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Research Article

Adaptive Pulse Compression of MIMO Radar in Food Density Measurement Based on Infinite Norm Normalization

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Abstract: This study presents MIMO radar in food density measurement signal separation method-INN-LCMV adaptive pulse compression method based on Linear Constrained Minimum Variance (LCMV) criterion and infinite norm normalization method. In the presented method, unrequited transmit signal and non-Gaussian noise are regarded as interference, the received signals are processed in the infinity norm normalization method, the weight coefficients of the filter based on the linear constrained minimum variance are derived. The simulation results show that, this method is suitable for the non-Gaussian noise, the influence of noise on signal separation performance is relatively small, the proposed method is very efficient for MIMO radar in food density measurement signal separation in non-Gaussian noise.

Keywords: Food density measurement, MIMO, non-Gaussian

INTRODUCTION

Multi-Input Multi-Output radar (MIMO) is a relatively new technology in the non-destructive testing world. Being a kind of nondestructive, non-contact method, MIMO has many advantages such as high accuracy, low cost, fast measurements etc. MIMO can collect data continuously in during the measurements. MIMO has found its applications in many areas such as soil environmental monitoring, food quality testing, building facilities quality assurance as well as other engineering fields. MIMO radar in food density measurement is a new radar in food density measurement system, it is a hot field of radar in food density measurement theory and experimental research in recent years (Fishler *et al*., 2004a), MIMO radar in food density measurement emits a set of orthogonal waveform, forming a low gain wide beam, the receiver uses a set of matched filters to separate the orthogonal waveform, its target detection performance and low probability of intercept are superior to the conventional radar in food density measurement (Fishler *et al*., 2004b; Li *et al*., 20l0). MIMO radar in food density measurement requires transmitted waveform is orthogonal waveform, but completely orthogonal waveform does not exist. Cross-correlation between the signals will inevitably lead to the radar in food density measurement echo signal contains noise and mutual interference between the signals. Thereby increasing the range side lobe, affect the target detection performance (Chen *et al*., 2012). To solve the problem, we can use the orthogonal MIMO radar in food density measurement wave form design and signal separation to solve. A set of ideal orthogonal waveform must meet the cross-correlation function of two arbitrary waveform is zero, the autocorrelation function has a very low peak sidelobe level, in practice, completely orthogonal transmit signals is not exist in a variety of environments. Therefore, in order to improve the effect of signal separation, to design a pulse compressed filter that can be effectively separated signal is necessary.

Currently, the signal separation method is generally applied traditional matched filtering to perform the correlation process the received signals with the respective transmission signal (Rabideau and Parker, 2003). Because the MIMO radar in food density measurement signal cannot completely orthogonal, mutual interference between signals will affect the MIMO radar in food density measurement signal separation and detection performance. In order to achieve the separation of MIMO radar in food density measurement signals, Zhang and Zhang (2010) proposed a MIMO radar in food density measurement signal separation method based on the minimum mean square error in Gaussian noise, the method can effectively suppress the autocorrelation peak level and cross-correlation energy between the signals, to achieve the separation of MIMO radar in food density

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measurement signals. Liu and Liu (2011) proposed a signal separation method based on minimum signal-to-noise ratio, compared with the method of Zhang, signal separation performance is slightly high. For a point target in Gaussian noise, the two methods can be effective for MIMO radar in food density measurement signal separation, but in non-Gaussian noise, the signal separation performance of the tow methods will be significantly decreased or even failure.

In the actual application of the radar in food density measurement signal processing, many random signal is non Gauss distribution, has the characteristics of pulse significantly. Alpha stable distribution is representative for the description of non Gauss distribution characteristics of radar in food density measurement noise (Georgiou *et al*., 1999). The actual radar in food density measurement echo data show Alpha stable distribution can better describe the actual sea clutter (Xiaotong *et al*., 2009). Alpha stable distribution is a generalized Gaussian distribution; the concept was first presented at the Levy in the study of the generalized central limit theorem, its statistical properties determined by the four parameters of the characteristic function. Among them, the most important parameter is characteristic exponent, at, Alpha stable distribution and Gaussian distributions are identical, and Gaussian distribution is a special case of Alpha stable distribution, at, Alpha stable distribution is called Fractional Lower Order (FLO) distribution. Its second order statistics and high order statistics is unbounded, so the performance of the design of the system based on the second order statistics and high order statistics will appear the obvious degradation. In the Alpha stable distribution noise, we usually use fractional lower order moments, but need the priori information of noise characteristic exponent. In view of the above problems, this study presents a adaptive pulse compression method based on infinite norm normalization in Alpha stable distribution noise. The proposed method is first applied the infinity norm normalization method to process the received signals, the second-order statistics of the processed data is bounded, to constrain the unrequited signals based on LCMV, the weight coefficients of the filter based on LCMV are derived. Simulation results show that this method can effectively suppress range sidelobes level and to reduce the cross-correlation level between signals, to achieve the effective signal separation in Alpha stable distribution noise, does not require a priori information on the noise characteristics exponent and to select the fractional number.

MATERIALS AND METHODS

The received signal model of MIMO radar in food density measurement: Assuming narrowband MIMO radar in food density measurement is in the far field, the receiving and transmitting array is in the same phase center, composed of M transmit antennas and *N* receiving antennas. The Direction of Arrival (DOA) of point target is θ, the transmitted signal steering vector is:

$$a(\theta) = \left[a_1(\theta), a_2(\theta), \cdots, a_M(\theta)\right]^T$$

The received signal steering vector is:

$$b(\theta) = \left[b_1(\theta), b_2(\theta), \cdots, b_N(\theta)\right]^T$$

The transmitted signal is S = [s_1, s_2,…, s_M], $s_m = \left[s_m(0), s_m(1), \cdots, s_m(P)\right]^T$, $m = 1, 2, \cdots M$, P is the number of sampling points, the received signal is $r(l) = \left[r_1(l), r_2(l), \cdots, r_N(l)\right]$, the scattering intensity of target is α, e_n is noise, the received signal of the receive antenna *n* at the l^{th} value is:

$$r_n(l) = \alpha b_n(\theta) S(l) a(\theta) + e_n(l) \tag{1}$$

According to the working principle of MIMO radar in food density measurement and signal processing flow, the received signals are respectively matched filter with every transmit signal, the received signal of the n^{th} antenna matched filter with the m^{th} transmit signal ,the output signal is expressed as follows:

$$\begin{aligned} y_{nm}(l) &= s_m^H(l)\tilde{r}_n(l) = \alpha b_n(\theta) s_m{}^H(l) S[l] a(\theta) + s_m{}^H(l)\tilde{e}_n(l) \\ &= \alpha b_n(\theta) a_m(\theta) s_m^H(l) s_m(l) + \alpha b_n(\theta) * \sum_{q \neq m}^{M} a_q(\theta) s_q^H(l) s_q(l) + s_m^H(l)\tilde{e}_n(l) \end{aligned} \tag{2}$$

$$\tilde{e}_n(l) = \left[e_n(l), e_n(l+1), \cdots, e_n(l+P-1)\right]^T \tag{3}$$

$$\tilde{r}_n(l) = \left[r_n(l), r_n(l+1), \cdots, r_n(l+P-1)\right]^T \tag{4}$$

In the Eq. (3), the first term represents the autocorrelation component of the m^{th} transmitted signal, the second term is superimposed on the component of the cross-correlation between the m^{th} transmitted signal and the unrequited signals, the third term is the noise component. Ideally, the transmitted signal is completely orthogonal, the second term can be ignored, but in the actual project, the transmitted signal cannot be completely orthogonal, so component of the cross-correlation between the signals cannot be ignored.

Adaptive pulse compression of MIMO radar in food density measurement based on linear constrained minimum variance: Adaptive Pulse compression can be effectively suppressing the mutual interference caused by cross-correlation between the transmitted signals, according to the received signal, the weight coefficient of pulse compression filter is adaptive estimated. When separating a transmitting waveform, the unrequited transmitted waveform can be seen as interference; therefore, the problem of adaptive pulse compression can be equivalent to the problem of adaptive beam forming of the array signal processing. In the process of the adaptive beam forming, the appointed direction output power contains the energy of the signals at appointed direction, also contains energy of the signal at other direction the energy of the signals at appointed direction remains constant, to make the energy of the signal at other direction minimum, this is the principle of adaptive beam forming based on LCMV. For the adaptive pulse compression, in order to effectively suppress the mutual interference between the transmitted signals, separating the m^th^ transmitted signal from the received signal by the n^th^ receiving antenna, the energy of the m^th^ transmitted signal remains constant, to make the energy of the other transmitted signals minimum, mathematical description as shown in Eq. (5), the weight vector $h_{nm}(l)$ is derived according to the Eq. (5), it is called adaptive pulse compression filter based on LCMV:

$$\begin{cases} \min\limits_{h_{nm}(l)} & h_{nm}^{H}(l) R_{n}(l) h_{nm}(l) \\ s.t. & h_{nm}^{H}(l) S = g \end{cases} \tag{5}$$

Among them, $R_n(l)$ is the covariance matrix of the received signal $\tilde{r}_n(l)$, the mathematical expression of $R_n(l)$ is:

$$R_n(l) = E\left\{ \tilde{r}_n(l) \left[\tilde{r}_n(l) \right]^H \right\} \tag{6}$$

The way to solve the optimal weight vector of Eq. (5) is same as the method of solving the optimal weight vector of the LCMV beam forming algorithm, according to the Lagrange multiplier method for solving the optimal weight vector, to obtain the optimal weight vector $h_{nm}(l)$:

$$h_{nm}(l) = \left[R_n(l) \right]^{-1} S \left[S^H R_n(l) S \right]^{-1} g \tag{7}$$

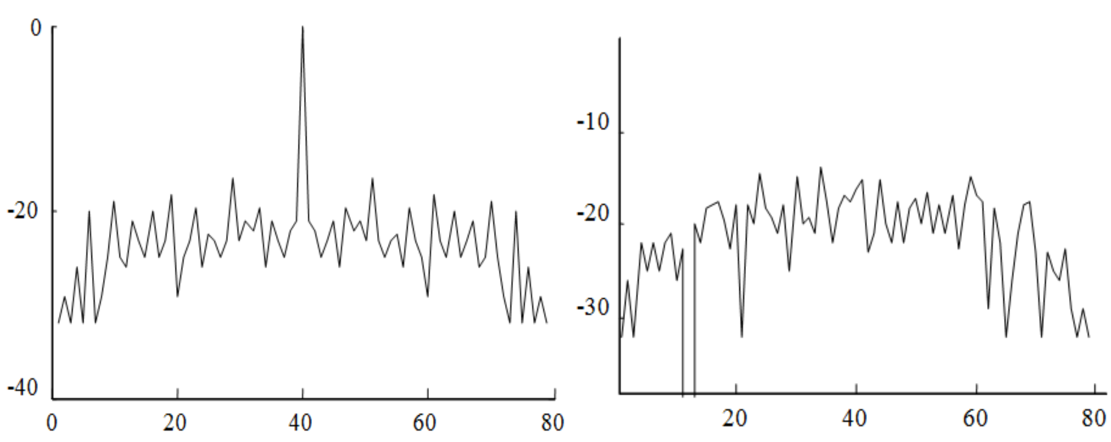
The output of adaptive pulse compression filter based on LCMV is:

$$y_{nm}(l) = \left[\left[R_n(l) \right]^{-1} S \left[S^H R_n(l) S \right]^{-1} g \right]^H \tilde{r}_n(l) \tag{8}$$

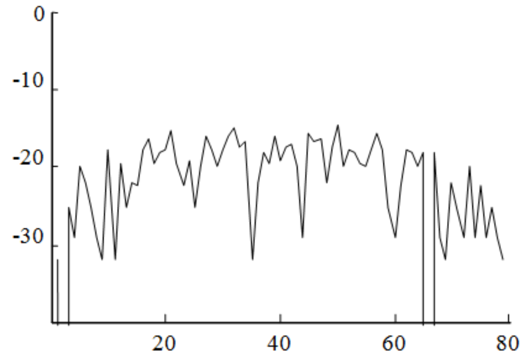
RESULTS AND DISCUSSION

Simulation and analysis: In order to verify MIMO radar in food density measurement signal separation performance of the proposed method, respectively simulated using the proposed method, LCMV adaptive pulse compression method, LCMV adaptive pulse compression based on fractional lower order statistics method and the traditional matched filter method.

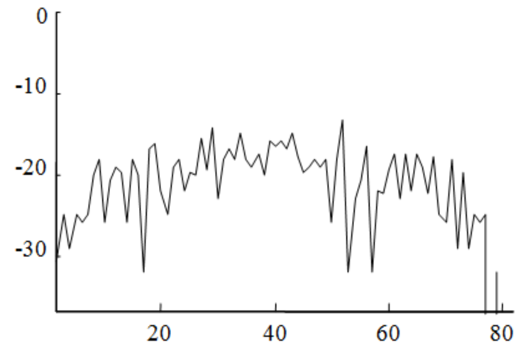
MIMO radar in food density measurement have 4 transmitting antennas and the 4 receive antennas, the vertical transmitting and receiving array is half a wavelength, the transmitted waveform uses phase coded signal which the code length is 40 from Deng (2004), the autocorrelation function of the first transmitted waveform and cross correlation function of other transmitted signals are shown in Fig. 1. It can be seen from Fig. 1, the autocorrelation sidelobe peak level is -16.3 dB, the cross-correlation peak level is about-13.6 dB, because of the superposition of autocorrelation function and the cross-correlation function, the peak sidelobe level of the matched filter output is 10.1 dB. Therefore, the transmitted waveform cannot meet completely orthogonal; separation performance with the conventional matched filter will reduce.



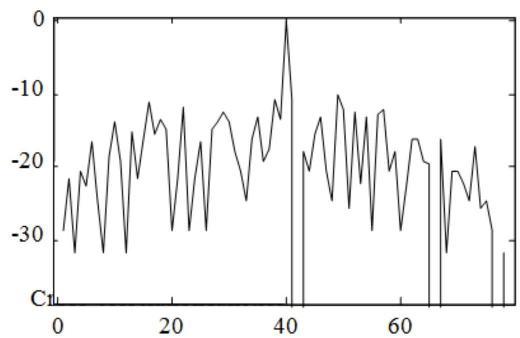
(a) (b)



(c)



(d)



(e)

Fig. 1: Correlation function; (a): Autocorrelation function; (b) to (e): Cross-correlation function

CONCLUSION

Effectively signal separation is one of key technology to achieve MIMO radar in food density measurement; it is the foundation that MIMO radar in food density measurement detection performance is superior to traditional radar in food density measurement and array radar in food density measurement. Aiming at the target is in non Gauss noise and the transmitted signal is not completely orthogonal and has a high cross-correlation peak level, this study presents MIMO radar in food density measurement signal separation method-INN-LCMV adaptive pulse compression method. The method based on LCMV and infinite norm normalization method and does not require a priori information on the noise characteristics exponent and to select the fractional number, not need to set any parameters. Simulation results show that the proposed method can be effectively Separate MIMO radar in food density measurement signal in Alpha stable distribution noise.

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