# A Frequency Selection Method Based on Fusion Algorithm in Bistatic HFSWR

Chen Weiwei, Yu Changjun, Chen Wentao
School of Information and Electrical Engineering
Harbin Institute of Technology at Weihai
Weihai, China
chenweiwei0320@126.com

***Abstract*-T/R-R High Frequency Surface Wave Radar can detect targets over the horizon. There is a large difference in working environment between stationary station and mobile station. The traditional frequency selection methods are hard to choose the best operating frequency for the T/R-R High Frequency Surface Wave Radar(HFSWR), and this flaw seriously affects detection performance and target positioning accuracy of the radar. This paper adopts the weighted fusion algorithm based on Kalman filter to fuse the spectrum information of the T/R-R bistatic radar in the electromagnetic environment, and selects the optimal working frequency band by average power and variance combination minimum, then finds the best operating frequency based on maximum signal-to-noise ratio(SNR) criterion of the target. Simulation results demonstrate the effectiveness of the adopted frequency method.**

## I. INTRODUCTION

High Frequency Surface Wave Radar(HFSWR) transmits vertical polarization electromagnetic wave to detect and track maritime targets over the horizon [1][2][3]. HFSWR usually works in the short-wave band. As a result, there are a lot of interferences in this band. A lot of attentions have been attracted on the operating frequency selection of HFSWR [4][5]. For example, [6] established real-time frequency selection adaptive communication system for high frequency OTHR frequency selection. [7] analyzed the communication station frequency occupancy, and presented that ground wave OTH radar should adopt adaptive frequency conversion technology against radio interference. However, these methods only provides reference for the frequency selection of bistatic radar [8]. In addition, the traditional frequency selection methods of bistatic radar select suitable frequency by artificial methods. Although these methods are simple and easy to operate, the frequency selected is not the best operating frequency for the T/R-R bistatic HFSWR with two stations, As a result, the bistatic HFSWR could not work in the best performance, and even affects the quality of target detection and tracking.

In this paper, A novel method is proposed to select the best operating frequency of T/R-R HFSWR by data fusion [9][10][11]. The core idea of this method is that it combines and fuses the external electromagnetic spectrum information of T/R and R stations, then selects the best operating frequency. This method makes full use of the redundant information of each sensors in space and time according to some optimization criterion. Kalman filter weighted fusion algorithm incorporates and fuses the external electromagnetic spectrum information [12][13] to get the optimal working frequency of bistatic radar. First, the silence working channel is confirmed based on average power and variance combination minimum. Secondly, the best operating frequency is determined based on maximum signal-to-noise ratio (MSNR) criterion of the target.

The rest of this paper is organized as follows. Section II describes the weighted fusion algorithm based on Kalman filter. The frequency selection principle and effect evaluation are presented in Section III. Conclusions are given in Section IV.

## II. WEIGHTED FUSION ALGORITHM BASED ON KALMAN FILTER

There are huge differences in the electromagnetic environment spectrum information between T/R and R stations. The spectrum information of two receivers should be fused with appropriate fusion model, so that a reliable operation frequency can be selected. The optimal spectrum band is selected with Kalman filter for each of the two receivers [14], respectively. The optimal operation frequency can be choosen with a weighted summation of the two optimal spectrum bands.

### *A. Algorithm Overview*

Kalman filter uses feedback control to achieve process estimation. The basic principle is to estimate the system state at certain time, and get feedback from the observed values (with noise).

So, the paper sees the external electromagnetic spectrum datas of T/R station and R station matriculated at Weihai as the measurement information that is $Z^k = \{Z(j): j = 1, 2, ..., k\}$, then we get the state estimation informations of the two stations by Kalman filter that is $\hat{X}(k+1/k+1)$.

Fusion block diagram is shown in Figure.1. We can get the state estimations by Kalman filter, then the information after fusion is

$$\hat{x} = \omega_1 \hat{X}_1(k+1/k+1) + \omega_2 \hat{X}_2(k+1/k+1) \quad (1)$$

where $\Omega = (\omega_1, \omega_2)$ ——the weighted of each sensor.

The paper selects the weighted by the optimal weighted that is because the weighted can correct those divergent estimated value or the large deviation estimated value.

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Weigthed fusion algorithm can make the mean-square error(MSE) minimum.

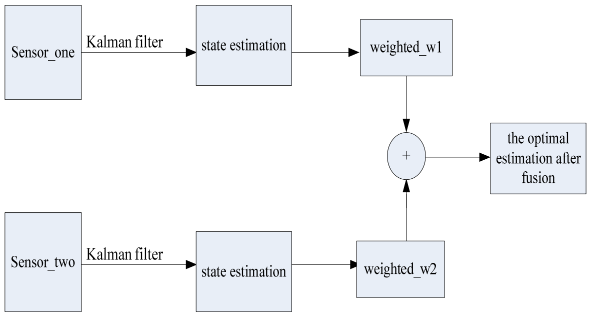


Figure.1 Fusion block diagram

So we can calculate the weighted by MSE, and the optimal weighted are

$$\omega_1^* = \frac{\sigma_2^2}{\sigma_2^2 + \sigma_1^2} \tag{2}$$

$$\omega_2^* = \frac{\sigma_1^2}{\sigma_2^2 + \sigma_1^2} \tag{3}$$

In the Kalman filter weighted fusion algorithm, we see the covariance estimates $\hat{P}(k/k)$ as the weighted factors .

## B. Simulataion Result

Spectrum data of T/R-R bistatic radar is matriculated in Weihai. The data is amplitude information of external electromagnetic spectrum and it can serve as the measurement information of Kalman filter. The measurement matrix is $H_1 = [1 \quad 0]$ , $H_2 = [0 \quad 1]$ , state-transition matrix is $\Phi = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$, controlling signal is $\Gamma = [0 \quad 0]^T$ . The initial value of state estimation is $x_0 = [0 \quad 0]^T$ , and the initial value of error covariance matrix is $P_0 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$, Fusion results are shown in Figure.2.

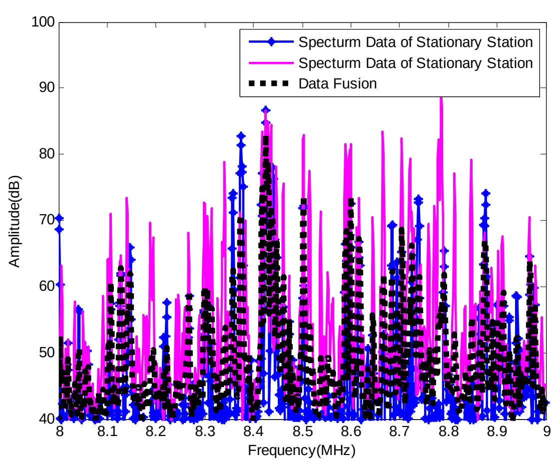


Figure.2 Data fusion results

# III. UNITS FREQUENCY SELECTION OF T/R-R HFSWR

## A. The Frequency Selection Principle based on Average Power and Variance Combination Minimum

Silent spectrum band is essential for power performance of T/R-R HFSWR. Sliding window method is the prevailing method to confirm the location of the favor band. Specific frequency selection programs are divided into the following steps.

Step 1 Choose sliding window of smallest average power according to the fused spectrum information and the initial frequency of the window are confirmed. The method of average power is defined as

$$Averagepower = \frac{\sum_i power(i)}{length(Slidewinwidth)} \tag{4}$$

The width of the sliding window is denoted as $Slidewinwidth$ .

Step 2 Calculate the noise threshold of spectrum information:

$$Threshold = noisefloor + constant \tag{5}$$

It means that the higher the threshold, the longer the silence time of the band. Therefore, the constant is selected to be 4.7dB, and the noise floor is computed by the minimum average power.

Step 3 In the selected sliding window, select three channels with minimum average power to be candidate bands, and compare their average power values with the Threshold:

If the average power of the three bands $Averagepoewr < Threshold$ , It means that three bands can be used theoretically. We can use variance to judge which is the best working band, and select the band with smallest variance to be the best band. The variance represents the degree of deviation average, and stands for stationarity of the band. It is defined as

$$Variance = \frac{\sum_i (a(i) - power(i))^2}{length(Slidewinwidth) - 1} \tag{6}$$

Other cases, the preferred band is determined by the minimum average power criterion.

## B. Simulation Results

(1) Silence sub-band duration comparison under different Threshold

Figure.3 shows that the silent time increases with the Threshold.

(2) The results of the frequency selection

The spectrum band we are interested is 8~9MHz, and Threshold=44.94.

TABLE I
SMILUTIONS

| *parameter* | *value* | | |
|---|---|---|---|
| Variance | 1.83 | 1.80 | 1.77 |
| Average power | 41.61 | 41.63 | 41.65 |

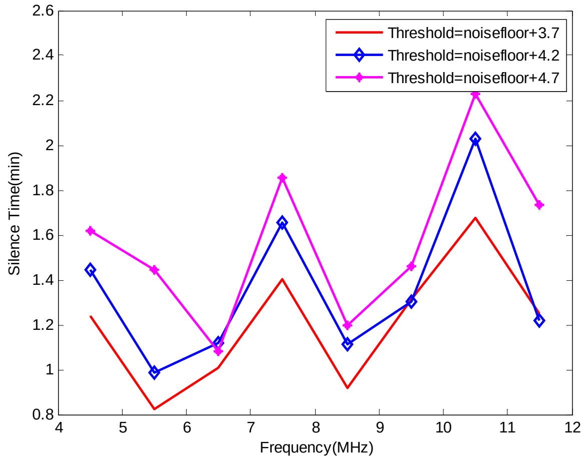


Figure.3 Silence subband duration under different threshold in 30kHz

From Table I, it shows that the averagepowers of the three candidate frequency bands are less than Threshold, So the optimal frequency band is determined by the variance. The results of the frequency selection are shown in Figure.4.

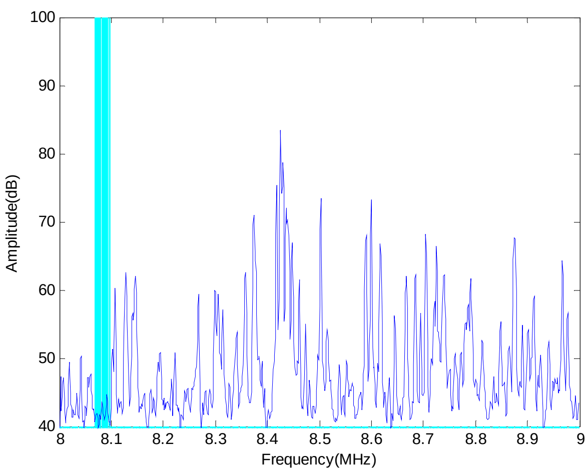


Figure.4 Fusion frequency selection results

From Figure.4, it demonstrates that the green belt is the optimal frequency band, but we still need to estimate this band by maximum signal-to-noise ratio (MSNR) criterion.

### C. *Frequency Selection Effect Evaluation*

The target detection performance is evaluated in T/R-R HFSWR, and atmospheric noise is defined as background noise. SNR is calculated as

$$SNR = \frac{P_r(f)}{P_0(f)} = \frac{P_r(f)}{KT_0F_a} \qquad (7)$$

where, $P_r = \dfrac{6.22\times10^{-38}E^2(R_t)E^2(R_r)P_tG_tG_r\lambda^2\sigma}{l}$

$P_r$ is radar echo power equation [15][16]. $P_0(f)$ is atmospheric noise power. $E(R_t)$ and $E(R_r)$ are electric field strength with range $R_t$ and $R_r$ in the smooth conductive sphere, respectively. Field strength value are calculated by GRWAVE program [17].

The simulation parameters are as follows:

Averagepower is 1kW, system loss is 6dB, equivalent bandwidth is 30kHz, radar cross section(RCS)is 40dB/m$^2$, and coherent integration time is 100s. The operating frequencies are 5、7.5、9、11 MHz respectively. The duty cycle is 0.1. Minimum signal detection SNR is 14dB (Detection probability is 90%, false alarm probability is $10^{-6}$). Radar transmits wide beam in fixed direction, 3dB width is 60 degrees, and the normal direction is north west 50 degrees. The number of the receivers is 8, and the distance of the element is 14.5 meters. whereas normal direction of stationary receiver array is north west of 50 degrees, the normal direction of mobile receiver array is north west of 50 degrees.

Simulation results are shown in Figure.5 and Figure.6. In Figure.5 and Figure.6, coordinates of the stationary stations are (250, 0), coordinates of the mobile stations are (0,100).

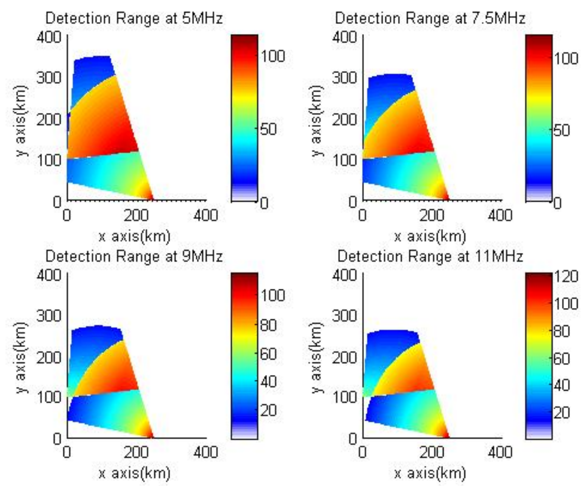


Figure.5 Maximum Detection Distance Criterion when the SNR threshold is given

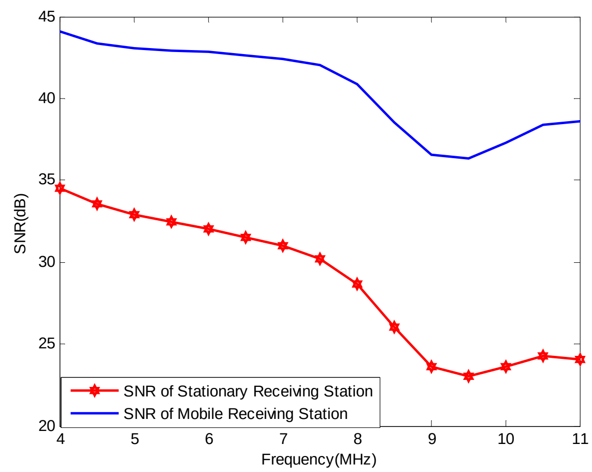


Figure.6 Maximum signal-to-noise ratio when target distance is given

From Figure.5, it demonstrates that the detection distance of stationary station and mobile station gradually reduces as the frequency increases, and the detected overlapping area of stationary and mobile stations are increasingly hardly.

Furthermore, detection distance of the T/R radar is increased. It demonstrates the superiority of the T/R-R radar. Under the view of maximum detection distance criterion with a given signal-to-noise ratio threshold, the lower operating frequency, the farther the detection range. If the study band can not reach the detection distance, study band shouled be reduced.

In Figure.6, coordinates of the target are (150, 190). SNR curves are presented at different frequencies of stationary and mobile stations in target location. Furthermore, the lower the frequency, the smaller the signal attenuation, and also the detection performance is improved.

## IV. CONCLUTION

(1) Simulation results show that the fusion algorithm can make full use of spectrum information of T/R and R statiions, and the band selected can make the bistatic HFSWR work worth preferable performance.

(2) The criterion of fusion frequency selection can be adjusted to meet the needs of practical application. We assess the effect of fusion frequency selection, and select the optimal operating frequency to match up the criterion. So, Maximum detection distance criterion when the SNR threshold is given is used to make the radar detect the farthest range and the maximum signal-to-noise ratio criterion when target distance is given is used to get the optimal effect of target detection and tracking in a given area.

## REFERENCES


[1] Wang W and Wyatt L R, "Radio frequency Interference Cancellation for Sea-state Remote Sensing by High-frequency Radar," *IET Radar, Sonar & Navigation*, vol. 5, no. 4, pp. 405-415, 2011.

[2] Maresca S, Greco M and Gini F et al, "The HF Surface Wave Radar WERA. Part I: Statistical Analysis of Recorded Data," *2010 IEEE Radar Conference*, 2010, pp. 826-831.

[3] Wyatt L R, Green J.J and Middleditch A et al, "Operational Wave, Current, and Wind Measurements with the Pisces HF Radar," IEEE Journal of Oceanic Engineering, vol. 31, no. 4, pp. 819-834, 2006.

[4] Su Hong-tao, Bao Zheng and Zhang Shou-hong, "OTHR Adaptive Selection of Operating Frequency Point," *Electronics & Information Technology*, vol. 27, no. 2, pp. 274-277, 2005.

[5] Lou Peng, Fan Jun-mei and Jiao Pei-nan et al, "The Operating Frequency Selection in HF Hybrid Sky-surface Wave System," *9th International Symposium on Antennas Propagation and EM Theory, 2010*, pp.513-516.

[6] Tian Jian-sheng and Wu Xiong-bin, "The Operating Frequency of the High-frequency Radar Online Real-time Optimal Choice," *Radar*, vol. 27, no. 7, pp. 8-10, 2005.

[7] Guan Rong-sheng, Xie Shu-Guo and Zhao Zheng-yu, "Ionosphere Return Oblique Detection Study 40 years in China," *Chinese Journal of Radio Science*, vol. 14, no. 4, pp. 479-484, 1999.

[8] Sun Xi-dong, "Ground Wave OTH Radar Anti-shortwave Radio Interference Study," *Aerospace Electronic Warfare*. no.5, pp. 56-58, 2004.

[9] Nichloas and J. Wills, "Bistatic Radar Technology Service Corporation. Silver Spring," *MI*. 1995, pp. 348-390.

[10] Chair Z and Varshney P. K, "Optimal Data Fusion in Multiple Sensor Detection System," *IEEE Trans. on AES*, vol. 22, pp. 98-101, 1986.

[11] Kang Yao-hong, "*Data Fusion Theory and Application*s," Xi 'an university of electronic science and technology press, 1997.

[12] J.Linas and E.Waltz, "Multisensor Data Fusion," *Artech House, Norwood, Massachusetts*, 1990.

[13] Deng Zi-li, "Information Fusion Filtering Theory and Application," Harbin: *Harbin Institute of Technology*, 2007.

[14] Quan Tai-fan, "*Information Fusion Theory and Application Based on NN-FR Technology*," Beijing, National Defense Industry Press, vol. 8, pp. 50-54, 2002.

[15] Liu Hai-bin and Gong Feng-xun, "An Improved Multi-sensor Weighted Fusion Algorithm," *The electronic products the world*, 2009, no.12.

[16] Xie Jun-hao, Li Bo and Chou Yong-bin et al, "The High-frequency Surface Wave Radar Ship Detection Range Analysis," *Radio Science*, vol. 25, no. 2, pp. 234-239, 2010.

[17] Zhou Wen-yu and Jiao Pei-nan, "Over-the-horizon Radar Technology," *Industry Press*, 2003, pp. 484-488.