GPS Anti-spoofing Algorithm Based on Improved Particle Filter

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***Abstract*—In the GPS system, the signal received by the receiver is easily effected by spoofing jamming, which leads to some error in the measurement of pseudo range and is bad for navigation positioning. Therefore, this paper proposes GPS Anti-spoofing Algorithm Based on Improved Particle Filter. By the introduction of positioning error correction and M-estimation theory, simulation results and analyses verify that proposed algorithm achieves the purpose of eliminating spoofing jamming by modifying pseudo range error.**

Keywords—GPS; Anti-spoofing; Pseudo range; Particle Filter; M-Estimation Theory

I. INTRODUCTION

As new generation of global navigation and positioning system, Global Positioning System (GPS) is superior to other navigation equipment, which has obtained more and more attention in recent years [1-3].However, because of the weakness of the GPS signal strength, all sorts of jamming can easily lead to the decrease of performance in satellite navigation system. Therefore, it has become the core to improve the anti-jamming ability in the development of various types of satellite navigation system in the future [4-5]. Among them, the spoofing jamming gives false navigation information or increases the signal propagation delay. Plenty of methods for anti-spoofing have been proposed. The least square (LS) estimate and Kalman filter is mostly applied to the research of positioning algorithm [6]. However, those require linear observation model and linear dynamic model of the system. Therefore, this paper proposes an improved particle filter positioning algorithm by introduction of positioning error correction and M-estimation theory [7-8]. The results of the simulation verified the effectiveness and superiority of the proposed method.

II. FOUNDATION

The pseudo range is the geometric distance between the receiver and the satellite, which can be formulated as

$$\begin{cases} \sqrt{(x^{(1)}-x)^2+(y^{(1)}-y)^2+(z^{(1)}-z)^2}+\delta t_u=\rho^{(1)} \\ \sqrt{(x^{(2)}-x)^2+(y^{(2)}-y)^2+(z^{(2)}-z)^2}+\delta t_u=\rho^{(2)} \\ \cdots \\ \sqrt{(x^{(n)}-x)^2+(y^{(n)}-y)^2+(z^{(n)}-z)^2}+\delta t_u=\rho^{(N)} \end{cases} \tag{1}$$

Where, $\mathbf{x}=[x,y,z]^T$ is the position vector for the unknown receiver, $\mathbf{x}^{(n)}=[x^{(n)},y^{(n)},z^{(n)}]$ is the position vector of the satellite.

III. IMPROVED ALGORITHM ON GPS ANTI-SPOOFING BASED ON PARTICLE FILTER

A. Design of jamming detection threshold

The maximum weight of particle filter can reflect the information of the pseudo range. Thus, we can regard it as the effective measurement values of Anti-spoofing. The maximum particle weight is as follows

$$\max\left(\mathbf{w}_{\mathrm{k}}^{(m)}\right)\approx\frac{1}{\mathrm{M}}\left(\frac{1}{\sqrt{2\pi\sigma^2}}\right)^2\exp\left[-\frac{\min\left\|\mathbf{y}_k^{(m)}\right\|^2}{2\sigma^2}\right] \tag{2}$$

where, $\left\|\mathbf{y}_k^{(m)}\right\|$ is the matrix 2-norm of the observation vector.

In this paper, we design the detection threshold of spoofing jamming γ. Use β for $\left\|\mathbf{y}_k^{(m)}\right\|^2$, when $\beta>\gamma$, it is considered to be attacked by the spoofing jamming. For the design of the detection threshold, we separately consider the interference detection probability and false alarm probability.

$$P_1=\int_\gamma^{+\infty}p_f(\beta)d\beta,\quad P_2=\int_\gamma^{+\infty}p(\beta)d\beta \tag{3}$$

In the improved positioning algorithm, the largest weight particle is $\mathbf{y}_k^{\max}$ .The positioning error of the improved algorithm is $\mathbf{d}_k^{(n)}$.

In the particle filter algorithm, we select the maximum particle weight residual as $dL_{\max}=\left\|\mathbf{d}_k^{\max}\right\|/\left\|\mathbf{y}_k^{\max}\right\|$. Then

$$\gamma=PL/dL_{\max} \tag{4}$$

B. Introduction of the M-estimation

According to M-estimation, and the minimized residual error is

$$\sum_{n=1}^{N} \varphi\left(e_n\right) h_n = 0 \quad (5)$$

where h_n is the weighted factor. And $\varphi(\bullet)$ is used to describe the impact of measurement errors on the positioning of the results of the solution. After that

$$H^T D\left(e\right) e = 0 \quad (6)$$

The selection of $D\left(e\right)$ is the key to realize anti-spoofing. This paper utilizes the weighted matrix of improved M-estimation:

$$D(e_i) = \begin{cases} 1 & \left|e_i\right| < c \\ 1/\left|e_i\right| & c \le \left|e_i\right| < d \\ 0 & \left|e_i\right| \ge d \end{cases} \quad (7)$$

It can be seen from the formula (7) that when the error is greater than *d*, which is considered to be caused by the spoofing jamming. The calculation equation is

$$\tilde{e}_{n,k}^{(m)} = D\left(e_{n,k}^{(m)}\right) \times e_{n,k}^{(m)} \quad (8)$$

IV. Simulation and Performance Analysis

Fig.1 shows the map of the interference detection probability, when the probability of false alarm is $p_f\left(\beta\right) = 0.01$ .When the additional pseudo range is larger, the interference detection probability also become greater. Also the interference detection probability of spoofing jamming is greater with the increasing of the visible satellites number.

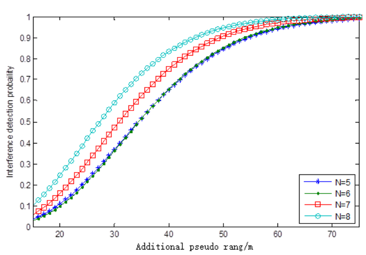
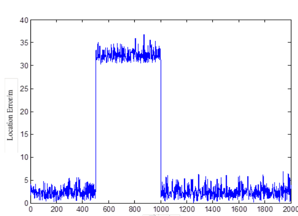


Fig. 1. Probability of interference detection

After that assuming that simulation experiment is from 500s to 1000s , and additional pseudo rang/m is $b_{s,k}$ =30m.



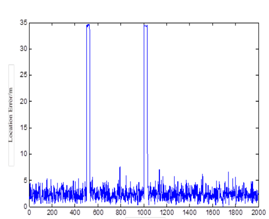


Fig. 2. Positioning error of the traditional particle filte

Fig. 3. Positioning error of improved particle filter

From Fig.2 and Fig.3, we can see that the improved particle filter positioning solution algorithm, after discovering the spoofing jamming that making interference suppression timely. Then in the time of disturbed, correct error value rapidly, inhibit the interference error results within 5m effectively, the positioning accuracy is better, and the ability of anti-spoofing jamming is stronger.

V. Conclusion

This paper proposes the GPS anti-spoofing algorithm based on improved particle filter. The scheme includes two steps: detection of spoofing jamming and spoofing jamming suppression. After detecting the spoofing jamming, the improved particle filter algorithm is used to combine with robust statistical theory of M-estimation to revise the process of the additional correction of pseudo range particle update, and then eliminate the effect of spoofing. Finally, the effectiveness and superiority of the proposed algorithm are verified

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