

# A New Adaptive Power Spectral Density Estimation Method Based on Projection of the Cross Spectral Metric Technique into the Amplitude and Phase Estimation (APES) Technique

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**Abstract:** Pulsed wave Doppler ultrasound has been used for estimation of blood velocity in human body as an implicit result of being non-invasive method. In this research, to compensate the drawbacks such as long observation window of prevalent methods in the Doppler ultrasound, we proposed a new adaptive method based on projection of the cross spectral metric technique into the amplitude and phase estimation (APES) technique.

**Keywords:** Spectral Doppler, Velocity, APES, Cross Spectral Metric.

## 1. Introduction

Employing non-invasive techniques for identifying diseases and abnormalities is one of the important issues in the realm of the medicine. Since periodic movement of cardiovascular system including heart and red blood cells makes them different from other organs and systems, pulsed wave Doppler ultrasound plays a crucial role to diagnose the abnormalities. Doppler refers to examine the movement of blood in and around the heart based on moving object. It is particularly useful for determining the hemodynamic significance or cardiac structured disease [1]. Additionally, pulsed wave Doppler is able to localize the blood velocity turbulence in arteries. Therefore, the objective of pulsed wave Doppler ultrasound system is to estimate blood velocities spectrum in human body. Pulses with the same repetition intervals have been emitted through the focal point and then, backscattering signal or radio frequency (RF) signal will be demodulated [2]. Because this RF signal contains both transducer center frequency and Doppler frequency, by removing transducer center frequency ( $f_0$ ), we obtain Doppler frequency as shown in (1).

$$f_d = \frac{2v_z f_0}{c} \quad (1)$$

In the above equation  $v_z$  represents the axial blood velocity. Estimating power spectral density (PSD) of RF signal, in the selected focal point makes it possible to estimate blood velocity [4]. In designing ultrasound system it is essential to have acceptable resolution and contrast. Temporal resolution in Doppler ultrasound defined as the capability of the system to visualize the moving object contrast refers to the capability of system to distinguish difference between two adjacent objects such as hyper echoic or hypo echoic [3]. Conventional systems which uses Welch method for estimating PSD encounters with low spectral resolution and contrast. Choosing long observation window has been proposed to overcome this problem. However, long observation window causes to have low temporal resolution [5], [6], [7]. It arises from appreciable difference in emitting pulse band width between pulsed wave Doppler and B-mode imaging. While pulse wave Doppler applies narrow band pulses, B-mode imaging uses broad band pulse. Besides, applying of long observation window causes to increase the execution time. To overcome mentioned issues variety of methods have been proposed to estimate the PSD. These methods can be classified into parametric and non-parametric methods. Parametric methods have the advantage of providing quite well resolution, but nevertheless consists some challenge such as requiring priori information about the number of scatters in blood vessels. Non-parametric methods include two

approaches, based on Fourier transform and based on filter bank. One common example of Fourier transform method is Welch method. It needs long observation window for accurate resolution and contrast, as mentioned above. Alternative filter bank methods potentially are capable of reducing the observation window. In [5], Capon and Amplitude and Phase estimation filter bank approaches are used and they introduce two data adaptive estimation technique. It is shown that observation window significantly can be reduced using these methods. Also, these methods are capable to provide sufficient spectral resolution and contrast. Ekroll et al. [6] introduced new adaptive method as projection based Capon and Multiple Signal Classification (MUSIC) which is a parametric method and shown that for a given observation window the frequency resolution can be increased. In [7], the author proposed two new iterative approach Blood Iterative Adaptive approach (BIAA) and Blood Sparse Learning via Iterative Minimization (BSLIM) and it is shown that these two methods could provide spectrogram with less artifacts.

In this study, we propose a new approach which is based on cross spectral metric and APES filter bank method. Our aim is to reduce OW to attain sufficient resolution and contrast. Furthermore reduce the execution time. The results are compared with Welch, Capon and APES in terms of resolution, contrast and execution time. Also covariance matrix is estimated by averaging over slow time and fast time. Simulated data is used as an input for femoral artery with Field II. It is concluded that proposed new approach show advanced performance for simulated data.

## 2. Overview

This section includes the investigation of three non-parametric PSD estimation methods. These methods are conventional Welch method, and two adaptive methods Capon and Amplitude and Phase estimation (APES) methods.

### 2.1. Welch Method

Scatters movement in human body is random and independent from each other. An assemblage of backscattering signals has been detected by transducer. This signal resembles to the Gaussian distribution. While this signals similar to the Gaussian distribution we are able to conclude the same thing for Doppler signal. Let the demodulated signal through the RF signal represented by (2).

$$X(k, l) = (x(k, l), x(k, l + 1), \dots, (k, l + N + 1))^T \quad (2)$$

Fourier vector has been depicted below:

$$\gamma(f) = (1e^{j2\pi f} \dots e^{j2\pi f(N-1)})^T \quad (3)$$

For estimating the power spectrum of Welch and other mentioned methods, Covariance matrix has been defined. This matrix is given below:

$$\mathfrak{R}_x = \frac{1}{KL} \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} x_k(l) x_k^H(l) \quad (4)$$

Where k indicates the fast time which means averaging over RF signal and L demonstrates the number of chosen segments for averaging over slow time. By Using (3) and (4), PSD which is estimated for Welch method is described by (5):

$$\Psi_{Welch}(f) = \gamma^H \mathfrak{R}_x \gamma(f) \quad (5)$$

In all mentioned methods for estimating PSD, observation window (OW) defines the length of chosen segments over slow time.

### 2.2. Capon method

Some references consider Capon method as a minimum variance method. Most of the times this method envisages as a narrow band filter which has a variable center frequency (Figure.1). The objective of Capon method is defining a filter, which minimizes the power of total output while we inspected each range of frequency.

$$\min E[|F^H(f)x_k(l)|^2] \quad (6)$$

$$F^H(f)\gamma(f) = 1$$

Suitable filter can be attained from (6) as shown below:

$$E[|F^H(f)x_k(l)|^2] = E[F^H(f)x_k(l)x_k^H(f)F]$$

$$= F^H E[x_k(l)x_k^H]F = F^H \Re_x^{-1} \gamma(f) F$$

$$F(f) = \frac{\Re_x^{-1} \gamma(f)}{\gamma^H(f) \Re_x^{-1} \gamma(f)}$$

Obtaining PSD is possible by substituting (8) into (7) [The result is described below:

$$\Psi_{Capon} = \frac{1}{\gamma^H(f) \Re_x^{-1} \gamma(f)}$$

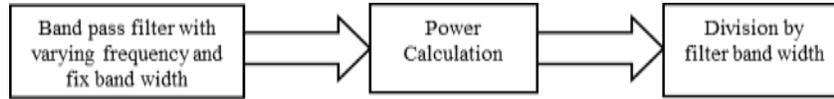


Fig. 1: The filter bank approach for PSD estimation [20]

### 2.3. Amplitude and phase estimation

For all frequency range which defined by Fourier vector, PSD estimation is carried out over slow time. Where the aim of this filter is to minimize the power of the noise in the output. For estimation it has:

$$\min(F^H(f)Z(f)F(f))$$

In (10), Z matrix include noise and covariance matrix. Definition of Z matrix is shown below:

$$Z = \Re_x - \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} z_{k,l}(f) z_{k,l}^H(f)$$

In above equation z depicted the noise and described by (12).

$$z(f) = \frac{1}{L} X \Im(f)$$

Now it is possible to define filter through the slow time (13).

$$F(f) = \frac{Z^{-1}(f)\gamma(f)}{\gamma^H Z^{-1}(f)\gamma(f)}$$

PSD have been defined by putting (13) into (10) as shown below:

$$\Psi_{APES}(f) = \frac{1}{KL} \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} |F^H(f)z(f)|^2$$

## 3. Methods and Materials

By applying APES and cross spectral metric makes it possible to propose a new method. Objective of the proposed method is to reduce number of steps during defining filter and signal processing. Least Mean Square method is chosen to show the purpose of the study among three other methods. It is associated to the data space. Further, it evaluates the cross spectral metric energy which is projected through the each vector. Cross spectral metrics Eigen value has been found by defining singular decomposition value of input as given in (15)

$$X = SDV^H$$

In (15), V matrix demonstrates the Eigen vector of covariance matrix. Minimizing Euclidean norm in reducing step is one of the crucial factors to obtain this aim. Transformed cross correlation vector has been defined in (16).

$$\mu = V^H r_{xd}$$

Where the  $r_{xd}$  indicates the cross correlation between the observed data and desired signal [20][21]. Euclidean norm has been defined below:

$$E = \sum_{k=1}^N \frac{\mu}{\lambda} = \sum_{k=1}^N \mathcal{G}_k \quad (17)$$

Where  $\lambda$  vector indicates the diagonals of  $S^2$  matrix and  $\mathcal{G}_k$  demonstrates the projected energy. We are able to define the relative filter as shown below

$$F(f) = \frac{\mathcal{G}_k \mathcal{G}_k^H Z^{-1}(f) \gamma(f)}{\gamma^H(f) Z^{-1}(f) \gamma(f)} \quad (18)$$

## 4. Results and Discussion

By executing demodulation over RF signal, this signal separates into real and imaginary parts. Then, different estimation methods have been tried on each of them. In this study we use simulated data in Field II program for femoral artery and estimate PSD by using mentioned methods over real part of RF data. Comparing the proposed method result with conventional Welch, Capon and APES methods have been performed through three different points of view temporal resolution, contrast and execution time.

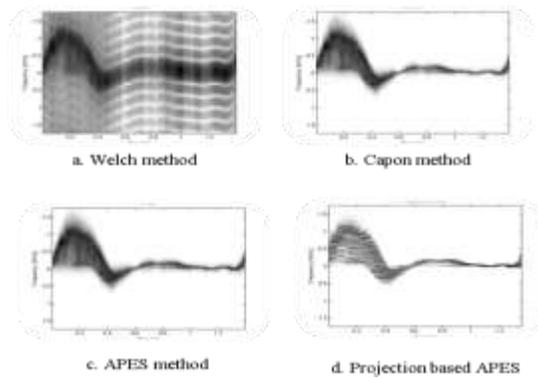


Fig. 2: Comparison of methods With OW=128

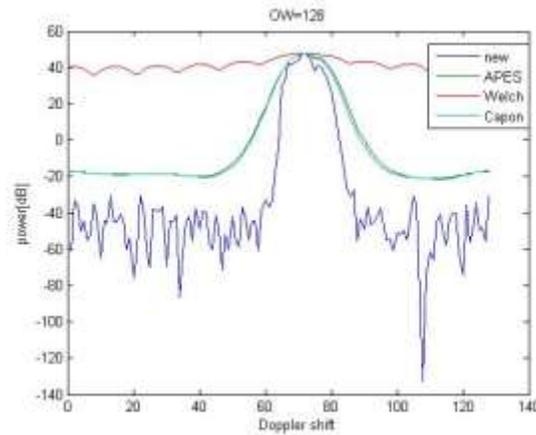


Fig. 3: Doppler shift and PSD relation in different methods

One of the most important points in this research is that, the fast time has to be constant. Therefore, we chose  $K=2$ . For defining the observation window and slow time we use the method which was proposed in [5], [7]. According to that method, if we chose  $OW=128$ , the slow time should be 129. Figure 2 depicts obtaining results from the mentioned methods with  $OW=128$ . In Figure 2, it is coherent that the adaptive methods given superior result in comparison with conventional Welch method. While the projection base APES has better resolution in long OW, Capon and APES have better contrast. Figure 3 illustrates relation between PSD and Doppler shift. From this figure it is obvious that by reducing the frequency range, the resolution is increased.

Our aim is to reduce the OW by separating data into small segments. Figure 4 shows the investigation of PSD with OW of 20. It is obvious that spectral resolution is best when using projection based APES, Capon and APES respectively. Moreover, the Welch method causes more artifacts in short OW.

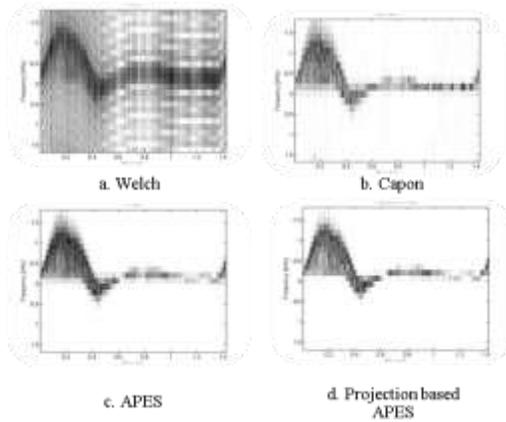


Fig. 4: Comparison of methods With OW=20

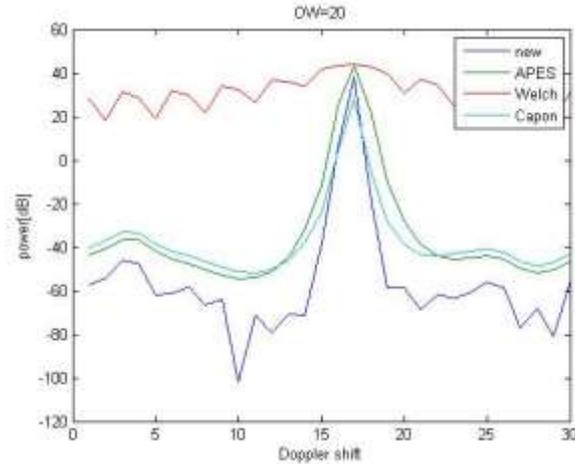


Fig. 5: Doppler shift & PSD relation in different methods

Another important factor in investigating these methods is the execution time. It is clear by reducing the OW, execution time has been reduced. Table 1 depicts the relation between OW and execution time. When the methods are compared, it is seen that for all mentioned methods reducing OW causes to decrease the execution time, but adaptive methods make it possible to handle resolution, contrast and execution time in conjunction with together.

Table I: Execution time

	Execution time (sec)			
OW	Welch	Capon	APES	Projection based APES
20	7.4257	6.0472	9.0541	8.4805
25	12.385	12.239	12.482	11.076
30	16.216	16.100	10,549	13.902
40	25.212	25.574	25.228	20.284
50	36.288	36.282	36.054	27.580
64	35.113	54.471	54.678	43.128
128	186.156	185.559	183.980	113.906

## 5. Conclusion

In this study, we have proposed new adaptive method for estimating PSD in ultrasound system and results compared with conventional Welch, Capon and APES. The result shows that OW has the direct relation with execution time, so by reducing OW, the execution time has been reduced. Adaptive methods are capable to attain acceptable resolution and contrast in comparison with Welch method. For estimating PSD in adaptive methods, there are two important assumptions, estimated power is approximately uniform over the filter pass band, filters gain over pass band are approximately one. Therefore, it is concluded that proposed method, projection based APES, has superior results in view point of mentioned factors.

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