A Simulation Tool for Space-time Adaptive Processing in GPS

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Abstract—With the wide use of GPS, it becomes more and more important to improve the positioning accuracy. The GPS signal is very weak, and can be easily interfered. Space-time adaptive processing(STAP) can suppress the jamming not only in the temporal domain, but also in the spatial domain. STAP has now become a good candidates for jamming mitigation in GPS.

In order to evaluate the performance of various kinds of STAP algorithms, and to develop the novel STAP algorithms. we need to simulate space-time array GPS data with high fidelity and the software GPS receiver. This paper mainly presents a simulation method for space-time GPS data, as well as the simulation of some typical kinds of jammers. The simulation method for software GPS receiver is also introduced. The data that after the process of STAP is computed by the simulated GPS receiver. The simulation results show that the simulation tool is a good platform for the development of STAP algorithms.

1. Introduction

GPS is a network which is composed of many satellites, it can provide accurate position and time information [1]. The signal received by GPS receiver has the characteristics not only in temporal domain, but also in spatial domain. With the advent of STAP algorithms, the jammings can be suppressed through spatial and temporal characteristics effectively, and the positioning precision can be further improved. To evaluate the effect of the STAP algorithms on GPS jamming mitigation, we set up this simulation platform for Space-Time array GPS data. Besides we also simulate the software GPS receiver to validate the data after being processed by algorithms [2, 3].

In the second section of this paper, the simulation method for Space-Time array data is introduced. In the third section we introduce the common jammings to the GPS and simulate some typical of them. In the forth section we introduce the simulation method of GPS receiver briefly. The simulation results are given in the fifth section and in the sixth section we get the conclusion.

2. The Method for Simulating Space-time Array Data

2.1. Single Channel Temporal GPS Data Generation

The GPS signal is composed of navigation data, PRN code and carrier for modulation. The navigation data is a binary coded file, and is transmitted in frames according to certain format. It contains ephemeris parameters, satellite almanac and so on. We can compute the satellites position with them. These parameters value can be found from related data resources. In this paper, we choose the data from CDDIS (http://cddisa.gsfc.nasa.gov). They are coded in RINEX format. We should find the corresponding parameters from them first. These parameters, multiply by themselves scale factors, are converted to binary bits that fit the navigation data format. We only need to simulate the first three sub-frames [3].

The GPS signal is of two kinds of PRN codes, that is C/A code and P code. The structure of P code is quite complex and secret to civil users. Here we only introduce the simulation of C/A (coarse/acquisition) code. The C/A code is coded in binary format, and has the characteristics of multi address, searching GPS signal, coarse acquisition and anti-jamming. It is generated by two 10-order feedback shift registers, which can generate $C_{10}^2 + 10 = 55$ kinds of different C/A code [3]. The 24 satellites have different C/A codes. The chip shift between the satellites is fixed. According to one satellite's C/A code, we can obtain the others' C/A codes.

After the navigation data is spread by the C/A code, they modulate the carrier centered at 1575.42 MHz by BPSK. Since the data we need is at the intermediate frequency that after down-conversion, we select it as $f_{IF} = 21.25\,\mathrm{MHz}$. And after band-pass sampling, the output center frequency is $f_0 = 1.25\,\mathrm{MHz}$. The power of the signal arrived at the receiver is about -155 db. We select the gain of the receiver antenna as 4 db, and the gain of its' amplifier as 31 db. Thus the signal at IF is -120 db. Once assume the position of the receiver, we can get the propagation time of the GPS signal.

2.2. Multiple Channel Space-time GPS Data Generation

Suppose the signal of a GPS Satellite arrive at the receiver antenna with the direction of θ, the expression of it is $f(t)$, refer to Fig. 1. So the signal that reaches the second antenna [4] is $f(t-\tau)$, $\tau = l/c$, $l = d\cos(\theta)$, where τ denotes the arrival time difference between the first antenna and the second antenna, and d denotes the inter-element distance. So the signal received by the second antenna can be expressed as $f(t - d\cos(\theta)/c)$, approximately to $f(t)e^{-j\omega\tau} = f(t)e^{-j2\pi f\times d\cos(\theta)/c}$.

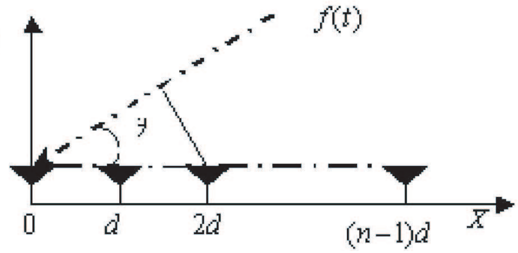

Figure 1: Uniform linear array.

Similarly, the signal of the satellite that arrives at the nth antenna can be expressed as:

$$f(t)e^{-j\omega(n-1)\tau} = f(t)e^{-j2\pi f\times(n-1)d\cos(\theta)/c} \tag{1}$$

Suppose that every antenna has M time delays, and each time delay is T, so the Space-Time satellite data can be expressed as:

$$F(t,\theta) = \begin{pmatrix} f(t) \\ f(t-T) \\ \cdots \\ f(t-(M-1)T) \end{pmatrix} \begin{pmatrix} 1 & e^{-j\omega\tau} & \cdots & e^{-j\omega(N-1)\tau} \end{pmatrix} \tag{2}$$

As for the arrived signal that contains four GPS satellites, its' multiple channel Space-Time data model can be expressed as:

$$S(t,\theta) = \sum_{i=1}^{4} \begin{pmatrix} f_i(t) \\ f_i(t-T) \\ \cdots \\ f_i(t-(M-1)T) \end{pmatrix} \begin{pmatrix} 1 & e^{-j\omega\tau_i} & \cdots & e^{-j\omega(N-1)\tau_i} \end{pmatrix} \tag{3}$$

where $f_i(t)$ denotes the ith satellite signal received, τ_i denotes the ith of the satellite time delay.

3. Jamming Simulation

During the GPS signal propagation, it can be affected by Satellite Clock error, Ionospheric error, multi-path jamming, radio station RF jamming, noise and so on. The typical jamming sources are broadcast TV–UHF channel, air-borne VHF, personnel electronic device, Ultra broadband communication, Multi-path, etc. For the purpose of build Space-Time data platform, we only consider narrowband RF jamming, broadband FM jamming, and receiver random noise.

Take the broadband FM jamming for example, its' model can be expressed as:

$$J(t) = A_0\cos[\omega_0 t + k_f\int_0^t V_\Omega(t)dt] \tag{4}$$

The system frequency scope is $\omega_0 - k_f \mid V_\Omega \mid \le \omega \le \omega_0 + k_f \mid V_\Omega \mid$. On the basis of typical value, the jamming requires lowest power lever and has the worst affection when the frequency bias is between 400 K–600 K. So we select the biased frequency $\Delta f = 500\,\mathrm{MHz}$, centered frequency $f_0 = 1.2\,\mathrm{MHz}$, and the jamming power is 60 db above the signal power, that is -60 db.

As the single channel temporal data extend to multiple channel Space-Time data, we also need to extend the jamming into multiple channel Space-Time form, its' mathematical model can be expressed as:

$$I(t,\theta) = \sum_{i=1}^{m} \begin{pmatrix} J_i(t) \\ J_i(t-T) \\ \vdots \\ J_i(t-(M-1)) \end{pmatrix} A_i(\theta) \tag{5}$$

where $A_i(\theta)$ denotes the steering vector of the jamming.

The receiver internal noise $n(t)$ obeys Gauss statistical distribution, it can occupy the whole frequency. The Space-Time GPS data with jamming can be expressed as:

$$D(t,\theta) = S(t,\theta) + I(t,\theta) + n(t) \tag{6}$$

4. The Simulation Method of Software GPS Receiver

In the simulation of software GPS receiver, we take the advantage of the flexibility of software. We mainly introduce the acquisition and tracking modules.

The traditional acquisition is a two-dimensional search process. The computation amount is quite large. Based on the software, we use the circular correlation method, showed as Fig. 2.

Assume the input signal is y_k. We take the local carrier at f_i as $l_{i,k} = exp(j2\pi f_i t_k)$. First the FFT result of N points of $y_k \cdot l_{i,k}$ is multiplied by the conjugate FFT of the N points of local C/A code. Then the IFFT of the product gives the correlation result in the time domain for all the 1023 code phase offsets.

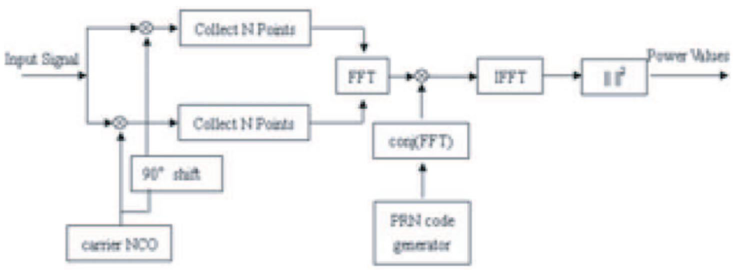

Figure 2: Acquisition based on circular correlation.

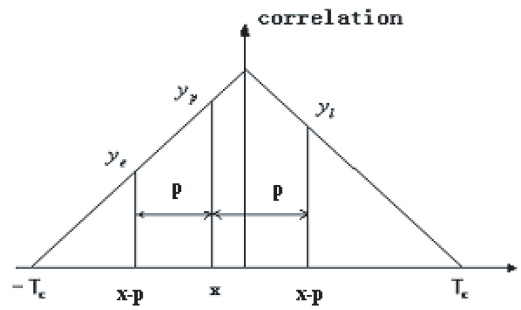

Figure 3: The correlation curve.

In the code tracking module [5], we use the numerical relation of correlation values of prompt code, early code and late code with the input IF sampled signal to adjust the input signal and get the finer code phase offsets x instead of traditional DLL. Assume the correlation values are y_p, y_e, y_l respectively. The relationship of them is showed as Fig. 3, where T_c is the code chip width, p is the code offset between prompt code and early/late code. From Fig. 3, we obtain that

$$r = \frac{y_l}{y_e} = \frac{T_c - x - p}{T_c + x - p} \Rightarrow x = \frac{(1-r)(T_c - p)}{1-r} \tag{7}$$

From x, we shift the input signal left or right one sample, and can evaluate the finer code phase error.

Due to the flexibility of software, we use third-order PLL to fit the high dynamic situation. We choose the loop filter as $F(s) = \frac{1+s\tau_2}{s\tau_1} \cdot \frac{1+s\tau_4}{s\tau_3}$, So the error transfer function is $H_e(s) = \frac{\tau_1\tau_3 s^3}{\tau_1\tau_3 s^3 + K\tau_2\tau_4 s^2 + K(\tau_2+\tau_4)s + K}$, where K is the loop gain. Let $a = \frac{K}{\tau_1\tau_3} = \omega_n^2\eta$, $b = a(\tau_2+\tau_4) = \omega_n^2 + 2\zeta\omega_n\eta$, $c = a \cdot \tau_2\tau_4 = 2\zeta\omega_n + \eta$, and we can get

$$H_e(s) = \frac{s^3}{s^3 + cs^2 + bs + a} = \frac{s^3}{(s+\eta)(s^2 + 2\zeta\omega_n s + \omega_n^2)} \tag{8}$$

From the formula (8), we can choose the ζ, ω_n and η according to the dynamic situation easily.

5. Simulation Results

In this paper, we choose the digital centered frequency as 1.25 MHz. According to Shannon sampling theorem, we choose acquisition frequency as 5 MHz, the power of jamming 60 db above that of GPS signal, that is -60 db. The receiver internal noise 20 db above that of GPS signal, that is -100 db. The Fig. 4 denotes the waveform of GPS data without jamming on one antenna. And the Fig. 5 denotes the waveform of GPS data with Broadband FM jamming on one antenna. Their spectrums that are with and without the broadband jamming are indicated in Fig. 6 and Fig. 7 respectively. In the experiment, we choose the antenna position as (X:-3173088.339 m;Y:-3625066.392 m;Z:4181362.566 m), and the position computed by our software receiver is(X:-3173092.972m; Y:-3625044.536 m; Z: 4181358.520 m). The Fig. 8 denotes the spectrum of GPS data after STAP processing.

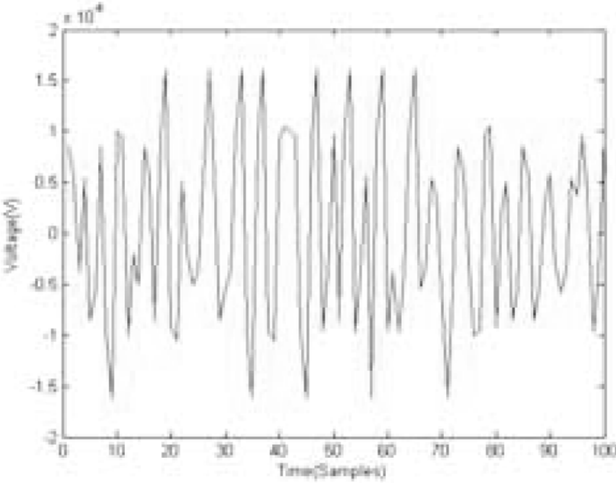

Figure 4: Waveform of Space-Time GPS data without jamming.

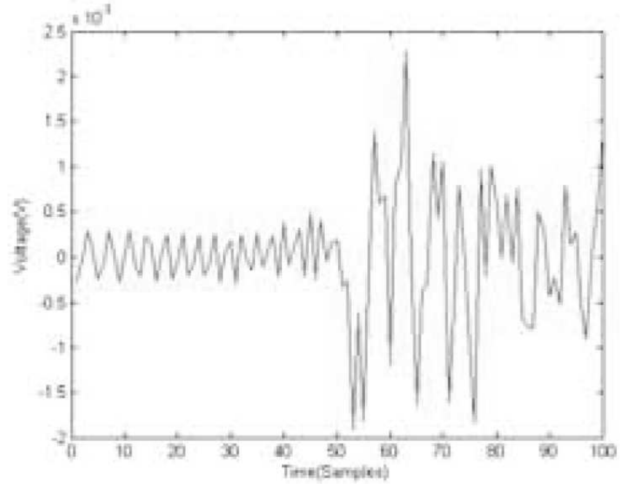

Figure 5: Waveform of Space-Time GPS data with broadband FM jamming.

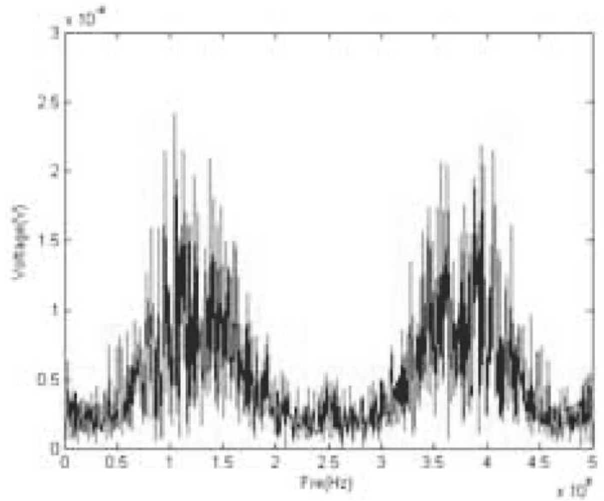

Figure 6: Spectrum of Space-Time GPS data without jamming.

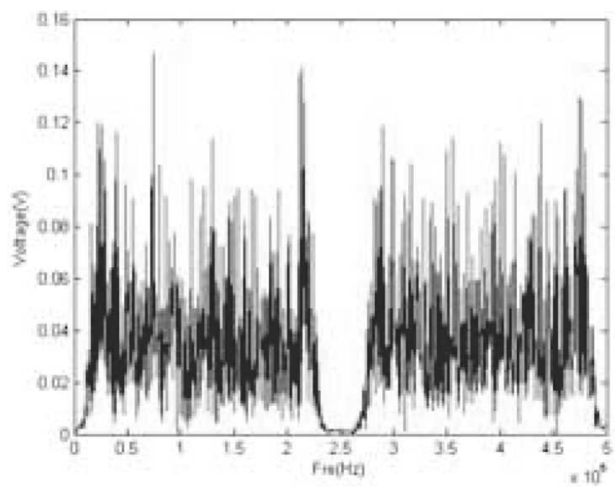

Figure 7: Spectrum of Space-Time GPS data with broadband FM jamming.

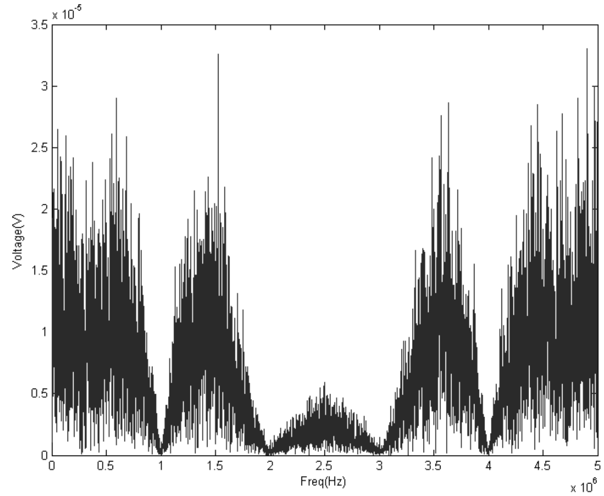

Figure 8: The spectrum of GPS data after STAP processing.

6. Conclusion

The simulation result shows that the Space-Time array data simulation method is valid and of high fidelity. And the simulation tool has been testified as a good platform for evaluating the STAP algorithms and using them in GPS. It will be of great help to improve the GPS positioning precision further.

Acknowledgement

This work was supported in part by the National Science Foundation of China under grant 60325102 and 60428101.

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