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Clutter Cancellation Based on Frequency Domain Analysis in Passive Bistatic Radar

DAWEI ZHAO, JUN WANG, GANG CHEN, JIPENG WANG, AND SHUAI GUO
National Laboratory of Radar Signal Processing, Xidian University, Xi'an 710071, China

Corresponding author: Jun Wang (wangjun@xidian.edu.cn)

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ABSTRACT In order to solve the problem when the target detection of passive bistatic radar is seriously affected by direct signal and multi-path, a clutter cancellation algorithm based on frequency domain analysis is proposed in this paper. By analyzing and processing the frequency domain correlation between the reference signal and the echo signal, the time delay and the amplitude of the direct signal and multipath in the echo signal can be estimated for clutter cancellation. This method can not only reduce the computation greatly, but also eliminate the influence of clutter echo residue on target detection. The effectiveness of the proposed algorithm is verified by simulation and real data processing.

INDEX TERMS Correlation, interference cancellation, passive bistatic radar, radar clutter, spectral analysis.

I. INTRODUCTION

Passive bistatic radar (PBR) refers to the radar detection system which does not transmit electromagnetic wave signal, but relies on existing electromagnetic wave in space to realize the function of target detection, positioning and tracking [1]–[2]. Compared with the conventional active radar system, the PBR system based on the non-cooperative or third-cooperative radiation source has the advantages of high concealment, strong anti- concealment ability, rich radiation signals and low cost, which has attracted extensive attention at home and abroad in recent years [3]–[10]. The target detection of PBR is realized by signal coherent processing [11]–[12]. The coherent processing of PBR is based on dual-channel, which means PBR system requires at least two physical receiving channels or two equivalent receiving channels. A typical PBR geometry is shown in Fig. 1. In PBR system, one channel points to the position of the base station, which is called reference channel to receive the direct signal and a small amount of multipath reflection signal and noise signal directly irradiated by the transmitting station. And the other channels are collectively called the echo channel which receive signals include the target reflection, a small amount of direct wave, multipath and noise. Due to the influence of non-transparency, fluctuation, radiation power and target RCS change transmitting station signal, the energy of target echo is far lower than that of direct signal and multipath. Therefore,

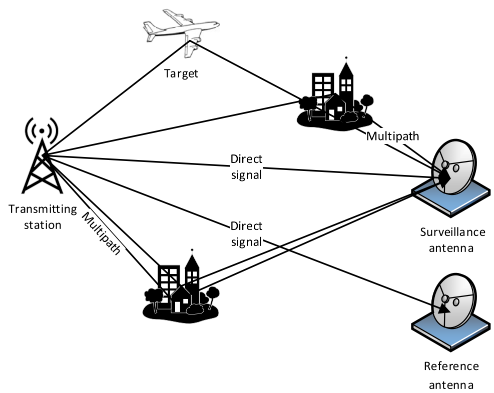

FIGURE 1. PBR system schematic.

before target detection, the clutter (including direct wave and multipath) in the echo signal should be eliminated first. In general, the energy of the actual target echo is still weaker than that of the noise signal. Therefore, it is necessary to carry out coherent processing (or range Doppler processing) for the residual echo signal and the reference signal to improve the detection signal-to-noise ratio of the target.

The existing methods are basically to eliminate the echo signal directly in time domain. In reference [13], a clutter cancellation algorithm based on sequential cancellation is proposed. A clutter cancellation algorithm for external emitter radar based on fractional delay estimation is proposed in reference [14]. Reference [15]–[16] attempt to design a suboptimal detector, such as the generalized likelihood ratio

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test, to detect the target. In reference [17]–[21], adaptive filter is used to filter echo signal, so as to eliminate the clutter and direct path signal. However, the most widely used algorithm today is orthogonal projection algorithm. The reference [22]–[24] presented ECA, SCA, ECA_B and other algorithms on the basis of projecting the received signal into sub-space orthogonal to the clutter and the pre-detection target, respectively. The extended cancellation algorithm (ECA) in reference [22] is an open-loop scheme. The basic idea of the scheme is to project the signal received by the echo antenna into the subspace from the base station direct signal and its delay expansion space. Because the target echo signal can be regarded as orthogonal with the direct signal and multipath of the base station, the target will not be affected when the clutter is eliminated in the echo signal. So that the direct wave and multi-path echo cancellation can be realized. But ECA algorithm needs to inverse the direct signal subspace, so its computational complexity is greatly affected by the cancellation order. At the same time, when the order of cancellation is too small, there is a multipath residual of echo signal, and false targets will be introduced.

In this paper, a clutter cancellation algorithm based on frequency domain analysis (Abbreviated as FDACA) is proposed. The multipath time delay is determined by frequency domain analysis, and the estimated multipath amplitude is used to suppress the multipath echo directly, which greatly simplifies the computation. In addition, the influence of multipath echo residual on target detection can be effectively suppressed by using frequency domain Range Doppler processing by using the characteristic that the Doppler of multipath residual is zero.

The structure of this paper is shown as follows. In Section II, signal model and the signal processing flow of PBR have been described in detail. In Section III, the ECA algorithm has been introduced and the FDACA algorithm is described in detail. In Section IV, the FDACA algorithm is simulated and analyzed using simulation data and real data respectively, and the ECA algorithm is compared. Conclusions are drawn in Section V.

II. SIGNAL MODEL AND PROBLEM ANALYSIS

From the PBR system schematic shown in Fig.1., assume that the reference signal in the reference antenna is pure. The sampled reference signal was written as

$$x(n) = Cs(n) \tag{1}$$

in (1), C is the amplitude of the reference signal. Because the signal intensity of the direct signal is much higher than the noise, the influence of noise is ignored. The sampled echo signal received after sample by surveillance antenna was (2),

$$r_{\text{sur}}(n) = \sum_{i=1}^{N_i} A_i s(n - \tau_i f_s) e^{j2\pi f_i \frac{n}{f_s}} + \sum_{p=1}^{N_p} B_p s(n - \tau_p f_s) + z(n) \tag{2}$$

in (2), $s(n)$ is the transmission signal. f_s is the sampling rate. A_i, τ_i, f_i are the amplitude, time delay and Doppler shift of each target respectively. B_p, τ_p are the amplitude and time delay (reference time delay is 0 by default) of *pth* interference (including direct signal, multipath), and $z(n)$ is the noise in the echo antenna.

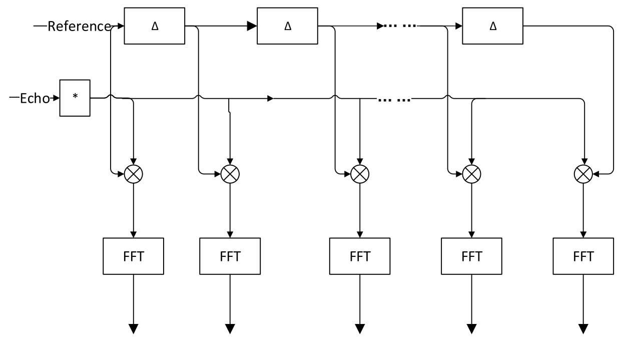

FIGURE 2. Rang Doppler processing schematic.

Because the received target reflector signal lags behind the reference signal, the target is in distance channel for Doppler coherent processing. In order to obtain multipal distance channels, Doppler Coherent processing, that is, Doppler pulse pressure, is generally achieved by means of Range Doppler matching filtering. Range Doppler processing schematic sits as shown in Fig. 2. where Δ is a tap delay. Doppler processing of the multiplication output of each tap achieves coherent accumulation, so that the output of each tap is equivalent to the Doppler distribution of different distance channels. The output in Fig. 2. is represented by time delay and Doppler as a two-dimensional plane, i.e. which is displayed at the corresponding delay and Doppler positions when there are multiple targets and fixed clutters.

However, in addition to the target reflected signal, there are direct signal and fixed object multipath echo signals in the echo channel, which produce signal leakage components similar to continuous wave radar. Therefore, there is inevitably a cluttered side lobe in Range Doppler processing. Because the target Doppler frequency is much lower than the sample frequency processed, the cluttered sidelobes fill the entire desired distance Doppler plane. The related peak of target signal will be submerged in the reference signal and short-range clutter side lobe for the direct signal and short-range multipath signal power being much higher than the target reflected echo. It cannot get a better detection performance by matching the coherent processing of filtering only, so the clutter suppression must be used before the target detection.

The time domain Rang Doppler processing in figure 2. is shown as (3)

$$\chi(\tau, f_d) = \sum_{0}^{Tf_s} r_{\text{sur}}(n) x^*(n - \tau f_s) e^{-j2\pi f_d \frac{n}{f_s}} \tag{3}$$

where, τ, f_d, is time delay and Doppler shift respectively, and T is the accumulation time of Range Doppler processing.

III. TARGET DETECTION BASED ON FREQUENCY DOMAIN ANALYSIS

The key problem of clutter cancellation is to find out the multipath delay, and the traditional clutter cancellation algorithm such as NLMS [14], ECA [18] etc. need to use the reference signal to construct time delay matrix for traversing all the time delay, which requires a higher degree of computational complexity. Therefore, this paper puts forward the scheme of using frequency domain related signal processing which can estimate the multipath delay information of strong multi-path directly, and realize the simplification of clutter cancellation.

A. EXTENDED CANCELLATION ALGORITHM(ECA)

As one of the most commonly used clutter cancellation algorithm, ECA algorithm is one of the current algorithms with lower computational complexity which is based on interference subspace projection. Its idea is to project the echo signal in the echo channel to the subspace opened by direct wave and its time delay to eliminate clutter interference. The subspace is as follows

$$D = \begin{bmatrix} x(1) & x(2) & x(3) & \cdots & x(N) \\ 0 & x(1) & x(2) & \cdots & x(N-1) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & x(N-L+1) \end{bmatrix}^{\mathrm{T}}_{N\times L} \tag{4}$$

where, N is the length of direct signal data; L is the number of cancellation distance elements, $[\cdot]^{\mathrm{T}}$ indicate matrix transposition. In the construction matrix, the first row to Lth row represent the multipath samples with delay of 0 to L-1 distance cells.

According to the orthogonality of subspace, the subspace coefficients of ECA algorithm can be transformed into the solutions of the following optimization problem.

$$\min_{W} J = \|R - DW\|^2 \tag{5}$$

where, W is the subspace coefficient, R is the echo matrix.

This is a standard second-order convex optimization problem. Solve the conjugate gradient of the cost function and make it 0

$$\frac{\partial J}{\partial W} = \frac{\partial \|R - DW\|^2}{\partial W} = 2D(R - DW)^H = 0 \tag{6}$$

Then,

$$W = \left(D^H D\right)^{-1} D^H R \tag{7}$$

After cancellation, the residual signal can be expressed as

$$e_{sur} = R - DW \tag{8}$$

B. FREQUENCY DOMAIN ANALYSIS CLUTTER CANCELLATION

The process of FDACA algorithm:

Firstly, transform the reference signal and echo signal to frequency domain. The reference signal and echo signal are analyzed and processed in frequency domain to eliminate the phase effect caused by the signal itself.

Secondly, obtain the coherent peak corresponding to multipath delay by inverse Fourier transform.

Thirdly, pass the signal processed in the second step through the threshold to get time delay and amplitude of the multipath.

At last, based on the time delay and amplitude of the multipath, clutter cancellation can be realized.

The specific process is as follows:

The spectrum of $r_{sur}(n)$ and $x(n)$ was written as

$$\begin{aligned} R(k) &= FFT[r_{sur}(n)] \\ &= \sum_{i=1}^{N_i} A_i S(k - \frac{f_i}{f_s}) e^{j\tau_i f_s k} + \sum_{p=1}^{N_p} B_p S(k) e^{j\tau_p f_s k} + N(k) \end{aligned} \tag{9}$$

$$X(k) = FFT[x(n)] = CS(k) \tag{10}$$

in (9), (10), $S(k)$ is the transmission signal spectrum; $FFT[\cdot]$mean Fourier transform.

Set

$$Y(k) = R(k)X^*(k) \tag{11}$$

$$V(k) = X(k)X^*(k) \tag{12}$$

in the above (11) (12), $*$ represents the conjugated operation.

Bring (9), (10), (12) into (11),

$$\begin{aligned} Y(k) = &\sum_{i=1}^{N_i} A_i CS(k - \frac{f_i}{f_s}) S^*(k) e^{j\tau_i f_s k} \\ &+ \frac{1}{C^2} \sum_{p=1}^{N_p} B_p CV(k) e^{j\tau_p f_s k} + CN(k)S^*(k) \end{aligned} \tag{13}$$

because the $V(k)$ is a real sequence, so

$$\begin{aligned} \frac{Y(k)}{V(k)} = &\frac{1}{V(k)} \sum_{i=1}^{N_i} A_i CS(k - \frac{f_i}{f_s}) S^*(k) e^{j\tau_i f_s k} \\ &+ \frac{1}{C^2} \sum_{p=1}^{N_p} B_p C e^{j\tau_p f_s k} + \frac{1}{V(k)} CN(k)S^*(k) \end{aligned} \tag{14}$$

refer to (14), it can be found that the multipath interference part of the signal only contains the delay term, which is independent of the signal itself. Then

$$G(k) = IFFT\left[\frac{Y(k)}{V(k)}\right] = I(k) + U(k) \tag{15}$$

$$U(k) = IFFT\left[\begin{aligned} &\frac{1}{V(k)} \sum_{i=1}^{N_i} A_i CS(k - \frac{f_i}{f_s}) S^*(k) e^{j\tau_i f_s k} \\ &+ \frac{1}{V(k)} CN(k)S^*(k) \end{aligned}\right] \tag{16}$$

$$I(k) = \frac{1}{C} \sum_{p=1}^{N_p} B_p \delta(k - \tau_p f_s) \tag{17}$$

in above (15)–(17), $IFFT[\cdot]$ represents inverse Fourier transform. $\delta(\cdot)$ represents shock response. In the PBR, the amplitude of the strong multi-path signal is much larger than that of the target echo, so the larger amplitude of $G(k)$ can be regarded as the position of strong multi-path delay. So set

$$[\Omega, \Gamma] = sort\,[G(k)] \geq A_{\mathrm{thd}} \tag{18}$$

$$\Gamma = \{k, G(k) \geq A_{\mathrm{thd}}\} \tag{19}$$

$$\Omega = \{|G(k)|\,, G(k) \geq A_{\mathrm{thd}}\} \tag{20}$$

where, sort[·] represent sorting operation from large to small. A_{thd} mean multipath amplitude threshold. The selection of threshold is on the basis of prior information of channel noise, and the values are different in different cases. the Ω corresponds to the amplitude of the $G(k)$ over the threshold, Γ corresponds to the position of the $G(k)$ over the threshold.

$$\begin{aligned} |G(k)| &= \sum_{i=1}^{N_i} \frac{A_i}{C} + \frac{|N(k)|}{C} + \frac{B_p \delta(k - \tau_p f_s)}{C} \\ &\approx \sum_{i=1}^{N_i} \frac{A_i}{C} + \frac{B_p \delta(k - \tau_p f_s)}{C} \end{aligned} \tag{21}$$

in (21), the complex amplitude C of the direct wave is much greater than the amplitude of the noise $N(k)$, and the amplitude B_p of the multipath echo is much large than that of the target echo energy A_i and the noise $N(k)$, so $|G(k)|$ is taken as the amplitude of multipath.

The delay matrix is shown in (22)

$$D_{\mathrm{f}} = \begin{bmatrix} \underbrace{0 \cdots 0}_{\Gamma\,(1)} & x(1) & \cdots & x[N - \Gamma\,(1)] \\ \underbrace{0 \cdots 0}_{\Gamma\,(2)} & x(1) & \cdots & x[N - \Gamma\,(2)] \\ \vdots & \vdots & \ddots & \vdots \\ \underbrace{0 \cdots 0}_{\Gamma(N_p)} & x(1) & \cdots & x[N - \Gamma(N_p)] \end{bmatrix}^T \tag{22}$$

$$e_{\mathrm{sur}} = r_{\mathrm{sur}} - \frac{\sum_{p=1}^{N_p} \Omega(p) D_{\mathrm{f}}(p)}{C} \tag{23}$$

in the (23), e_{sur} represent the echo residual signal. $D_{\mathrm{f}}(p)$ represents the p_{th} column of the matrix D_{f}.

C. FREQUENCY DOMAIN RANGE DOPPLER PROCESSING

By Formula (21), the amplitude estimation of multi-path echo will be affected by the amplitude of target echo, so the traditional time domain Range Doppler processing will produce more zero-frequency interference. Therefore, a target detection scheme based on frequency domain range Doppler processing is applied to in this paper.

The echo residual signal after the clutter cancellation:

$$\begin{aligned} e_{\mathrm{sur}}(n) = &\sum_{i=1}^{N_i} A_i s(n - \tau_i f_s) e^{j2\pi f_i \frac{n}{f_s}} \\ &+ \sum_{p=1}^{N_p} \left(\sum_{i=1}^{N_i} A_i \right) s(n - \tau_p f_s) + z(n) \end{aligned} \tag{24}$$

in (24), set

$$e_{\mathrm{mul}}(n) = \sum_{p=1}^{N_p} \left(\sum_{i=1}^{N_i} A_i \right) s(n - \tau_p f_s) \tag{25}$$

which indicates the residual of weak multipath signal after clutter cancellation.

$$\begin{aligned} E_{\mathrm{sur}}(k) &= FFT\,[e_{\mathrm{sur}}(n)] \\ &= \sum_{i=1}^{N_i} A_i S(k - \frac{f_i}{f_s}) e^{j\tau_i f_s k} \\ &\quad + \sum_{p=1}^{N_p} \left(\sum_{i=1}^{N_i} A_i \right) S(k) e^{j\tau_p f_s k} + Z(k) \end{aligned} \tag{26}$$

The residual signal of the echo is correlated with the reference signal, then

$$\begin{aligned} \chi(f, \tau) &= \sum_{f=1}^{f_s T} CS(k) E_{\mathrm{sur}}^{*}(k + \frac{f}{f_s}) e^{j\tau f_s k} \\ &= \chi_{\mathrm{tar}}(f, \tau) + \chi_{\mathrm{mul}}(f, \tau) \end{aligned} \tag{27}$$

in (27),

$$\chi_{\mathrm{tar}}(f, \tau) = C \sum_{f=1}^{f_s T} \sum_{i=1}^{N_i} A_i S(k) S(k - \frac{f_i}{f_s} + \frac{f}{f_s}) e^{j(\tau - \tau_i) f_s k} \tag{28}$$

$$\begin{aligned} \chi_{\mathrm{mul}}(f, \tau) = &C \sum_{f=1}^{f_s T} \sum_{i=1}^{N_p} \left(\sum_{i=1}^{N_i} A_i \right) S(k) S(k + \frac{f}{f_s}) e^{j(\tau - \tau_i) f_s k} \\ &+ CS(k) Z(k + \frac{f}{f_s}) e^{j\tau f_s k} \end{aligned} \tag{29}$$

in (24)–(26), T is the accumulation time of Range Doppler processing. Because there is no Doppler frequency offset in the multi-path residual, when $f \neq 0$, $\chi_{mul}(f, \tau)$ can be approximately regarded as the cross-correlation of noise signals. When $(f, \tau) = (f_i, \tau_i)$, the maximum value of $\chi_{tar}(f, \tau)$ is obtained. Then after the interference cancellation, the multi-path residual energy is similar to the target echo energy, and the $\chi_{mul}(f_i, \tau_i)$ is far less than $\chi_{tar}(f_i, \tau_i)$, so the target detection can be realized.

D. CALCULATION ANALYSIS

Assuming that the length of the data is N, and the order elimination of this paper is M and ECA cancellation order is L. The main amount of computation of the ECA algorithm is concentrated in calculation and inversion of the matrix $D^H D$. Compared with the traditional target detection scheme, the computational complexity of the frequency domain Range Doppler processing is basically the same as that of the time domain Range Doppler processing. However, in the case of clutter cancellation, the algorithm only needs two Fourier transform, one inverse Fourier transform, MN times multiplication, and $3N$ sub-point multiplication, and the amount of computation is shown in the following table:

Refer to FDACA algorithm, the computational complexity is only related to the strong multipath number M. Generally speaking, the strong multi-channel number is much smaller than the cancellation order L of ECA algorithm and does not need to carry out matrix inversion. Therefore, the algorithm of this paper can greatly simplify the computational complexity of clutter cancellation.

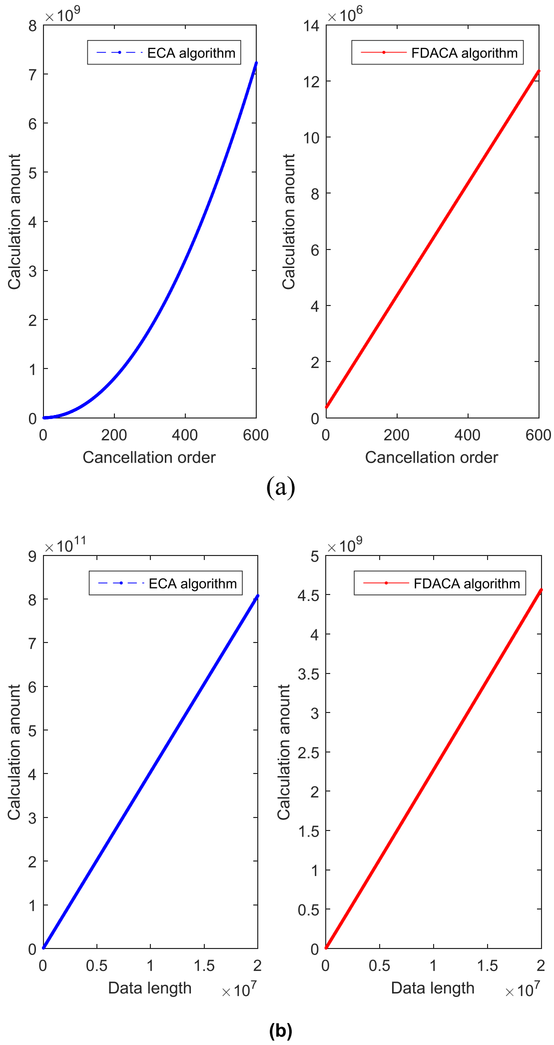

FIGURE 3. **Calculation amount comparison ((a): Calculation amount varies with cancellation order (b): Calculation amount varies with data length).**

For a more intuitive comparison of the amount of computation, the calculation simulation of Table 1 is shown in Fig.3. The data length of the signal is 20000. From the Fig.3.(a), the amount of computation in FDACA algorithm is linear and is much smaller than that in ECA algorithm for the number of operations in ECA increasing exponentially with the order of cancellation. Meanwhile, the calculation amount of both algorithms are linear in Fig.3.(b) with the cancellation order is 200. But the calculation amount of ECA algorithm is three orders of magnitude higher than that of FDACA algorithm.

TABLE 1. **Comparison of multiplication times.**

	Multiplication Times
ECA	$O[NL^2 + L^2(\log L + 1) + 2NL]$
FDACA	$O[NM + \frac{3}{2}N\log N + 3N]$

IV. SIMULATION ANALYSIS

A. SIMULATION DATA PROCESSING

In this part, the results of the algorithm are verified by simulation. In simulation, the data is Gaussian white noise with length of 20×10^3, and seven multi-path clutters with two weak targets are added to the echo signal. In order to observe the direct signal in the echo channel, the delay of 10 range units is added to the direct signal. The parameters are set as shown in Table 2. Generally speaking, the target energy is more than 60 dB lower than direct signal energy in PBR system.

TABLE 2. **Simulation parameter settings.**

	Distance unit	Doppler unit	Amplitude（dB）
Target1	200	-150	-25
Target2	100	100	-20
Multipath 1	550	0	-10
Multipath 2	450	0	8
Multipath 3	350	0	15
Multipath 4	250	0	20
Multipath 5	150	0	25
Multipath 6	55	0	28
Multipath 7	50	0	30
Direct signal	10	0	40
noise	\	\	0

Fig. 4. shows the target detection processed by Range Doppler in time domain after traditional ECA clutter cancellation with different cancellation order. It can be found from Fig. 4. that the traditional ECA algorithm is difficult to eliminate clutters in echo signal when the cancellation order is smaller than the multi-path range. In the simulation, when the cancellation order is less than 550 order, the multi-path clutter cannot be eliminated effectively. Multipath clutter with larger time delay will be left.

$$A_{thd} = \sum_{l=1}^{N} |G(l)| \Big/ N \times 100 \tag{30}$$

Fig. 5. is the simulation of multipath position which refer to (12). In Fig 5., comparing with Table 2, the multipath time delay can be estimated accurately expect Multipath1. It is because that the multipath amplitude is less than the noise energy, which means the multipath will be flooded by noise. Meanwhile, it can be seen from the figure that the pre-estimation of multipath delay in echo signal can be realized by the large-selected scheme. In this paper, the value of elimination threshold A_{thd} is as follows:

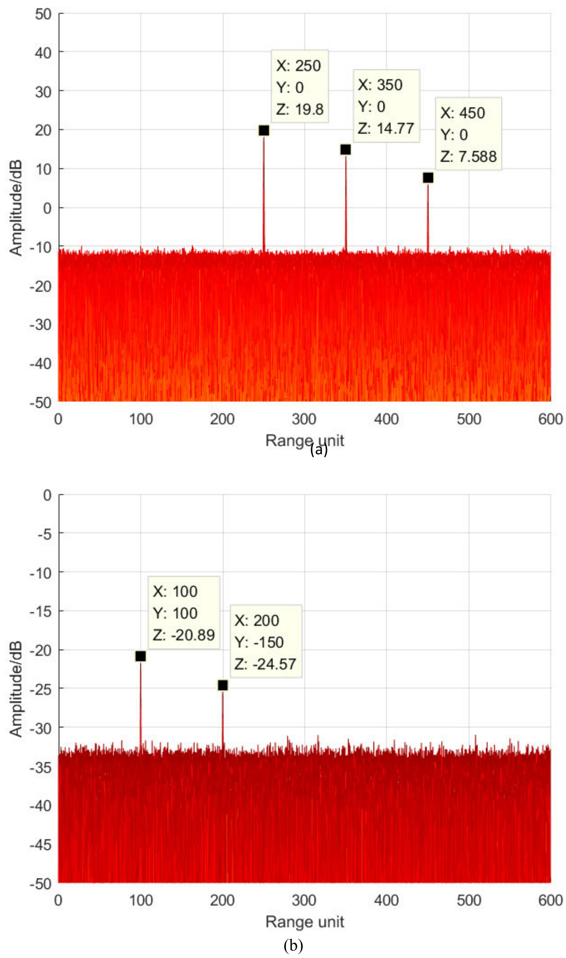

FIGURE 4. **ECA cancellation & Time domain Range-Doppler processin: (a) cancellation order is 200; (b) cancellation order is 550.**

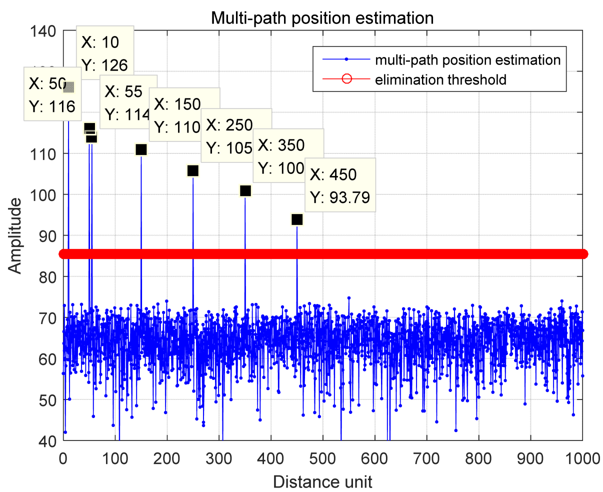

FIGURE 5. **Multipath delay estimation.**

However, it can be found from Fig. 6. that there will be a certain echo residual in cancellation due to the multi-path amplitude estimation error in this algorithm, and there will be more false peaks when the time domain Range Doppler processing is used, which will affect the accuracy of target detection.

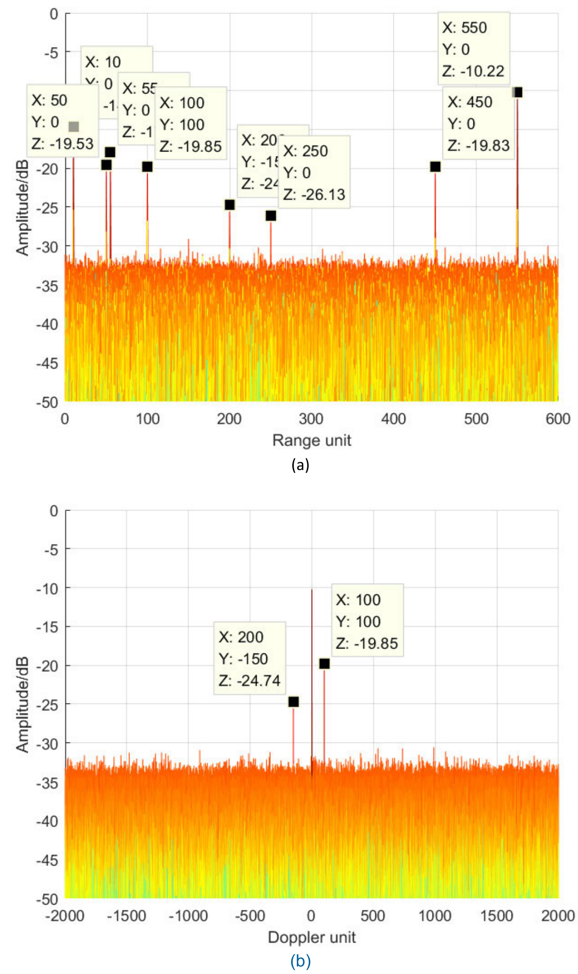

FIGURE 6. **FDACA cancellation & Time domain Range-Doppler processin: (a) Range dimension; (b) Doppler dimension.**

In order to solve the above problems, after the multi-path cancellation processing of frequency domain analysis, the target detection is realized by using frequency domain Range Doppler processing. The simulation results are shown in Fig. 7. Since the Doppler of the echo residual signal is 0, the influence of echo residual on target detection is suppressed after frequency domain Range Doppler processing. In addition, the Doppler transform of signal has been realized in the elimination process, so the calculation quantity is consistent with the traditional time domain Distance Doppler processing scheme.

B. PROCESSING OF REAL DATA

The real data is the audio signal part of the digital television signal, the center frequency of the signal is $74MHz$, the accumulation time of the audio signal is $1s$, and the corresponding data length is 20000.

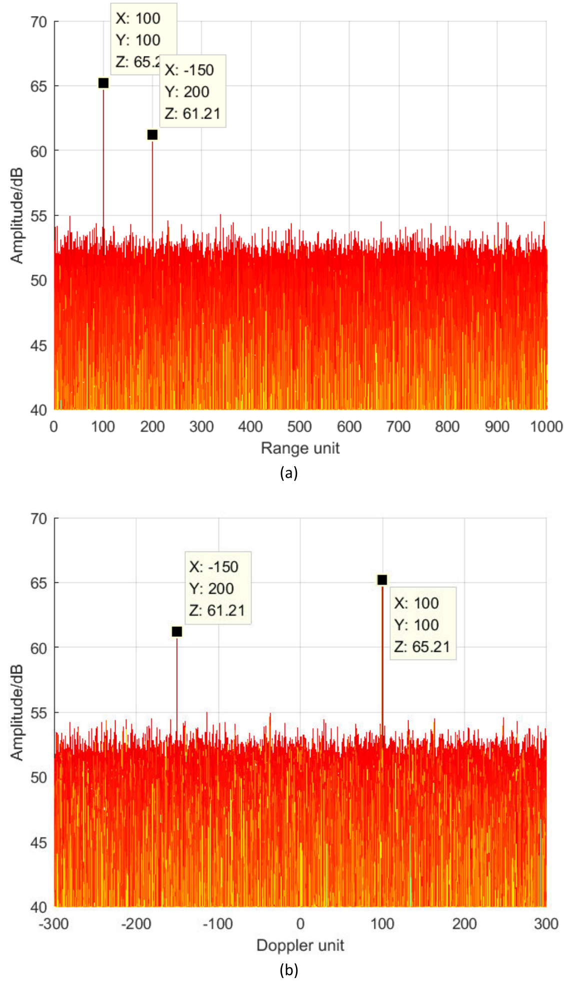

FIGURE 7. FDACA cancellation & Frequency domain Range-Doppler processing: (a) Range dimension; (b) Doppler dimension.

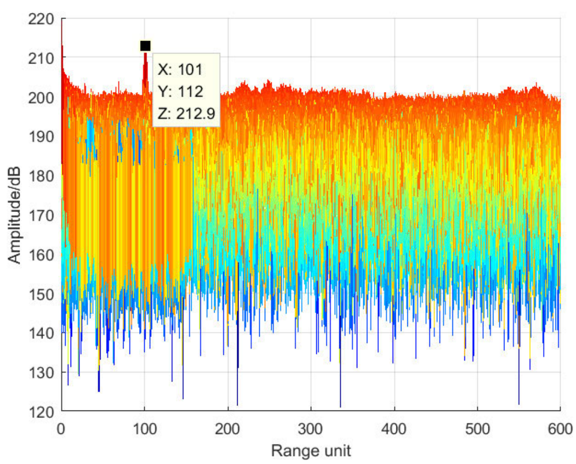

FIGURE 8. ECA Cancellation & Time domain Range Doppler processing (cancellation order 400).

From Fig 8. and Fig 9., both algorithms can realized accurately target detection. It can be seen from Fig. 8. that after 400 orders cancellation, there is a large near-region multipath echo residual for the Doppler shift of some multipath in the near part being not 0. Fig. 9. shows that the performance of the proposed algorithm is basically same as that of the traditional target detection algorithm. At the same time, the computational complexity of FDACA algorithm is much smaller than that of ECA algorithm.

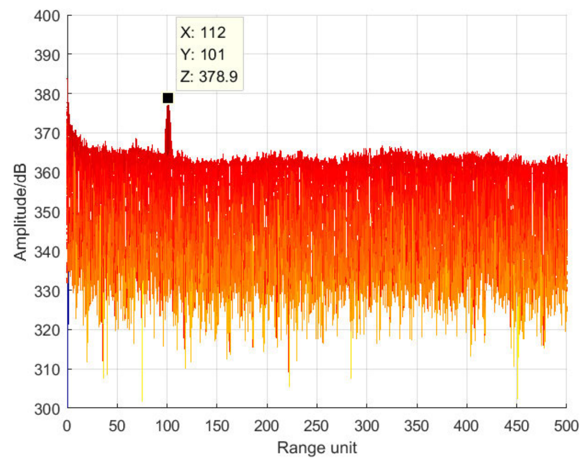

FIGURE 9. FDACA Cancellation & Frequency domain Range-Doppler processing.

C. CALCULATION ANALYSIS

The Table 3 is the operation time comparison between the FDACA algorithm and the ECA algorithm. The processor used in the simulation of Table 3 is Intel Core i5-6300HQ@2.30GHz. The simulation software is MATLAB 2015b. The parameters are set as shown in Table 2.

TABLE 3. Comparison of operation time.

	FDACA	ECA		
Cancellation order	\	20	200	600
Operation time(s)	0.0119	0.07958	0.30598	1.08057
Cancellation ratio(dB)	40.1627	7.6359	19.4467	40.4265

From Table 3, the operation time of this algorithm is much smaller than that of ECA algorithm, and it is more suitable for real time processing of radar signals. At the same time, the cancellation ratio of FDACA algorithm is slightly lower than that of higher order ECA algorithm, but operation time is the far less than that of the ECA algorithm.

V. CONCLUSION

In this paper, a new clutter cancellation algorithm based on frequency domain analysis is proposed, and the frequency domain Range Doppler algorithm is adopted. In this paper, the reference signal and echo signal were analyzed in freqency domain for removing the phase of signal itself. Then the multipath delay and multipath amplitude can be estimated by inverse Fourier tansform which can be used to eliminate the clutter. After that, in view of the problem that there is still some residual clutter in the residual echo, frequency domain Range Doppler algorithm is adopted in this paper. The residual clutter can be suppressed for its Doppler shift being zero. The simulation result shows that the proposed algorithm can realized the same performance with ECA algorithm. Meanwhile, the FDACA algorithm can greatly simplifies the computational complexity of clutter cancellation and can suppress partial false targets caused by clutter residue.

In this paper, the result of real data also supports FDACA algorithm. Compared with the traditional algorithm such as ECA, this algorithm has better real time performance and can achieve consistent target estimation performance. However, it can be found from the formula deduction that the algorithm in this paper is greatly affected by noise, and the estimation performance needs to be improved at low SNR.

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DAWEI ZHAO was born in Shandong, China, in August 1990. He received the bachelor's degree in electronic information engineering from the Xi'an University of Posts and Telecommunications, in 2012, and the master's degree in electronic information engineering from the Tianjin University of Technology, in July 2017. He is currently pursuing the Ph.D. degree with the National Laboratory of Radar Signal Processing, Xidian University. His research interests include array signal processing and adaptive signal processing and their application in passive bistatic radar.

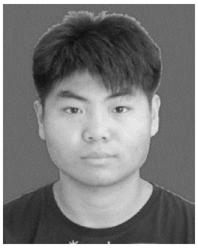
JUN WANG was born in Guizhou, China, in August 1969. He received the B.S. degree in measurement engineering and the M.S. and Ph.D. degrees in signal and information processing from Xidian University, in 1990, 1995, and 2000, respectively.

From 1990 to 1992, he was a Research Assistant with the Department of Measurement Engineering and Instrument, Xidian University. He joined the National Laboratory of Radar Signal Processing, Xidian University, in 1995, where he was a Lecturer, from 1996 to 2000, and an Associated Professor, from 2000 to 2004. Since 2004, he has been a Professor with the National Laboratory of Radar Signal Processing. His current research interests include passive coherent detection and location, radar imaging, and weak signal detection. He is a Senior Member of the Chinese Institute of Electronics. He serves as a Reviewer for the *IET Radar, Sonar & Navigation, Electronics Letters*, the *Journal of Systems Engineering and Electronics*, and other international technical journals.

GANG CHEN was born in Xi'an, China, in January 1992. He received the B.S. degree in electronic and information engineering from Xidian University, in 2014, where he is currently pursuing the Ph.D. degree with the National Laboratory of Radar Signal Processing.

His research interests include array signal processing and adaptive signal processing and their application in passive bistatic radar. He serves as a Reviewer for the *IET Radar, Sonar & Navigation*, the *IET Electronics Letters*, and the IEEE Radar Conference.

JIPENG WANG was born in Nei Mongol, China, in September 1992. He received the B.S. degree in electronic engineering from Xidian University, in 2014, where he is currently pursuing the Ph.D. degree with the National Laboratory of Radar Signal Processing. His research interest includes clutter suppression methods in airborne passive bistatic radar.



SHUAI GUO received the B.S. degree in electronic engineering from Xidian University, Xi'an, China, in 2014, where he is currently pursuing the Ph.D. degree with the National Laboratory of Radar Signal Processing.

His research interests include area of signal processing, including blind source separation processing, blind equalization processing, passive bistatic radar signal processing, and space-time adaptive processing.