-14766144.0234, Y=39493846.18746944,Z=0.00000;

The unit is meter. The position of the receiver can be expressed as :

Longitude=116.25311,latitude=39.660222;

Based on the deduction, the coordinates of the receiver under this coordinates system is :

X=-2172438.491219755,Y=4403331.893923063,Z=4070634.2545;

When the coordinates system had been constructed, the corresponding Doppler frequency shift at different time caused by the movement of the satellite transponder should be calculated, where the real time coordinates of the position and velocity are needed. So, how to calculate the real time coordinates of the satellite becomes the one of the key points in determining locate successful or not. In this paper, ephemeris transformation method is used to get the accurate ephemeris. Based on the Six root orbit parameters offer from internet, the algorithm is designed to process the six parameters and then the parameters can be converted to another set of the six parameters: Position X、Y、Z and velocity V_x、V_y、V_z。Based on the analysis, the movement traces can be described.

On the basis of the position and velocity, combining the uplink frequency and LO of the transponder, the theory Doppler frequency shift can be calculated。Then considering the total measured frequency change of the uplink and downlink signals, the satellite interference can be GEO located. So the Single satellite GEO location can be realized.

3. Status construction of the Doppler frequency shift

At the time of the k, $\boldsymbol{\chi}_s=\left[x_{s,k},y_{s,k},z_{s,k}\right]^T$, velocity of the satellite $\boldsymbol{\upsilon}=\left[v_{x,k},v_{y,k},v_{z,k}\right]^T$, coordinates of the receiver, $\boldsymbol{\chi}_r=\left[x_{r,k},y_{r,k},z_{r,k}\right]^T$, the longitude and latitude of the interference source $(\varphi,\ \lambda)$. Which can be converted to Cartesian coordinates: $\boldsymbol{\chi}_t=\left[x_t,y_t,z_t\right]^T$。

Assuming that the $\mathbf{d}_{s\to t}=\left[x_{s,k}-x_t,y_{s,k}-y_t,z_{s,k}-z_t\right]^T$, and normalized, $\mathbf{d}_{s\to t}=\mathbf{d}_{s\to t}/\left\|\mathbf{d}_{s\to t}\right\|_2$。

Uplink Doppler frequency shift can be calculated as:

$f_{up}=-\dfrac{f_{u0}}{c_0}\mathbf{d}_{s\to t}^T\boldsymbol{\upsilon}$, where the f_{u0} is the center frequency of the uplink signal, $c_0=3\mathrm{e}^8$ means the light speed。

Downlink Doppler frequency shift can be calculated as:

$$f_{down}=-\frac{f_{d0}}{\left(c_0-\mathbf{d}_{s\to r}^T\boldsymbol{\upsilon}\right)}\mathbf{d}_{s\to r}^T\boldsymbol{\upsilon} \tag{2}$$

where the f_{d0} is the center frequency of the uplink signal, So the total Doppler frequency shift can be expressed as: $f_{total} = f_{up} + f_{down}$。

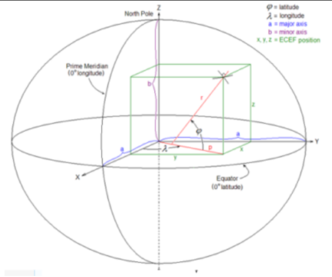

Figure 1. Construction the X、Y、Z 3D Earth Fixed Coordinate system

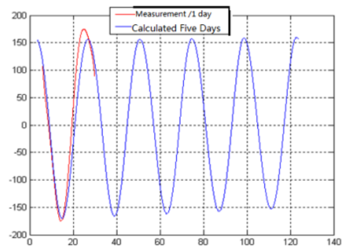

Fig2 Theory Doppler frequency in five days of the ZhongXing 10 based on the true ephemera r in Ku band

4. Algorithm realization using the particle filter

Realization step：

（1）Using the particle filter algorithm to filter the Doppler Frequency Shift.

（2）To select the excellent data and filter it to get the object longitude and latitude.

The detail algorithm can be shown as following:：

The module should be constructed in Single satellite GEO location using the particle filter algorithm, and also the status space equation and observation equation should also be constructed [2].

Status space equation is ：

As the interference source is stable, so

$$\begin{cases} \theta_k = \theta_{k-1} + n_k^{\theta} \\ \varphi_k = \varphi_{k-1} + n_k^{\varphi} \end{cases} \tag{3}$$

Where， n_k^{θ} and n_k^{φ} is the Gauss white noise which the mean is 0 and the variance is the σ_{θ}^2 and σ_{φ}^2.

Observation equation：

$$f_{total,k} = h\left(\theta_k, \varphi_k\right) + u_k \tag{4}$$

Where $f_{total,k}$ means the measured Doppler Frequency at the time of k， $h\left(\theta_k, \varphi_k\right)$ means the theoretical value of the Doppler Frequency shift. It can be expressed with the longitude and latitude regarding with the interference source. u_k means the noise， including the noise of the frequency shift and environment noise.

The particle $\theta_k^i \in U\left(\theta_{\min}, \theta_{\max}\right)$ and $\varphi_k^i \in U\left(\varphi_{\min}, \varphi_{\max}\right)$ can be generated， where $i = 1, 2, \ldots, N$， N means the number of the particle。

When refresh the status of the particle：

$$\theta_k^i = \theta_{k-1}^i + n_k^{\theta}, \quad \varphi_k^i = \varphi_{k-1}^i + n_k^{\varphi} \tag{5}$$

The weight of the importance can be calculated:

$$w_k^i = w_{k-1}^i \exp\left(-\frac{\left| f_{total,k} - h\left(\theta_k^i, \varphi_k^i\right) \right|^2}{2\sigma_u^2} \right), \tag{6}$$

Then normalize and resample to the particles。The particle θ_k^i and φ_k^i should be substitute in the function $h(\square)$, so we can get the $h\left(\theta_k^i, \varphi_k^i\right)$. After weighted average, the estimation expression to the Doppler frequency shift：

$$\hat{f}_{total,k} = \sum_{i=1}^{N} h\left(\theta_k^i, \varphi_k^i\right) w_k^i \tag{7}$$

Then, we should intercept to the output signal $\hat{f}_{total,k}$ of the filter. The data with max change rate should be intercepted。The intercepted data should be filtered again using the particle method. The goal of the filter at this time is to estimate the longitude and latitude θ_k^i and φ_k^i, and also the particle $\theta_k^i \in U\left(\theta_{\min}, \theta_{\max}\right)$ and $\varphi_k^i \in U\left(\varphi_{\min}, \varphi_{\max}\right)$ should be generated. After renewing the particles 'status, calculating the weight and resampling the particles, finally the longitude and latitude of the interference source can be estimated as:

$$\hat{\theta}_k = \sum_{i=1}^{N} \theta_k^i w_k^i \tag{7}$$

$$\hat{\varphi}_k = \sum_{i=1}^{N} \varphi_k^i w_k^i \tag{8}$$

5. Location Algorithm test under the real environment

In order to verify the location algorithm based on particle filter technology only using single satellite, an experiment signal in Ku band had been transmitted to ZhongXing 10 satellite and the signal had also been forwarding to the earth. We receive the signal in BeiJing（E116.25311°，N39.660222°）. The satellite reference source Calibration system, satellite monitoring and receivers can process the signal. Then the frequency with high accuracy had been estimated, we get the real Doppler frequency shift. The frequency then is loaded to the location algorithm. The result shows that the algorithm can improve the accuracy. The result as following shows:

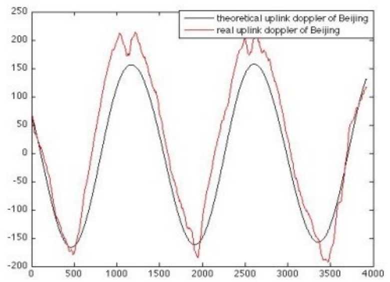

Figure 3 : Measured Doppler frequency from ZhongXing 10 satellite in Ku band (red)

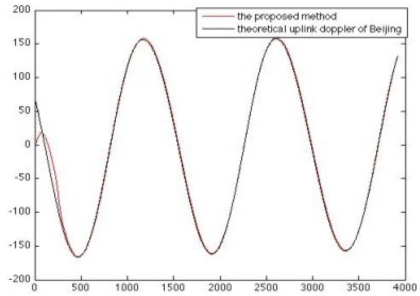

Figure 4 Filtered Doppler Frequency shift（Red Line）and theory Doppler Frequency shift（Blue line）

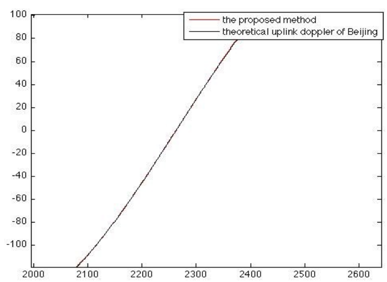

Fig5. The selected data using the algorithm

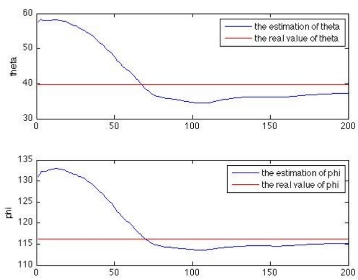

Fig6 The GEO location result using the particle filter

6 Conclusion

1. After the many times experiment and stastically analysis, the locaiton resualt can be with 3 degree in Longitude and latitude, which is much more accurate than the mesh searching method.
2. Operating time of the algrtihm：using the selected data，the first step need 16 second, and the second step need 3s。The total time to locate is no more than 20s。

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