Range resolution improvement for two close targets by using the FM signals

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In this paper, we have focused on the improvement of the range resolution of two close targets by using FM signal. Two algorithms comprise IFFT and MUSIC have been used to reach our goals. On both algorithms, we have tried to improve the range resolution by using more FM channels. The simulation results show that the music method by using the same FM channel gives us a good range resolution twice as well as IFFT method.

Introduction: Echoes that are usually received from antennas will be amplified, and after that, their frequency will suppress. Afterward, it passes from a threshold comparator circuit in which the signal envelope extraction is done. The signal’s envelope is proportional to power received reflections [1], [2].

The Range resolution of two targets in constant false alarm radar systems is inversely proportional to the transmitted signal bandwidth [3], [4]. According to this, the range resolution of close targets could be improved by increasing modulation bandwidth in FM broadcasting radar systems [5-7].

The modulation bandwidth could be increased by using more FM channels in FM broadcasting systems. A maximum bandwidth of 20 MHz could be employed in the spectrum of FM broadcasting radio which occupies the frequency band of 88 to 108 MHz [4].

In this paper, three states of one, three and seven FM channel broadcasting, has been investigated. Each of these states examined by two detections methods including inverse Fourier transforms (IFFT) and multiple signal classification (MUSIC) algorithm.

Two targets with the distance of 3 km from each other has been detected easily by IFFT detection method while in this case the two targets at a distance of 2 km detected easily by applying MUSIC detection method. With the same procedure, the IFFT method applied to 3 and 7 FM channel signal for detecting two targets at a distance of 2 and 1 km, respectively. In such a case, the ever employing MUSIC method the range resolution is improved about 1 km, that means For 3 and 7 FM channels signal the two targets has been detected easily with a distance of 1 km and 300m, respectively. Within these results, the MUSIC method compared to IFFT method in the corresponding state of occupied FM channels, improved the range resolution about 1 km. Comparatively, the range resolution of two close targets by applying MUSIC algorithm is twice as good as IFFT method.

In the section 2 the detection based on IFFT is reviewed then the multiple signal classification algorithm has discussed in chapter 3. The simulation results are depicted in chapter 4 and finally conclusions are described in chapter 5.

Detection based on IFFT: To detect targets, the received signal is first transmitted to the receiver and then its frequency would suppress to intermediate frequency (IF) in mixer. After that the signal passes through analog-to-digital converter (ADC) to be processed as a digital signal. Fig. 1 shows the detector's block diagram based on the direct signal and the signal received from the receiver’s antenna which is depicted in detail in Fig. 2.

In (1) and (2), A and A_r are the amplitude of the direct signal and received target signal, respectively. f_c is the carrier frequency and f_d is the maximum frequency deviation. x_m(λ) is the direct message signal. According to detection algorithm the antenna’s received signal should pass from RF receivers and enters the mixer block. After sampling and mitigating its frequency by DDC block, its FFT would calculated by

\[ S_r(f) = \int_{-\infty}^{\infty} s_r(t') \exp(-j2\pi ft') dt' \]

\[ = A_r \int_{-\infty}^{\infty} \exp \left( j2\pi (f_c - f) t' - f_c t_0 \right) \]

\[ + f_d \int_{0}^{t_0} x_m(\lambda) d\lambda \] \[ dt' \]

Also these procedures are performed on direct message signal:

\[ S(f) = \int_{-\infty}^{\infty} s(t') \exp(-j2\pi ft') dt' \]

\[ = A \int_{-\infty}^{\infty} \exp \left( j2\pi (f_c - f) t' \right) \]

\[ + f_d \int_{0}^{t_0} x_m(\lambda) d\lambda \] \[ dt' \]
Then division operation which is shown in Fig. 2 should be performed.

\[ D(f) = \frac{S(f)}{I(f)} \]  

(5)

Crossing \( D(f) \) from band-pass filter and calculating its IFFT and probing its maximum points, would obtained the range resolution of targets finally.

**Detection basis on MUSIC algorithm:** Multiple signal classification algorithm is one of the newest algorithm of detecting the direction of targets with a high range resolution [8], [9]. Consider \( x[n] \) as desired signal.

\[ x[n] = a_0 e^{j \omega_0 n} + a_1 e^{j \omega_1 n} + w[n] \quad n = 0, 1, \ldots, N - 1 \]  

(6)

where \( a_0 \) and \( a_1 \) are signal's attenuation coefficient and \( \omega_0 \) and \( \omega_1 \) are angular frequency of signal. \( w[n] \) is additive Gaussian White Noise signal with average of zero and variance of \( \sigma^2 \).

define \( \mathbf{x} \) as:

\[ \mathbf{x} = \begin{bmatrix} x[0] \\ x[1] \\ \vdots \\ x[N-1] \end{bmatrix} \]  

(7)

if \( \mathbf{a} \) and \( \mathbf{w} \) define as follows, by substituting these into \( \mathbf{x} \) obtained.

\[ \mathbf{s} = \begin{bmatrix} 1 \\ e^{j \omega_0} \\ \vdots \\ e^{j \omega_0(N-1)} \\ 1 \\ e^{j \omega_1} \\ \vdots \\ e^{j \omega_1(N-1)} \end{bmatrix} \]  

(8)

\[ \mathbf{a} = \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \]  

(9)

\[ \mathbf{w} = \begin{bmatrix} w[0] \\ \vdots \\ w[N-1] \end{bmatrix} \]  

(10)

\[ \mathbf{x} = \mathbf{s} \mathbf{a} + \mathbf{w} \]  

(11)

Now the cross correlation function of \( x[n] \) is calculate

\[ R = E[\mathbf{x} \mathbf{x}^*] = E[(\mathbf{s} \mathbf{a} + \mathbf{w})(\mathbf{a}^* \mathbf{s}^* + \mathbf{w}^*)] = \mathbf{R}_s + \sigma^2 \mathbf{I}_n \]  

(12)

Where \( \mathbf{I}_n \) is the unity (identity) matrix and \( \mathbf{R}_s \) is equal to \( \mathbf{s} \mathbf{a} \mathbf{a}^* \mathbf{s}^* \).

Therefore the order of \( \mathbf{R}_s \) matrix is equal to 2 while it has 2 independent column, based on these assumptions \( \mathbf{R}_s \) matrix has two non-zero values of \( \lambda_0, \lambda_1 \) and its rest eigenvalues are zero.

\( \mathbf{R} \) matrix has two eigen values as \( \lambda_0 + \sigma \) and \( \lambda_1 + \sigma \) and its rest values are equal to \( \sigma \). With the assumption of \( q_0, q_1, q_2, \ldots, q_{n-1} \) as the eigen vectors of \( \mathbf{R} \) matrix, the vectors from \( q_0 \) to \( q_{n-1} \) are the former of the noise subspace. Assume vector \( \mathbf{g}(\omega) \) as:

\[ \mathbf{g}(\omega) = \begin{bmatrix} 1 \\ e^{j \omega} \\ \vdots \\ e^{j \omega(N-1)} \end{bmatrix} \]  

(13)

Whereas signal and noise are orthogonal vectors, therefore \( \mathbf{g}(\omega) \) and vectors from \( q_0 \) to \( q_{n-1} \) have to reaches their minimum values for the angular frequency estimation. So \( P_{\text{MUSIC}}(\omega) \) is defined as

\[ P_{\text{MUSIC}}(\omega) = \frac{1}{\sum_{m=0}^{N-1} |\mathbf{g}(\omega)q_m|^2} \]  

(14)

The maximum points in \( P_{\text{MUSIC}} \) are the desired points which their corresponding delay could be calculated by mathematical equations. Fig. 3 is truly the same as Fig. 2 that is designed by MUSIC algorithm. In this method, the direct message signal and the signal which received from antennas are sampled then their digital frequency will suppressed by DDC. Afterward, FFT and division operation calculated and then the signals cross through a band-pass filter. So far, the procedures of IFFT and MUSIC algorithms are the same. After that, by using MUSIC algorithm instead of IFFT, the target's delay is estimated. The results demonstrate the high range resolution of this method and its capability of close targets detection.
The real part of the signal's IF\textsubscript{T} which is passed from the band-pass filter for two targets with 2km distance.

Delay time estimation of two targets with the distance of 1km by applying MUSIC algorithm with one channel FM.

The real part of the signal's IF\textsubscript{T} which is passed from the band-pass filter for two targets with 1km distance.

Delay time estimation of two targets with the distance of 300m by applying MUSIC algorithm with one channel FM.

With the ever increasing in occupied FM channel, the range resolution of two targets improves. The obtained range resolution in MUSIC algorithm is twice as well as IFFT method. The comparison of range resolution between IFFT and MUSIC methods is depicted briefly in Table 1.

| Number of channels | IFFT | MUSIC | Improvement percentage |
|--------------------|------|-------|------------------------|
| 1                  | 3 km | 2 km  | 150 %                  |
| 3                  | 2 km | 1 km  | 200 %                  |
| 7                  | 1 km | 300 m | 300 %                  |

Error percentage of IFFT and MUSIC methods.

Conclusion: In this paper the range resolution of two close targets is proposed by applying MUSIC and IFFT algorithms. In these methods, more FM channels have been occupied by transmitted signal to increase the bandwidth. Simulation results verified that the accuracy of the range resolution increased by using more FM channels and the close targets detects perfectly. The improvement of range resolution by using the same number of FM channel in MUSIC method is twice as good as IFFT but its Error is a little more than IFFT.

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