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GPS Signal Acquisition Based on Compressive Sensing and Modified Greedy Acquisition Algorithm

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ABSTRACT The first task of GPS receiver is to acquire the satellite signal, which tests the all likely 2-D hypotheses of the code phase and the Doppler frequency of the incoming GPS signal. Compressive sensing is a new signal sampling theory, for sparse signal, the signal can be sampled at a lower sampling rate than Nyquist sampling theory. In this paper, a new GPS signal acquisition method is proposed based on compressive sensing. We designed a GPS signal sparse representation dictionary according to the satellite; the position of sparse spike corresponds to the code phase and Doppler frequency. The modified greedy acquisition algorithm that is different from the compressive sensing signal reconstruction, which is used to acquire the GPS satellite. The numerical simulations illustrate that the new method can efficiently acquire the satellite with artificial or real GPS signal. The new method can compress the GPS signal greatly and reduce the transmission energy consumption accordingly, which is hoped to be applied to aircraft or animal monitoring that have little interference noise and need to record GPS data for a long time.

INDEX TERMS Compressive sensing, GPS acquisition, sparse dictionary, greedy algorithm.

I. INTRODUCTION

The Global Positioning System (GPS) is ubiquitous equipment for civilian applications, which provides global users with positioning, navigation and timing (PNT) services. GPS satellites fly in medium earth orbit (MEO) at an altitude of approximately 20,200 km (12,550 miles). The GPS signal is direct sequence spread spectrum (DSSS) system, which is composed of 24 satellites arranged in 6 orbital planes with 4 satellites perplane. All satellites are differentiated by spread code named GOLD codes or pseudo-random noise sequence (PRN). The navigation data are combined with the PRN through modulo-2 adders, and then they are transmitted on L1 frequency at 1575.42 MHz and L2 frequency at 1227.60 MHz [1].

The GPS signal that arrives at the receiver is down-converted and sampled according to the Nyquist sampling theory. For the GPS receiver, the first task is to acquire the visible satellite signal. The satellite signal propagation delay is unknown, so the signal is misaligned in time. Furthermore, due to the relative movement of the GPS satellite and receiver, the carrier frequency is changed, called Doppler offset. The purpose of acquisition is to determine satellites in the field of view and coarse PRN code phase and Doppler frequency. The acquisition stage tests all the likely 2-D hypotheses of the code phase and the Doppler frequency via searching over the binned time-frequency space across all the satellite spread codes. There is 1023 code phase and $\pm$10kHz frequency shift for high dynamic receiver, so the acquisition of GPS is time consuming and exhausted. The problem has received significant attention in the past few years. The fast Fourier transform (FFT) based acquisition technique using parallel process method improved the acquisition affect. But this method needs FFT of incoming GPS signal and receiver PRN replica, and complex multiplications, and an inverse FFT (IFFT) of complex multiplications products [2]. Folding techniques

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fold the receiver's code replica then the folded code is correlated with the incoming signal. This method degrade when the folding number increase [3], [4].

Compressive sensing (CS) theory points out that sparse signal can be sampled in a lower rate than Nyquist sampling theory and reconstructed through some sparse reconstruct algorithm [5], [6]. Since compressive sensing is proposed, it attracts researcher's attention and is applied in many fields including image processing [7], Multiple Input Multiple Output radar [8], communication [9], etc. In previous works, several CS-based techniques have been studied for GPS signal acquisition. In [10], the authors proposed an efficient acquisition scheme for GPS receivers using a bank of randomized correlators. The new framework is based on the analog compressed sensing method, which is consists of a multi-channel sampling structure. Experiments shows that GPS signals can be detected and acquired by the proposed sampling structure at a lower computation complexity. In [11], the author proposed a two-stage deterministic compressed global navigation satellite system (GNSS) signal acquisition technique using Walsh-Hadamard matrix has accepted good effect, but the method need two stage which maybe has a little complicated.

Our research group is currently engaged in the design and simulation of global navigation satellite system (GNSS) signal sources. In the study, we find that a large number of redundant data are generated at high sampling rate for navigation simulation system which is a heavy burden for storage, transmission and receiving. So we study how to apply the theory of compressive sensing to GNSS signal processing. In this paper, a modified greedy acquisition (MGA) technique based on compressive sensing theory is proposed. The GPS signal sparse representation dictionary is designed according to the different satellite, and a modified greedy acquisition algorithm is used to acquire the GPS satellite. Simulation results illustrate that the new method can efficiently acquire the satellite with artificial or real GPS signal.

The paper is organized as follows. Section 2, 3 introduces compressive sensing and GPS signal acquisition respectively. Section 4 describes the sparse dictionary of GPS, and gives the modified greedy acquisition algorithm. Section 5 gives the experiments results of the new schemes. Section 6 concludes the paper.

II. COMPRESSIVE SENSING

Compressive sensing is a new signal sampling theory which is proposed by Donoho and Candès in 2006 [5], [6]. If the signal x is sparse or sparse in a certain transform domain, the signal can be sensed by a lower data than Nyquist sampling theory which is used in modern digital system, and the signal can be recovered accurately and efficiently from the small number of compressed measurements. Compressive sensing has important significance for high frequency signal in signal processing field. According to Nyquist sampling theory, the sampling rate must be more than twice the maximum frequency of the signal, which get a large number of redundant data. It put a heavy burden on the system to save and transmit these redundant data. The high dimensional sparse signal $s \in R^N$ can be sensed using compressive sensing method via a M row and N column measurement matrix, which can be expressed as:

$$y = \Phi s + n \tag{1}$$

where $y \in R^M$ is the observation vector called sensing measurement data, $\Phi \in R^{M\times N}$ is the measurement matrix and $M \ll N$, $n \in R^M$ is interference noise. If the high dimensional signal is not sparse, but the signal can be expressed by the sparse dictionary $\Psi \in R^{N\times N}$ as:

$$x = \Psi s = \sum_{i=1}^{N} s_i \psi_i \tag{2}$$

where s is a coefficient vector of x in the transform domain. Most coefficients are zero or very small. The sparse dictionary is some transformation which used in signal processing such as Fourier transform (FT), discrete cosine transform (DCT), wavelet transform (WT) or some processing according to the signal feature [12]. The signal x is K-sparse if only K of the coefficients in (2) is nonzero. Under these circumstances, the compressive sensing can be expressed as:

$$y = \Phi x + n = \Phi\Psi s + n = \Theta s + n \tag{3}$$

The compressive sensing signal reconstruction is to get the source sparse signal s from the sensing measurement data y. The signal reconstruction problem is given as:

$$L0: \quad s_0 = \arg\min \|s\|_0 \quad s.t.\ y = \Theta s + n \tag{4}$$

In this formula, $\|\|_0$ means 0-norm which counts the number of nonzero elements in its argument. The 0-norm provide a very simple and easily notion of sparsity, but is not necessarily the right notion of norm for empirical work, which does not conform to the definition of norm. The sparsity optimization formula (4) looks superficially like the minimum of 2-norm problem, but the solution is different [13]. The solution of 2-norm is always unique, and can get through some standard optimization tools. Because of the discrete and discontinuous nature of 0-norm, the standard convex optimization method cannot be used. In the recent years, researchers have proposed some methods for solving the problem of formula (4). Convex program algorithm has stability and high accuracy, but its complexity is high [14], [15]. The approximate 0-norm algorithm has gained more attention because of the advantages of effectiveness, but has the bad performance in strong noise surrounds [16], [17]. The greedy algorithm is a kind of effective method for sparse signal reconstruction, for example matching pursuit (MP) algorithm [18], orthogonal matching pursuit (OMP) algorithm etc., [19]. The greedy algorithm has low complexity, but has high computation load and low accuracy. Among Greedy algorithm, matching pursuit algorithm has lower implementation complexity, and good performance in strong noise surrounds.

III. GPS SIGNAL

GPS satellite signal is compose of navigation data, spread code and carrier. The navigation data are sent by the satellite with a low date rate of 50 bps (20 milliseconds per data) containing satellite orbit location, time stamp and satellite health states etc. The GPS signal is known as direct sequence spread spectrum system, which shares the same carrier frequency and encode a different PRN sequence. In the GPS system, the signal transmitted by the satellites is modulated onto L1 and L2 frequencies at 1227.60MHz and 1575.42MHz respectively. For civil users, the DSSS signal received at the user end is carried on L1 frequency and the PRN sequence is 1023 bits length named GOLD code or coarse acquisition (C/A) code. The PRN code is transmitted at 1023 kbps and repeats every millisecond, so it has 20 recurrences in one bit navigation data [20].

In wireless telecommunications system, multipath propagation phenomenon is inevitable because of ionospheric reflection or refraction, reflection from objects such as water, mountains and buildings. The GPS signals arrive at the receiver with two or more paths including the line of sight (LOS) component. Multipath disturbance affect the measuring of propagation time, is a major error that limits the accuracy of GPS precise positioning. Some techniques have been proposed for mitigating the multipath error including narrow correlators [21], multipath estimating delay lock loop [22] and reduced rank multistage Wiener filtering algorithm [23], etc. In this paper, we first examine the GPS signal which takes the multipath into account, however, how to mitigate the multipath components is out the scope of this paper.

At the receiver, the incoming GPS signal is down-converted and sampled, of which the signal model can be expressed as:

$$X_k(t) = \sum_{i=0}^{R} a_i C_k(t-\tau_i) D_k(t-\tau_i) e^{j(\omega_I t+\phi_i)} + n(t) \quad (5)$$

where k denotes the k-th satellite, R is the multipath number, a_i is multipath signal amplitude with delays τ_i, $C_k(t)$ is the k-th satellite C/A code, $D_k(t)$ is navigation data, ω_I is the intermediate frequency(IF) after down-converter, ϕ_i is the carrier phase, and $n(t)$ is the additive white Gaussian noise.

For GPS signal acquisition, serial search acquisition is an often used method. For each satellite, the acquisition process finds the PRN code phase delay and the Doppler frequency of the received signal, which is a two dimension search process. The locally generated reference signal copy $C_k(t-\tau)e^{-j(\omega_I+\Delta\omega)t}$ is cross-correlated with incoming intermediate GPS signal, so the correlated output can be expressed as:

$$r(\tau,\omega) = \left\langle C_k(t-\tau)e^{-j(\omega_I+\Delta\omega)t}, X_k(t)\right\rangle \quad (6)$$

$$(\hat{\tau},\hat{\omega}) = \arg\max |r|^2 \quad (7)$$

where $\langle\rangle$ means correlation inner product operation, $C_k(t-\tau)$ is the PRN code phase delay, Δw is referred to as the frequency search step. If the code phase and frequency of the locally generated matches the incoming signal, the output will be significantly higher than others that any of these criteria were not fulfilled.

The serial search algorithm is easy to implement, but is very time consuming. It has two different searching: a frequency searching over all the possible Doppler frequency of IF±10kHz for a high dynamic receiver in steps of 500Hz and the code phase searching over all 1023 different phases. In this case, the total number of correlation is:

$$1023 \times (2\frac{10000}{500} + 1) = 41943 \quad (8)$$

It need 41943 correlations for each satellite, this is very exhausting obviously. Figure 1 is shown the serial search acquisition results of the sixth GPS satellite. In this experiment, the sampling frequency is 40MHz, intermediate frequency is 9.548MHz. Because the PRN code length is 1ms, the selected correlation data size is 1ms. The signal-to-interference ratio (SNR) is −20dB. The simulation signal has two paths, and the multipath signal amplitude is half of the LOS signal. From the figure, we can see that the output is very sparse. Only when the PRN code phase and Doppler frequency is in accord with the given satellite signal, there is a significant correlation value.

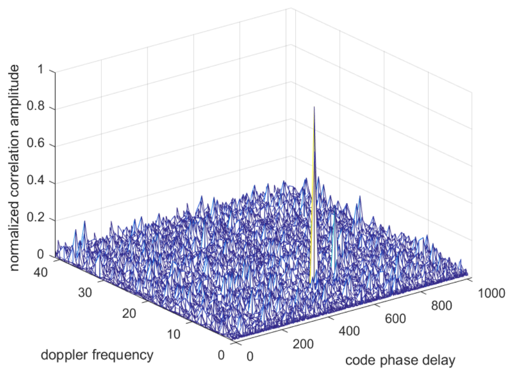

FIGURE 1. GPS signal serial search acquisition result.

IV. GPS SIGNAL ACQUISITION BASED ON MODIFIED GREEDY ALGORITHM

An acquisition method based on CS has been proposed. The GPS signal has been compressed by random matrix, sparse dictionary is designed on the base of the specific satellite. The new GPS signal acquisition system has two departments: sparse dictionary and reconstruction algorithm. The sparse is an essential prerequisite according to the CS theory. Figure 2 gives the 1000 sampling point of the GPS signal according to formula (5). From the figure we can see that the GPS signal is not sparse, so a sparse dictionary must be designed to represent the GPS signal sparsely.

A. SPARSE DICTIONARY

Considering the serial search acquisition method, we can find that if the code phase and frequency of the locally generated

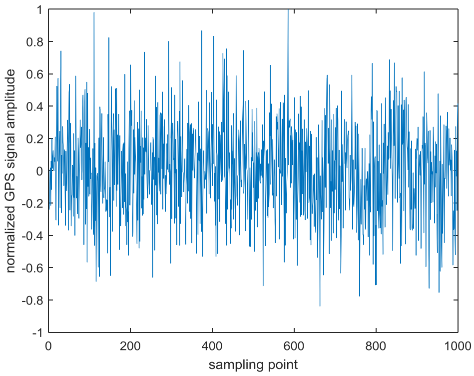

FIGURE 2. GPS signal in the time domain.

matches the incoming signal, the output will be significantly higher than that any of these criteria were not fulfilled, so the output is very sparse. We can design the sparse dictionary as:

$$\Psi^k = C_{n-\tau}^k \otimes e^{-j(\omega_I+\omega_d)n} \tag{9}$$

where $C_{n-\tau}^k$ is the code phase sweep over all 1023 different code phases of the k-th satellite PRN code and $e^{-j(\omega_I+\omega_d)n}$ is the frequency sweep over all possible carrier frequencies of $\omega_I \pm 10$ kHz for a high dynamic receiver in the steps of 500Hz, ω_I stands for intermediate frequency, $\otimes$ is Kronecker product. For a high dynamic receiver, the frequency searching range can reduce to $\omega_I \pm 10$ kHz for simplification, so the Kronecker product of code phase and frequency sweep is $1023 \times 41 = 41943$. If the length of GPS signal is N, the dictionary dimension is $N \times 41943$ [24].

According to the k-th satellite sparse dictionary, the GPS satellite signal x^k can be represented as:

$$x^k = \Psi^k s^k \tag{10}$$

From the formula (10), we can find that if the k-th satellite is in the field of view, only few of s^k are higher, and the others are closer to zero but not zero because of strong noise, s^k can be viewed as sparsely.

B. SPARSE GPS SIGNAL ACQUISITION

Based on the sparse dictionary, the GPS signal can be represented sparsely, so compressive sensing can be used for acquiring the GPS satellite signal for that the sparse highest value position correspond to the code phase and Doppler frequency. The GPS signal can be sensed by a random matrix Φ which is carried out orthogonalization between the arbitrary column vectors firstly, a lower dimension signal y^k is obtained

$$y^k = \Phi(x^k + n) = \Phi\Psi^k s^k + \Phi n = \Theta^k s^k + \Phi n \tag{11}$$

It must notice that this formula is different from formula (3). In (3), the sparse signal is sensed by random matrix firstly, and then the interference noise is added in the CS theory model. That is to say, transmitted signal is the sensed data. But for GPS system, receiver receives the signal is contaminated by interference noise firstly. Then the polluted signal is sensed by random matrix. The two models are equivalent with the important difference that the signal to noise ratio is differentiated by a factor proportional to n/m, where n is the dimension of the signal and m is the number of sensing data [25], [26].

The sparse higher value can obtain from the sparse reconstruction formula (4) according to the compressive sensing theory. But there is difference between GPS signal acquisition and traditional sparse signal reconstruction problem. Firstly, the aim of compressive sensing reconstruction algorithm is to reconstruct the source sparse signal. For the GPS signal acquisition, the position of the sparse higher value is interested rather than the accurate value, which is different from the traditional compressive sensing signal reconstruction. Secondly, for a designated sparse dictionary, there is only one satellite, so the sparsity is $K = 1$ in theory without regard for interference noise and multipath. Thirdly, some classical reconstruction algorithm (e.g. convex program, approximate 0-norm) is unfit to acquire GPS signal for the strong noise. In this paper, we use greedy algorithm to implement GPS signal acquisition.

The greedy algorithm uses exhaustive search by a series of optimal dictionary atom updates. Starting from $s0 = 0$, the initial support set is empty, at each iteration, expanding that set by one additional column. At each stage, the atom chosen maximally reduces the residual error. If the error falls below the threshold or the iteration times exceeds the given value, the algorithm terminates. The Orthogonal Matching Pursuit (OMP) is the most famous in greedy algorithm, which can obtain good sparse signal reconstruction effect. But OMP algorithm has inverse matrix operation, which cost much more computation load. For GPS signal acquisition, the dictionary is big, the inverse operation cost much more resource. The Matching Pursuit (MP) is a simpler algorithm than OMP, in the residual error updates steps; it does not have inverse matrix operation, so is more suitable for GPS signal acquisition.

GPS signal acquisition is interested in the sparse value position rather than the sparse value. With this insight, a modified greedy acquisition (MGA) is proposed. The new algorithm is given as follows:

The modified greedy acquisition algorithm is connected with the greedy algorithm. In the iteration 1, inner product of residual and sensing matrix is identical to the greedy algorithm. But the new acquisition algorithm has some difference. Firstly, it is different to update the residual. For OMP algorithm, it requires a least square calculation to obtain the sparse value. In MGA algorithm, the maximum inner product value is selected as the sparse value directly which is similar to MP algorithm. Secondly, stopping the iteration of greedy algorithm is controlled by residual which is unsuitable for GPS satellite acquisition because of strong noise. In the MGA algorithm, the aim is to acquire the satellite signal but not reconstruct the sparse signal. When the sparse value satisfies the judgment condition, the algorithm stops the iteration immediately. Thirdly, the output of greedy algorithm is sparse signal but the MGA is acquiring the satellite or not. The MGA

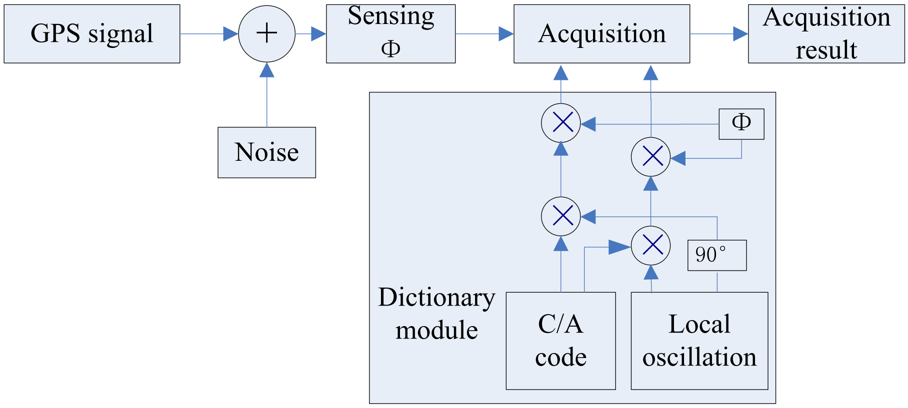

FIGURE 3. GPS signal acquisition based on compressive sensing.

Algorithm 1 Modified Greedy Acquisition Algorithm

Task: acquiring satellite in the line of sight based on $y = \Phi x^k = \Phi\Psi^k s^k = \Theta^k s^k$;

Input: sensing matrix Θ, sensing measurement data y, threshold coefficient γ, total iteration times I;

Initial: sparse solution $s^0 = 0$, residual error $r^0 = y$, support set $C^0 = \emptyset$;

Iteration:

1) Perform the inner product of residual error and the sensing matrix according to $p^i(j) = \left\langle r^{i-1}, \Theta_{(j)} \right\rangle \Big/ \left\| \Theta_{(j)} \right\|_2^2$;

2) Find the maximum inner product $p^i_{j_{\mathrm{m}}} = \arg\max \left| p^i(j) \right|$, add the index of the maximum into the support set $C^i = C^{i-1} \cup \{j_{\mathrm{m}}\}$, and add the maximum inner product value into the corresponding position of sparse signal $s^i(j) = s^{i-1}(j) + p^i_j$;

3) Judgement: if $|S_m|^2 \geq \gamma\, |S_{ms}|^2$, $S_m = \arg\max s$ and S_{ms} is the second highest sparse value, acquisition complete and break the iteration, turn to output 2;

4) Update the residual error $r^i = y - \Theta_C s^i$;

5) Iteration stopping rule: if $i = I$, stop the iteration and turn to output 1. Otherwise, apply another iteration.

Output1: There is no satellite in the line of sight.

Output2: Acquire the satellite successfully, and output the corresponding position index of S_m;

algorithm can reduce the computational complexity significantly compared to the greedy algorithm.

In the MGA algorithm, there are two new parameters. One is the total iteration times I. Because one satellite sparse dictionary is corresponding to one satellite, the sparsity is $K = 1$. Considering there has multipath interference and strong noise, the total iteration times I can be set to 5-10 to enhance the sparse value. The other is threshold coefficient γ. The coefficient controls the iteration and affects the acquiring result. We adjust it according to the Specific experimental conditions which will be given in the specific experiments.

V. NUMERICAL SIMULATION EXPERIMENTS

The MGA algorithm diagram is shown in Figure 3. In the front end, GPS signal is sensed by sensing matrix $\Phi \in R^{M\times N}$ which is a random matrix with entries drawn from the normal distribution. In the dictionary module, C/A code module generate the PRN code of satellite, the local oscillation module generate the sine-wave carrier. Because the phase of GPS signal carrier is unknown, the dictionary needs a 90° phase-shifted version. The all satellite dictionaries can be generated once and saved in the memory [27].

A. SIMULATION 1: DIFFERENT NOISE AND COMPRESSIVE RATIO

The GPS satellite signal arriving at the receiver is polluted by strong noise. In simulation 1, we analyze the noise and compressive ratio affection for MGA algorithm. According to formula (11), the length of sensing data and source GPS signal length is M and N respectively. To facilitate the discussion, the compressive ratio (CR) is defined as:

$$\alpha = M/N \tag{12}$$

In this simulation, the 21st GPS satellite (which is selected at random) is selected for numerical simulations. The sampling frequency is 40MHz, intermediate frequency is 9.548MHz. The source GPS data size is 1ms, so the length of N is 4000. The simulation signal has two paths, and the multipath signal amplitude is half of the LOS signal. To reduce the simulation burden without incurring loss of generality, we assume that the statistical model for the PRN code phase and Doppler frequency consist of uniformly distributed delay and the delay time is limited to 0-510 code; the Doppler frequency is limited to $\omega_I \pm 5$ kHz. The Kronecker product of code phase and frequency sweep is $511 \times 21 = 10731$, so the dictionary dimension is 40000×10731. The added noise is white Gaussian noise (WGN) with MATLAB function "awgn", and the signal-to-interference ratio (SNR) is set to −15dB, −20dB, −25dB. The compressive ratio is set to 0.6, 0.4 and 0.2. There are 9 cases with combinations of SNR and

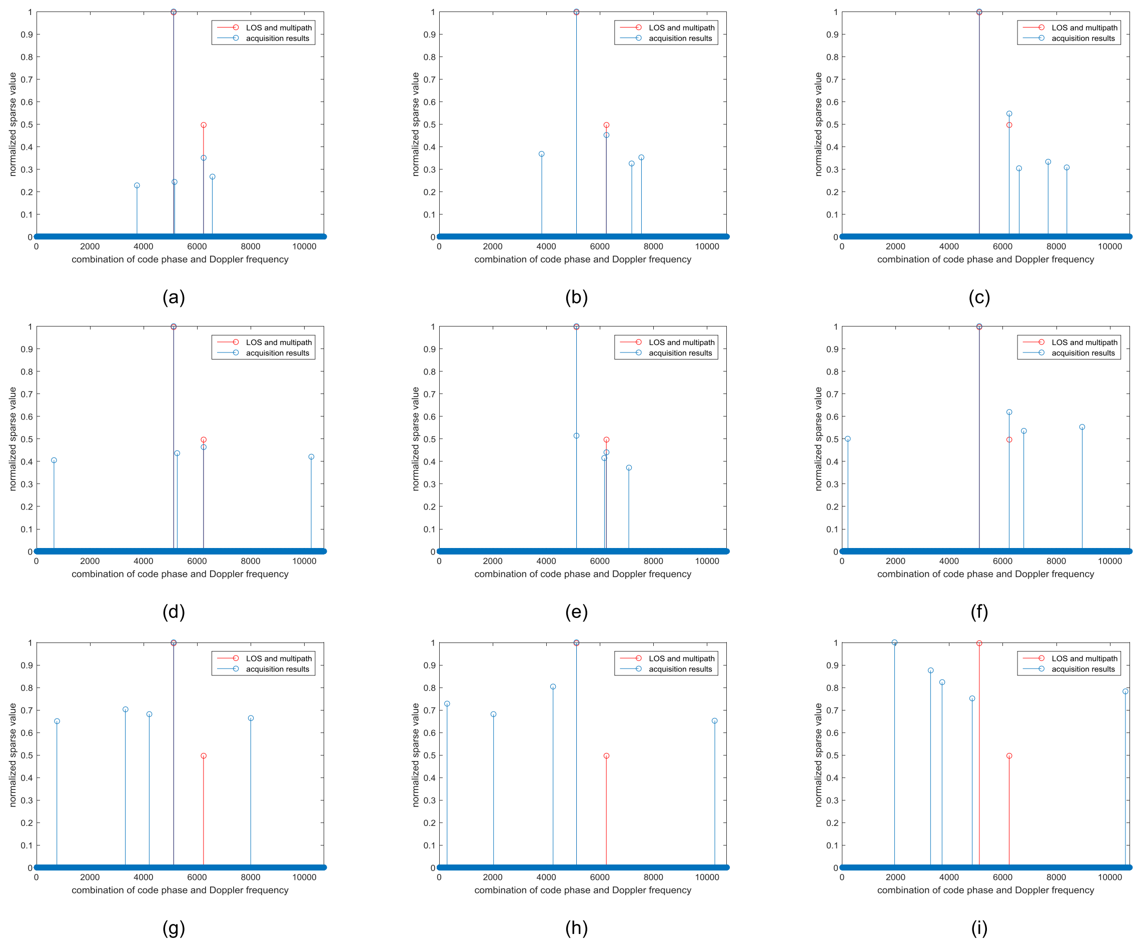

FIGURE 4. GPS signal acquisition based on MGA. (a) SNR = −15dB, CR = 0.6 (b) SNR = −15dB, CR = 0.4 (c) SNR = −15dB, CR = 0.2 (d) SNR = −20dB, CR = 0.6 (e) SNR = −20dB, CR = 0.4 (f) SNR = −20dB, CR = 0.2 (g) SNR = −25dB, CR = 0.6 (h) SNR = −25dB, CR = 0.4 (i) SNR = −25dB, CR = 0.2.

compressive ratio. Iteration times and threshold coefficient γ are 5 and 10, respectively.

The purpose of simulation 1 is to analyze the affection of two parameters in different noise and CR. The acquisition results are shown in figure 4; the two red stems are the right position of GPS signal and multipath from which we can see that the satellite signal can be acquired successfully in −15dB and −20dB. The MGA algorithm is not good with −30dB strong noise which can find right signal position in 0.6 and 0.4 CR but the second highest sparse value is too high. The algorithm is out of work in 0.2 CR with −30dB. The experiments show the efficiency of the algorithm, and it is appropriate for acquisition that threshold coefficient γ and CR are 2 and 0.4 respectively.

B. SIMULATION 2: SATELLITE ACQUISITION BASED ON ANOTHER SATELLITE DICTIONARY

For GPS receiver, the acquisition is a blind operation. That is to say the receiver does not know which satellite in the line of view. This is an important problem for MGA algorithm because it need satellite sparse dictionary. The simulation 2 is a failed acquisition experiment that one satellite signal is acquired based on another satellite sparse dictionary. The GPS signal is the 21st GPS satellite signal which is given in simulation 1, but the sparse dictionary used in MGA acquisition is another satellite (the second satellite sparse dictionary which is selected at random). All the parameters are the same as simulation 1.

Figure 5 shows the acquisition results of simulation 2. Only three results are given to save the space because other experiments have similar results. The two red stems are the right position of GPS signal and multipath. The highest sparse acquisition value is equal to the second highest almost and all the values are very close. Because the GPS satellite signal is not sparse any more in another satellite dictionary, the MGA algorithm based on compressive sensing is failed.

C. SIMULATION 3: ACQUISITION OF REAL GPS SATELLITE SIGNAL

For real GPS signal, the noise is not necessarily white Gaussian noise and the receiver receives all satellite signals in the line of view. The practical circumstance is complex.

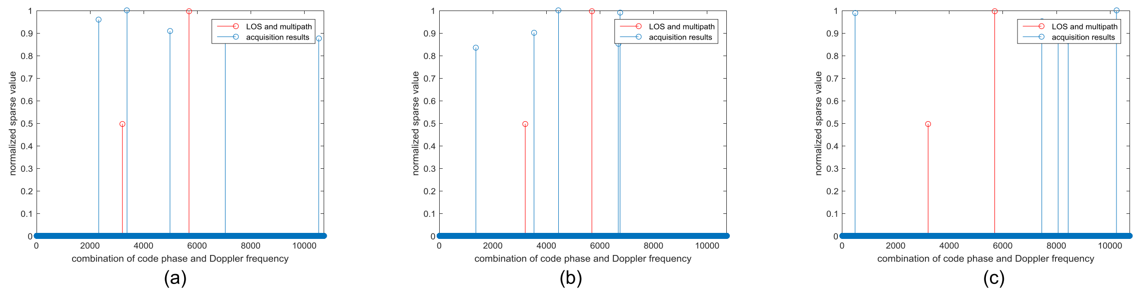

FIGURE 5. Acquisition of GPS signal based on another satellite dictionary. (a) SNR = −15dB, CR = 0.4 (b) SNR = −20dB, CR = 0.4 (c) SNR = −25dB, CR = 0.4.

In this experiment, we select a real GPS signal for testing the MGA algorithm. The intermediate frequency of GPS signal is 9.548MHz, and sampling frequency is 38.192MHz. All the satellite in the line of view is given in figure 6 according to the signal intensity which is measured by the highest correlation value compared to the second highest correlation value according to the method given by Borre and Akos in reference [20].

In this simulation, 1ms GPS source data (38192 sampling point) is used for experiment. The Doppler frequency sweep is ±5 kHz and PRN code phase is 0-1022 code shift, so each satellite dictionary dimension is 38192×21483. The CR is set to 0.4 which is a reasonable compromise based on acquisition effect and high compressive ratio; threshold coefficient and iteration times are similar to simulation 1.

Three typical satellites acquisition results are shown in figure 7. The four strong satellites (15, 18, 21 and 22) signals can be acquired successfully (only satellite No. 18 is shown because it is the worst signal in the four satellites), but the weakest satellite (3 and 9) cannot be acquired. Figure 7(c) shows the acquisition of the weakest satellite No. 3, the right satellite position is not at the highest value. The MGA algorithm cannot effectively acquire the real GPS signal with strong interference noise.

D. SIMULATION 4: CONTRAST BETWEEN MGA AND SERIAL SEARCH ACQUISITION

Serial search acquisition is an often used method for GPS receiver which is introduced in part three. In this experiment, we will compare it to the MGA algorithm with different CR in different SNR circumstance.

The first GPS satellite is selected for numerical simulations (which is selected at random). All the parameters are the same as simulation 1. The SNR increase from −35dB to −10dB by 5, and CR is 0.6, 0.4 and 0.2. In each case the acquisition experiment repeats 100 times for calculating the acquisition probability which is the ratio of number of acquisition to the total simulation times.

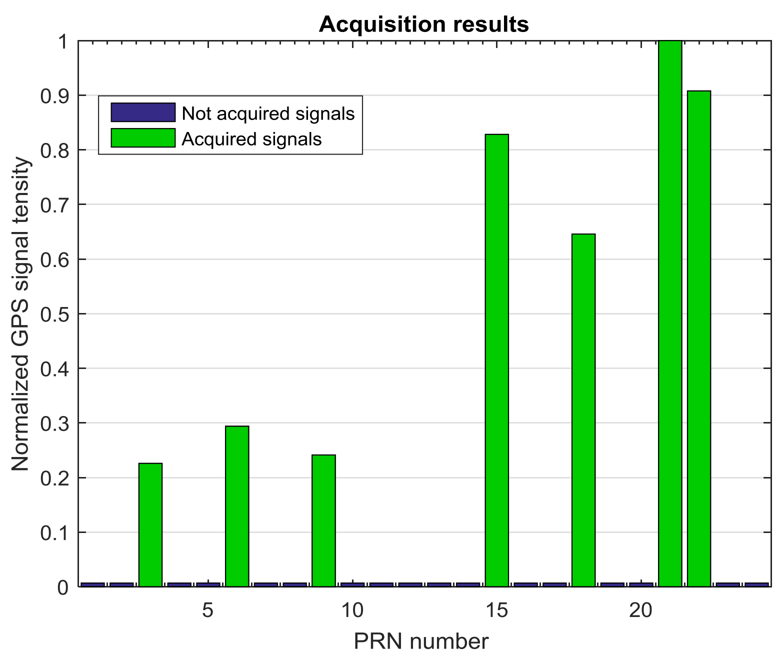

FIGURE 6. GPS satellite signal intensity.

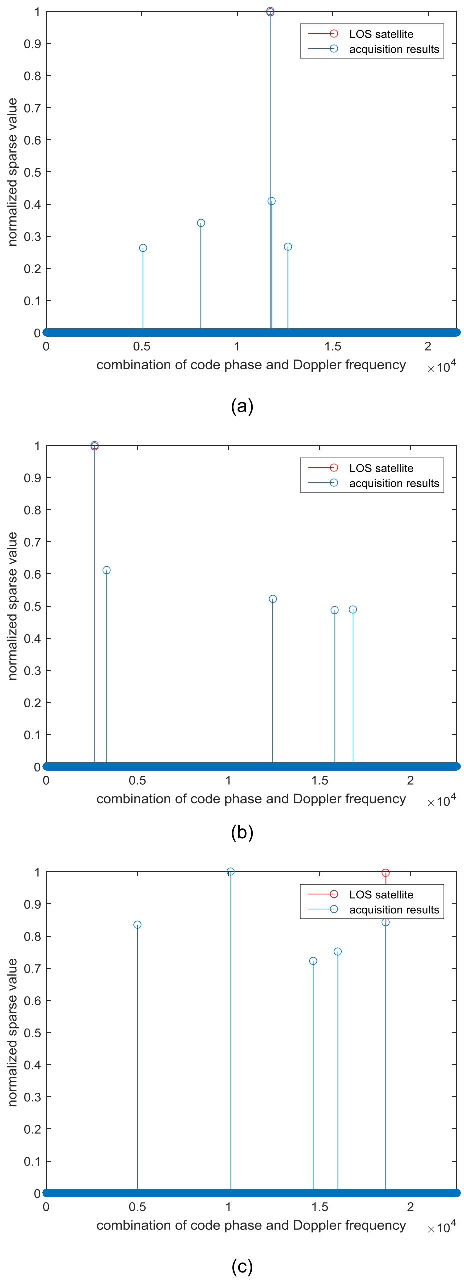

FIGURE 7. Real GPS signal acquisition result based on MGA. (a) Satellite No. 18. (b) Satellite No. 6. (c) Satellite No. 3.

The simulation results are shown in figure 8. For all method, the acquisition probability decreases when the SNR decrease. When CR is 0.6, the MGA algorithm is very close to the serial search acquisition method. In the compressive sensing model, the GPS receiver receives the polluted signal, and then the polluted signal is sensed by sensing matrix. This model can enhance the noise by a factor proportional to n/m, where n is the dimension of the signal and m is the number of sensing data [25], [26]. That may be the main reason for the decline of acquisition probability.

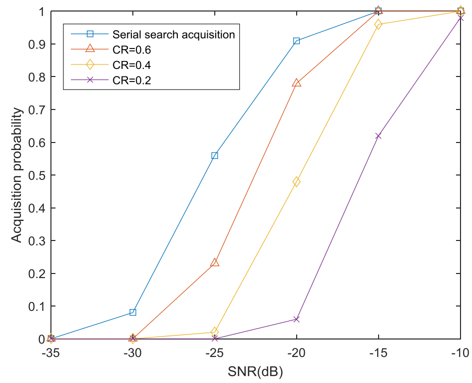

FIGURE 8. Contrast between MGA and serial search acquisition.

VI. CONCLUSIONS

In this paper, a modified greedy acquisition algorithm based on compressive sensing is proposed to acquire the GPS satellite. As shown in the simulation results, the new algorithm can efficiently reconstruct the unknown sparse delay-Doppler pairs using little artificial or real GPS measure data in low SNR circumstances. New technique can scale down the original GPS signal greatly and transmission energy consumption, which is hoped to be applied to aircraft or animal monitoring which have little interference noise and need to record GPS data for a long time. Because the acquisition performances are not ideal under the lower SNR surroundings, which may be improved through reference [26] method or enhancing the SNR by increasing the signal length because there are 20 PRN code periods in one bit navigation data. The authors' research group will continue to study how to improve the acquisition effect.

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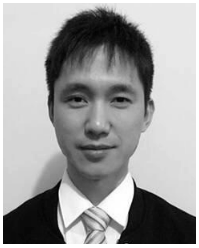

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