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Estimation of Delay Profiles from FMCW Channel Data with In-band Interference using Eigenvector Method

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Abstract – The aim of this study is to reduce the effect of in-band interference in delay profiles estimated from frequency modulated continuous wave sounder channel data. In-band interference distorts the detector output signal, and increases the noise floor of delay profiles, which obscures weak multipath components. This study shows that the Eigenvector method can be used to improve estimates of delay profiles from FMCW channel data corrupted with in-band interference.

Keywords - *in-band interference, RF interference (RFI), Eigenvector method, frequency modulated continuous wave, Fast Fourier Transform (FFT), delay profile*

1. Introduction

Frequency modulated continuous wave (FMCW) systems have been used for various applications such as channel sounding [1] and automotive radar [2, 3]. This technique provides better resolution of position and enables low power transmission.

In-band interference, also known as radio frequency interference (RFI), is defined as an unwanted transmission operating in the same radio frequency band as the desired signal. Being within the band of the desired signal, the interfering signal is not suppressed by the front end filter of the receiver. In band interference distorts the detector output of the FMCW sounder. The interference manifests itself as abrupt fluctuations in time domain [4] and increased noise floors in Average Power Delay Profile (APDP) [5] and average Doppler profiles. This effect becomes more severe when power and/or bandwidth of the

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interfering signal increases and, if not mitigated, may result in loss of channel data. Attempts are therefore made to reduce the effect of interference.

Several methods have been proposed. The most common is to clip the amplitude of the corrupted section of data or to add zero data in place of the corrupted section [3, 6-7]. These methods are generally used whenever the bandwidth of the interference is narrower than the RF bandwidth. Other methods are to use Prony modelling [8] or to use subspace based methods [9].

Subspace methods (also known as high resolution methods [10] or Eigenvector methods [11]), are based on Eigen-decomposition of the autocorrelation matrix into signal subspace and noise subspace, and are used for frequency estimation. These methods include Pisarenko harmonic decomposition (PHD), multiple signal classification (MUSIC), Eigenvector (EV) and min norm (MN) methods. The subspace methods have been used for different applications such as direction of arrival (DOA) estimation [10], feature extraction [11], APDP and Doppler spectrum estimation [12]. Eigenvector methods produce frequency spectra of high resolution when the signal-to-noise ratio is low [11]. MUSIC, PHD and EV methods were compared with FFT for DOA estimation and for two sources, the EV method was better than all other methods regards error in resolution [10].

In this study, the EV method [13] is investigated for estimating delay profiles from FMCW channel data corrupted with interference. The paper begins with an introduction of the Eigenvector method and describes and presents FMCW channel data and effect of in-band interference. Processing steps for the EV method are then described which is followed by assessment of delay profile estimates from EV method compared to those from FFT processing.

2. Eigenvector Method

A signal *x(n)* that is defined as sum of p complex exponentials and additive noise can be written as [14]:

$$x(n) = \sum_{i=1}^{p} A_i \exp(jw_i n) + w(n) \tag{1}$$

where A_i is amplitude of i-th complex exponentials ($A_i = |A_i|\exp(j\varphi_i)$), w_i is frequency of i-th complex exponentials and *w(n)* is white noise that has a variance of σ_w^2.

The Eigenvector method is a subspace method which is based on Eigen-decomposition of autocorrelation matrix of the original signal (R_x) into signal (R_s) and noise autocorrelation (R_n) matrices: an MxM autocorrelation matrix R_x is then the sum of the autocorrelation matrix of the signal (R_s) and the autocorrelation matrix of the noise (R_n). The Eigenvectors of R_x are divided into two groups: if we assume the rank of R_s is *p*, then this gives signal Eigenvectors ($v_1, \ldots, v_p$) and noise Eigenvectors ($v_{p+1}, \ldots, v_M$).

Each vector in the signal subspace ($e_1, \ldots, e_p$) is orthogonal to each of the noise Eigenvectors ($v_{p+1}, \ldots, v_M$). This orthogonality property of signal and noise subspaces is used for estimating frequencies in spectrum of *x(n)*. Pseudospectrum of subspace methods are given as:

$$\hat{P}\left(e^{jw}\right) = \frac{1}{\sum_{i=p+1}^{M} \alpha_i |e^H v_i|^2} \quad (2)$$

where α_i are coefficients.

As given in equation (2), if $\alpha_i = 1$ and M=p+1 then this method is defined as PHD, if $\alpha_i = 1$ then this method is defined as MUSIC, if $\alpha_i = 1/\lambda_i$ where λ_i are the Eigenvalues then this method is defined as EV method. In this study, the frequency estimation function is:

$$\hat{P}_{EV}\left(e^{j2\pi f}\right) = \frac{1}{\sum_{i=p+1}^{M} \frac{1}{\lambda_i} |e^H v_i|^2} \quad (3)$$

3 FMCW Channel Data

In FMCW systems where the transmitted frequency is changed linearly over sweep period, the transmitted signal is given as eq. (4):

$$v_T(\mathrm{t}) = A_T cos[\phi_T(t)] = A_T cos\left[2\pi f_C t \pm \pi \frac{B}{T} t^2\right] \quad (4)$$

where A_T, f_c, B and T are the amplitude of the transmitted signal, the carrier frequency, the bandwidth, the sweep repetition period, respectively. The transmitted signal arriving at the receiver via different paths may be attenuated, delayed and Doppler shifted. This is known as multipath propagation. A transmitted signal arriving at the receiver via L separate paths will have L multipath components, and the received signal can be written as eq. (5):

$$v_R(\mathrm{t}) = \sum_{i=1}^{L} A_{Ri}\, cos\left[2\pi f_C (t-\tau_i) + \pi \frac{B}{T} (t-\tau_i)^2\right] \quad (5)$$

At the receiver, the received signal is multiplied with a replica of the transmitted signal and applied to a low pass filter in order to remove high frequency components after the frequency mixer.

As can be seen from Equation (5), the output of channel sounder will be a sum of sinusoidal signals. The frequencies of the sinusoidal signals correspond to time delays of the multipath components and the amplitudes correspond to the amplitudes of the multipath components. The APDP of the channel data can provide information on the time delay and amplitude of the multipath components. The APDP can be obtained by Fourier transforming the data from each sweep and taking the average of the magnitude squared over time (i.e. across sweeps) or by using any other spectrum estimation technique.

When the instantaneous frequency is changed linearly over the sweep period, the instantaneous frequency is linearly related to the sweep time. Therefore, this approach makes it possible to obtain channel parameters for any desired section of the RF band, or identify whether there are other signals being transmitted in the RF band, i.e. in-band interference. In the presence of in-band interference, the interference undergoes the same process at the detector as the desired signal. In-band interference causes abrupt changes in the detector output signal in the time domain, and will increase the noise floor of the APDP. The detector output signal will no longer appear as a sum of sinusoidal signals over the section of a sweep that corresponds to the RF band of the interfering signal.

3.1 Measured Propagation Data

The propagation data used in this study was collected in the Manchester city center using a FMCW sounder [4]. The instantaneous RF frequency was changed linearly over the sweep period. The center frequency of the transmitter was 1945 MHz with 60 MHz bandwidth. The transmit antenna was located 46 m above street level, and the receive antenna was 2.5 m above ground. Two sweep periods were used; 10 ms and 4 ms.

During analysis, in-band interference was observed in the data at a number of locations. The level of interference at some locations was so high that the noise floor of APDPs for 5 MHz subsections was increased to -10 dB or above, and made the data unusable for statistical modelling.

3.2 Effect of In-band Interference

Fig. 1 presents an example of channel data with in-band interference. The data for one complete sweep is given as Fig. 1.a; a section of the sweep without interference as Fig. 1.b and a section of the sweep with in-band interference as Fig. 1.c. The sections of sweeps presented in Fig. 1.b and 1.c correspond to 5 MHz sections in RF band. In the absence of interference (Fig. 1.b) the detector output is a sum of sinusoidal signals, however interference causes an abrupt change in the amplitude of demodulated signal (Fig. 1.c).

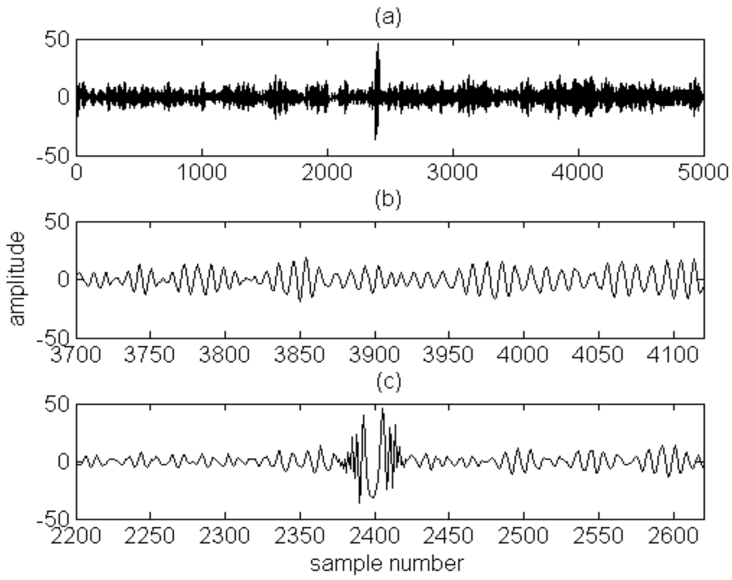

Figure 1. Time domain signal for the channel 1 (CH1) data

The APDPs corresponding to the two 5 MHz sections, with and without interference, (Fig. 2) were obtained using FFT method (average the power spectrum of all the sweeps).The figures show that the noise floor of the APDP increases with in-band interference, which will obscure late-arriving weak multipath components. In this example, the noise floor of the APDP is well below -30 dB for the interference-free section, and increases to about -15 dB for the section with in-band interference. This also shows that the conventional FFT technique for obtaining delay profiles fails to eliminate the effect of interference.

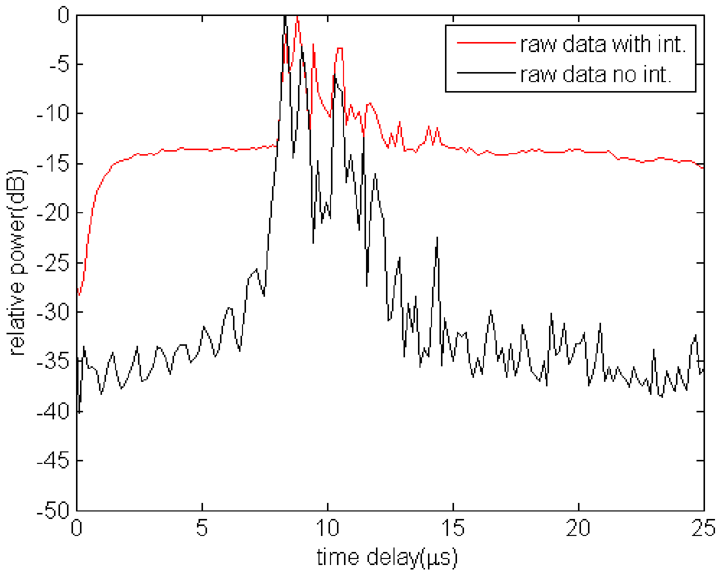

Figure 2. APDP of CH1 data

3.3 Eigenvector Method for Estimating Delay Profile

The process of estimating delay profiles with the Eigenvector method can be divided into four main steps:

1. Determine each section with interference corrupted data and select a window of 2N samples about the interference that corresponds to a bandwidth of interest which is 5 MHz or 3.3 MHz in this study.
2. Take the Discrete Fourier transform of the 2N samples for each sweep and keep the positive half of the frequency spectrum.
3. Calculate inverse Discrete Fourier transform of the spectrum from the step 2 to create a signal in a form given in eq. (1), and place the results row-wise into a matrix x_n, an KxN matrix where K is the number of sweeps.
4. Apply the Eigenvector algorithm to each row of the x_n matrix and average across the rows, i.e. over time, to obtain the average delay profile.

3.4 Examples

The two techniques (FFT and EV) are applied to two examples of data with interference to demonstrate that early- and late- arriving weak signals are detected.

3.4.1 Channel 1 Data

Fig. 3 presents the average delay profile for channel 1 data for both the FFT method (red) and the Eigenvector method (black). As is seen, the Eigenvector method detects the weak multipath components with 10-14 μs time delay not detected with the FFT method.

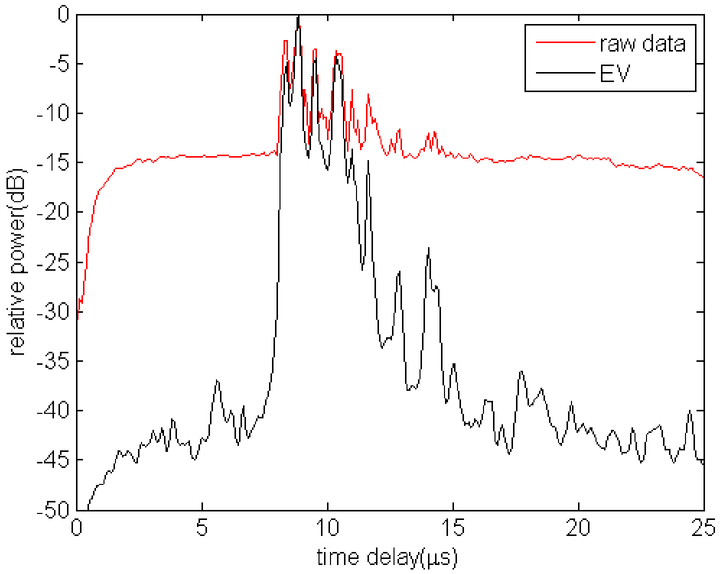

Figure 3. Average delay profile of CH1 data

3.4.2 Channel 2 Data

Fig. 4 presents the average delay profile for channel 2 data for both FFT (red) and Eigenvector (black) methods. Here the Eigenvector method detects the weak multipath components with 5-10 μs delay not detected with the FFT method.

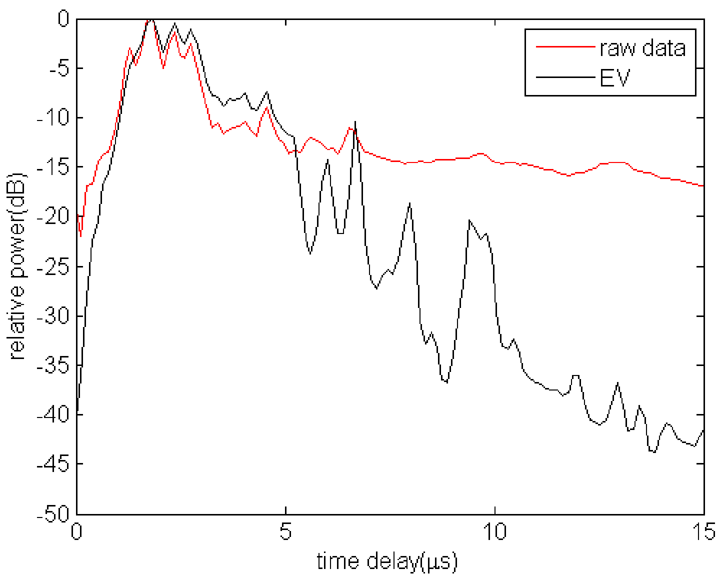

Figure 4. Average delay profile of CH2 data

4 Conclusions

This paper describes the effect of in-band interference on the output of the detector of an FMCW sounder, which manifests as abrupt fluctuations in the time domain. This increases the noise floor in the APDP, and using the conventional FFT method to estimate delay profile fails to detect weak multipath components. The paper presents how the Eigenvector method, a high resolution spectrum estimation method, can be used to detect weak multipath components, otherwise not detected by the FFT method.

References

[1] S. Salous, *Measurement of multipath delay statistics over 72-90 MHz bandwith at 1.8GHz in two European cities using a Chirp sounder*, Radio Science, 34(4) (1999) 797-816.

[2] M. Goppelt, H. -L. Blocher, W. Menzel, *Automotive radar – investigation of mutual interference mechanisms,* Advances in Radio Science, 8 (2010) 55-60.

[3] G. M. Brooker, *Mutual interference of millimeter-wave radar systems,* IEEE Transactions on Electromagnetic Compatibility, 49(1) (2007) 170-181.

[4] S. Salous, H. Gokalp, *Medium- and large- scale characterization of UMTS-allocates frequency division duplex channels*, IEEE Transactions on Vehicular Technology, 56(5) (2007) 2831-2843.

[5] E. D. R. Shearman, R. R. Unsal, *Compatibility of high frequency radar remote sensing with communication*, International Conference on Radio Spectrum Conservation Techniques, London, 1980.

[6] J. H. Choi, H. B. Lee, J. W. Choi, S. C. Kim, *Mutual interference suppression using clipping and weighted-envelope normalization for automotive FMCW radar systems,* IEICE Transactions on Communications, E99.B(1) (2016) 280-287.

[7] T. Schipper, M. Harter, L. Zwirello, T. Mahler, T. Zwick, *Systematic approach to investigate and counteract interference-effects in automotive radars*, 9th European Radar Conference (EuRAD), Amsterdam, 2012.

[8] H. Gokalp, G. Y. Taflan, S. Salous, *In-band interference reduction in FMCW channel data using Prony modelling*, IET Electronics Letters, 45(2) (2009) 132-133.

[9] W. Wang, L. R. Wyatt, *Radio frequency interference cancellation for sea-state remote sensing by high-frequency radar*, IET Radar, Sonar and Navigation, 5(4) (2011) 405-415.

[10] M. F. Al-Azzo, K. I. Al-Sabaawi, *High resolution techniques for direction of arrival estimation of ultrasonic waves*, American Journal of Signal Processing, 4(2) (2014) 49-59.

[11] E. D. Übeyli, İ. Güler, *Features extracted by eigenvector methods for detecting variability of EEG signals*, Pattern Recognition Letters, 28 (2007) 592–603.

[12] H. Gokalp, G. Y. Taflan, S. Ustun, *Min-norm method for estimating delay and doppler profiles from FMCW channel data with in-band interference*, IET Electronics Letters, 40(11) (2010) 799-800.

[13] D. H. Johnson, S. R. DeGraaf, *Improving the resolution of bearing in passive sonar arrays by eigenvalue analysis*, IEEE Transactions on Acoustics, Speech and Signal Processing, 30(4) (1982) 638-647.

[14] M. H. Hayes, *Statistical digital signal processing and modelling*, John Wiley&Sons, Inc., 1996.