WAVELETS AND MULTIRATE DIGITAL SIGNAL PROCESSING

Lecture 42: Application Assignment: Wavelet Based Denoising

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1 Introduction

In the second session of interaction in the course of Wavelets and Multirate Digital Signal Processing in which for variety, we bring in now the student presentations largely speaking we shall have tutorial sessions, a very infrequently we shall have prepositions, expression of thoughts and presentations by the students of the course on the theme of the course.
In that spirit, we are going to discuss the presentation of one of the student namely, '**Toney Sabstian**' as part of his application assignment that he worked upon in this course. The broad theme of his presentation is 'Denoising'. Now denoising as the name suggests, is the operation of separation of wanted and unwanted in a mixture of signal and noise.
As expected normally the noise or perturbation is unwanted and it is often the case when one goes in wavelet domain particularly in the context of biomedical signals, it is easier to separate the wanted signal from unwanted noise. We could have several instances of this, but what we have in today's lecture is essentially a separation of respiratory artifacts described by '**Toney Sabstian**'.

2 Wavelet based denoising for suppression of respiratory artifacts in impedance cadiogram signals (ICG): By Toney Sebastain

The technique that is used in this presentation was originally developed by Dr. Vinod K Pandey and Prof. P.C. Pandey [5,10] of Electrical Engineering Department, IIT Bombay. First of all, we will see what is mean by '**Impedance cardiography**'.

2.1 Impedance Cardiography (Definition)

A noninvasive technique for monitoring stroke volume (SV) and other cardiovascular indices, there by obtaining diagnostic information on cardiovascular functioning by sensing variation in the thoracic impedance due to change in blood volume.

2.2 Structure and functioning of Heart

The actual structure of the heart is as shown in Figure-1. It essentially consists of four chambers namely:
(1) Right atrium
(2) Left atrium
(3) Right ventricle
(4) Left ventricle
These four chambers can be visualized as a four pumps similar to mechanical pumps whose function is just pump the blood. The blood from the different part of the body enter into the

heart.
There are two major vessels namely:
(1) Superior vena cova
(2) Inferior vena cova
Superior vena cova will be bringing the blood from the upper part of the body to the heart where as Inferior vena cova will be bringing the blood from the lower part . The names superior and inferior are not due to their functioning but as per their positions.

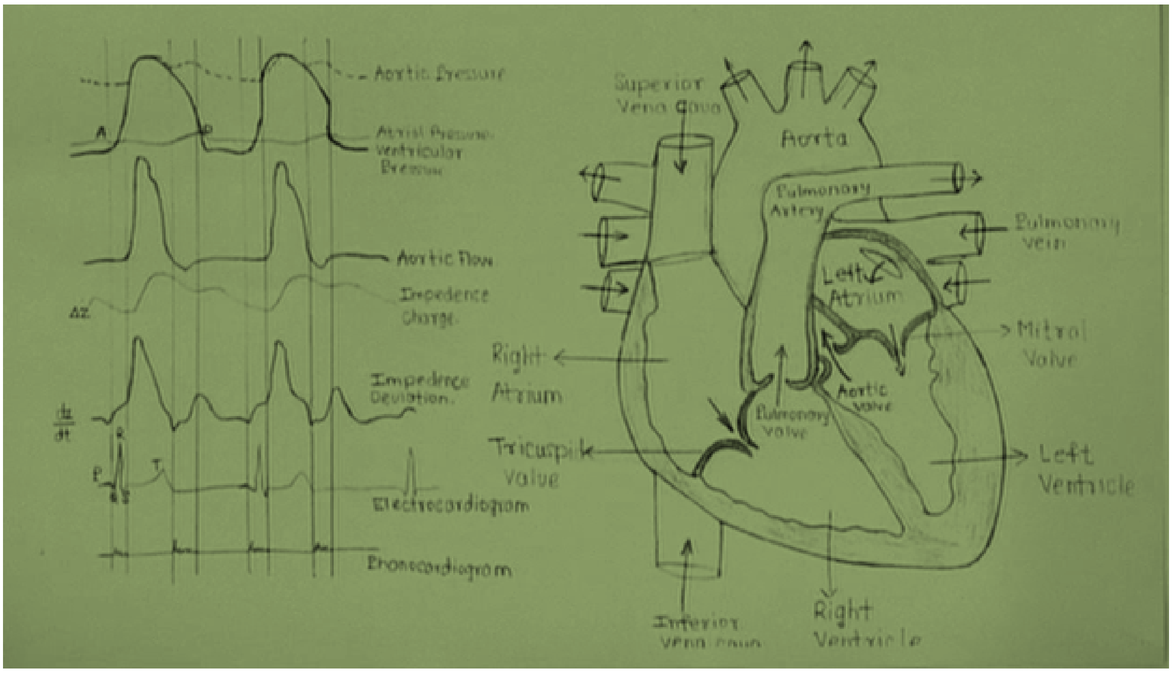

Figure 1: **Structure of Heart**

The right side of the heart deals with the deoxygenated blood and left side of the heart deals with the oxygenated blood. As soon as the right atrium filled with the blood, right atrium will pump the blood to right ventricle. There is valve separating the right atrium and right ventricle known as tricuspide valve. The right ventricle pumps the blood to lungs for getting oxygenated. As we know blood coming from different parts of the body to the heart has carbon-dioxide in it. We need oxygen in the blood for body functioning. Now, this blood will exchange *i.e.*, carbon-dioxide and oxygen, for that the right ventricle pumps the blood to the lungs through pulmonary artery. During this period pulmonary valve will be open and tricuspide valve will be closed. The blood will come back to the heart in left atrium through pulmonary vein. From this left atrium blood will be pumping in left ventricle. There is valve separating left atrium and left ventricle known as mitral valve.
Out of the four chambers, left ventricle is the most important part because left ventricle is supplying the blood to all parts of the body. Since our body parts are far away from the heart, left ventricle has to do a lot of work. The left ventricle is contracting with maximum force and will pass through aortic valve to the aorta and blood will be supplied through different branches of aorta to the different parts of the body. Even though if atrium pumps are not working due to some problem, tricuspide valve and mitral valve will be opened due to gravitational force and weight, the 70% of blood will automatically fall in ventricle. So disorders related to atrium are not much dangerous compared to disorders related to ventricle.
Now look at the some waveforms related to heart blood cycle as shown in left side of Figure-1.

In the first waveform the upper doted line shows the aortic blood pressure *i.e.*, when we are measuring blood pressure using pressure meters with the help of doctors, we will be getting this aortic blood pressure (80 to 120 for healthy persons). The related variations of other two pressures namely atrial pressure and ventricular pressure are shown in the same first waveform. The next waveform is aortic flow showing blood flow aorta which is pulsating in nature. The waveform shows electrocardiogram signal (ECG) which is a measure of electrical activities of the heart. The last waveform is phonocardiogram which are actually cardiac sounds of valves.

2.3 ICG Signal and artifacts

In impedance cardiography, the four sensors are placed on the body, the corresponding region is known as thoracic region, as shown in Figure-2 below.

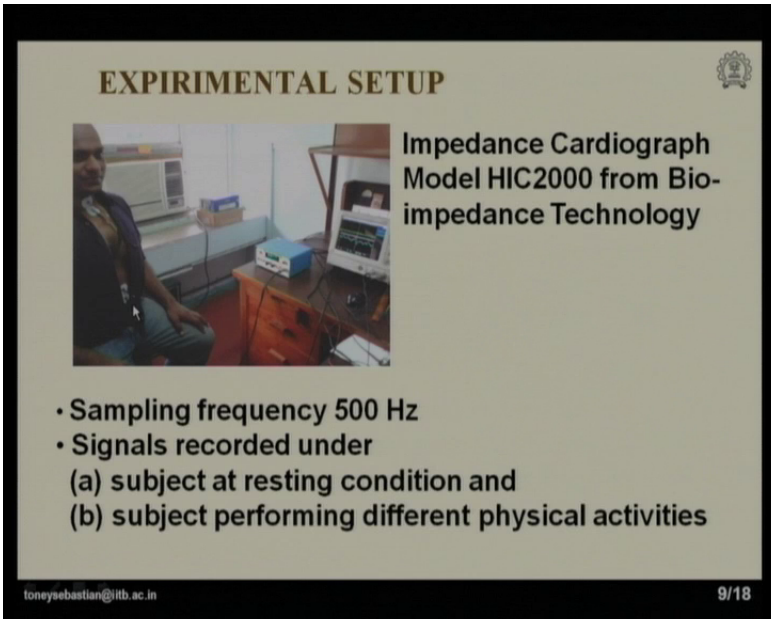

Figure 2: **Experimental Setup of 'ICG' recoding**

A high frequency and low amplitude current is passed through upper and lower electrodes and voltage is measured between the two middle electrodes and hence the impedance. As shown in the Figure-1, the third waveform $\Delta(Z)$ shows the impedance variation and forth waveform is the time derivative ($\frac{dZ}{dt}$) of it known as impedance cardiogram signal (ICG).
The stroke volume (SV) is the amount of blood pumped by the heart during one heart bit and is given by,

$$SV = \rho \frac{L^2}{Z_0^2}(-\frac{dz}{dt})_{max} T_{lvet}$$

where,
SV = Stroke volume (mL)
ρ = Resistivity of the blood (Ω-cm) $\cong$ 150
L = Length of the modeled conductor (cm)
Z_0 = Basal impedance(Ω) $\cong$ 25 (Varies from patient to patient)
$(-\frac{dz}{dt})_{max}$ = Maximum of the derivative of the impedance during the systole (Ω/s)
T_{lvet} = Left Ventricle Ejection time (s)

Cardiac output = SV × HR (heart rate)

Basically impedance cardiogram signal (ICG) have few types of artifacts, these are manmade signals which are unnecessary in impedance cardiography point of view. We have two major artifacts *i.e.*, respiratory and motion artifacts. Respiratory artifacts are very low frequency (0.04 - 2 Hz) and motion artifacts (0.1 - 10 Hz). The Figure-3 shows ICG signal during exorcize of a normal person. The baseline drift is due to the respiratory artifacts and peaks due to motion artifacts.
As shown the ICG signal range is 0.8 to 20 Hz, therefore respiratory and motion artifacts lie within same band. In this presentation particularly we are looking for respiratory artifacts suppression because these create difficulties in calculating stroke volume and other cardiovascular indices.

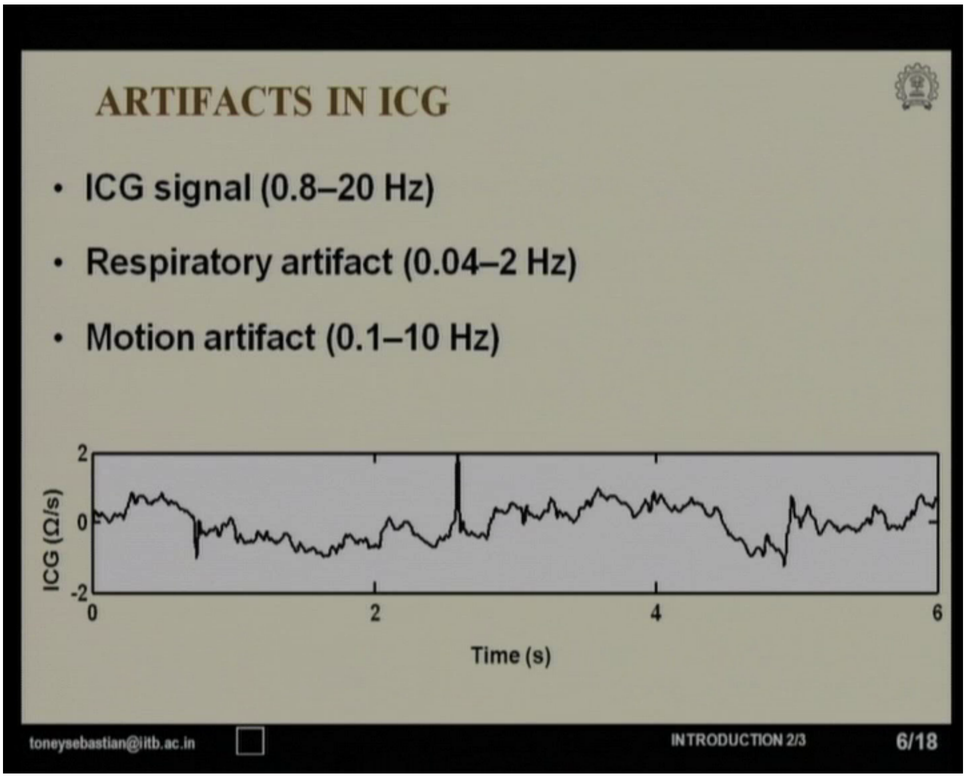

Figure 3: **Artifacts in 'ICG'**

3 Project objective

- Investigate the different de-noising techniques for the suppression respiratory artifacts.
- Study the wavelet based de-noising for artifact suppression.
- Study different wavelets and its applicability in artifact suppression.

There are few techniques of suppression of respiratory artifacts namely:
a) **Breath Hold**: Respiratory artifacts are because of respiration and the easiest way to suppress these artifacts is to hold the breath. The problem to breath hold is that when we are

holding the breath cardiac activity will always go down. Another problem is when we are recording 'ICG' after exercise it is difficult to hold the breath.

b) **Ensemble averaging[8]**: The bit to bit variability in the 'ICG' will be removed in ensemble averaging technique, so it blur the important points of 'ICG' waveform such as B, X points. Hence it will introduce errors in calculating stroke volume (SV).

c) **Adaptive filtering[10]**: Adaptive filtering is always good in biosignal de-noising if we have a reference signal, but obtaining a reference signal is difficult task.

d) **Wavelet based level dependent thresholding[5]**
In wavelet based de-noising selection of wavelet basis is important task. In many de-noising applications it is observed that if wavelet and waveform has some similar shape, then those wavelets gives better separation of noise and signal. Hence selection of wavelet basis is an important step in wavelet based de-noising. In this presentation we are using this technique for the suppression of respiratory artifacts in 'ICG' signal.

4 Wavelet based de-noising

The basic wavelet decomposition is as shown in Figure-4 and Figure-5. The original waveform is sampled at 500 Hz. Each detail gives a bandpass signal and each approximation gives a low-pass signal when we are decomposing the signal into different levels. In this method, we are decomposing the signal into different levels and artifacts into different levels and we are seeing up to what levels the signal is present and up to what levels the artifacts are present. We have used different wavelets for decomposition in this project. We have tested different wavelets such as Coif5, db6, demey (discrete meyer wavelet) and symlet wavelet in decomposition of 'ICG' signal. Based on these results we will choose specific wavelets for de-noising application. The 10-level wavelet decomposition of an 'ICG' signal under breath hold condition is as shown in Figure-6, Figure-7 and Figure-8 by using 'Coif5', 'db6' and 'demey' wavelets respectively.
In Figure-6, the details D1 to D3 has no signal content because they contains high frequency components and the signal has only components up to 20 Hz. The details D4 to D10 contains the signal content so we can not use this particular wavelet for separation of signal and artifacts since it is not capturing signal components in any particular details. As we can see D8-D9 has signal content and if artifacts are present along with the signal.
In Figure-7, the same 10-level wavelet decomposition of an 'ICG' signal using Daubechies wavelet (db6), again we can see all the details and approximation contains the signal content, so this wavelet also will not serve the purpose of artifact separation from the 'ICG' signal.
In Figure-8, we can see that there is no signal content in D1 to D3, but D4 to D8 have signal content, but one important observation here is that in D9-D10, we don't have signal components. The D9 details contains frequency components in the range 0 to 0.98 Hz. In our de-noising experiment we are adding the details D1 to D8 and removing D9, D10 and A10 for artifacts suppression.
By observing these results, we can see that the choice of wavelet basis plays a critical role for artifacts suppression in 'ICG' signal.

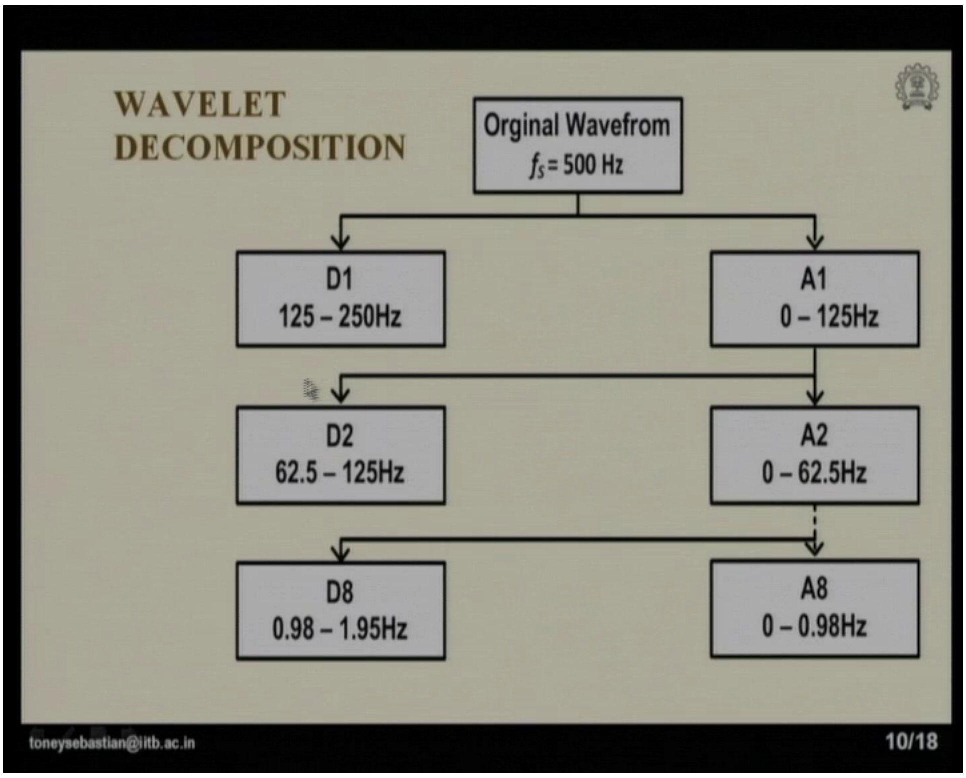

Figure 4: **Wavelet decomposition**

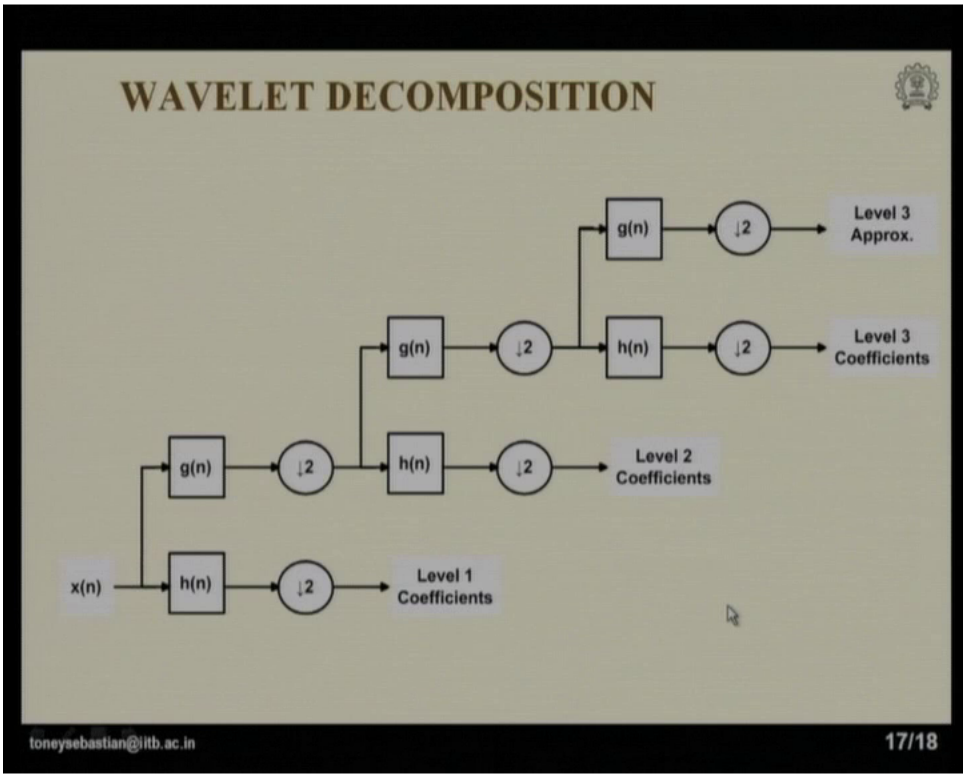

Figure 5: **Block diagram of DWT**

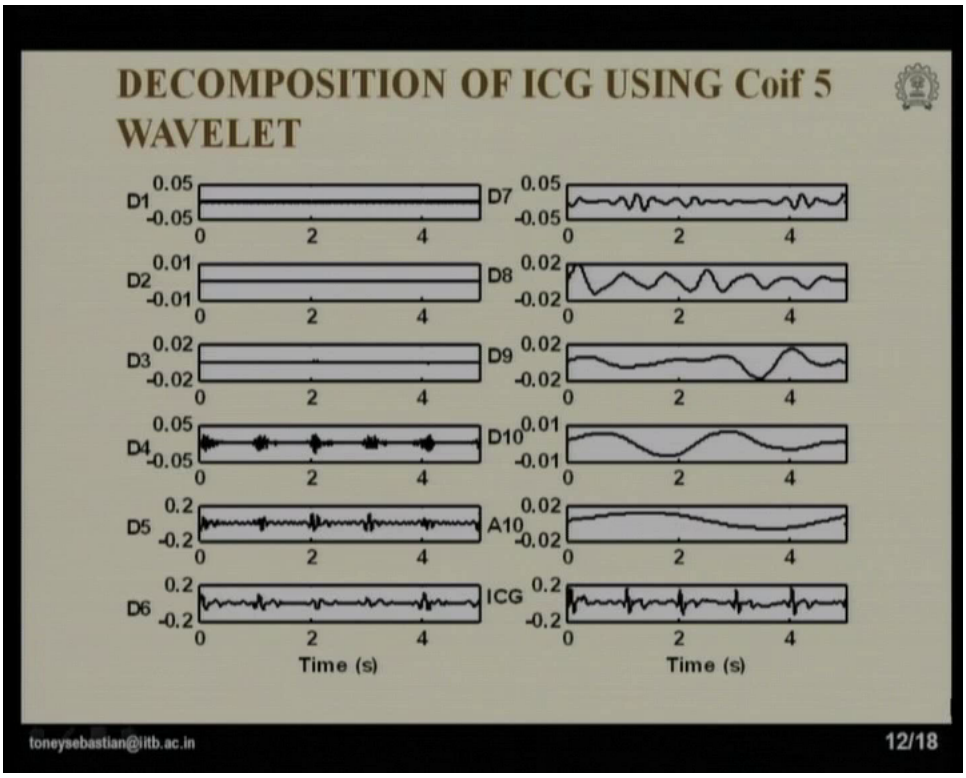

Figure 6: **10-level decomposition of ICG with 'Coif 5' wavelet**

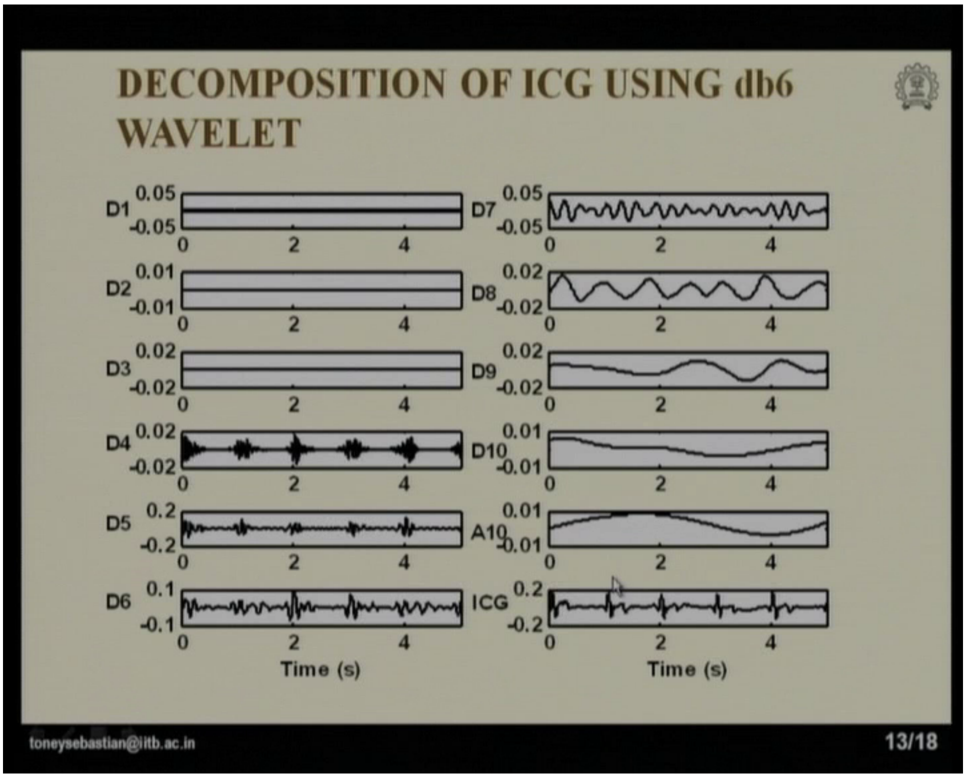

Figure 7: **10-level decomposition of ICG with 'db6' wavelet**

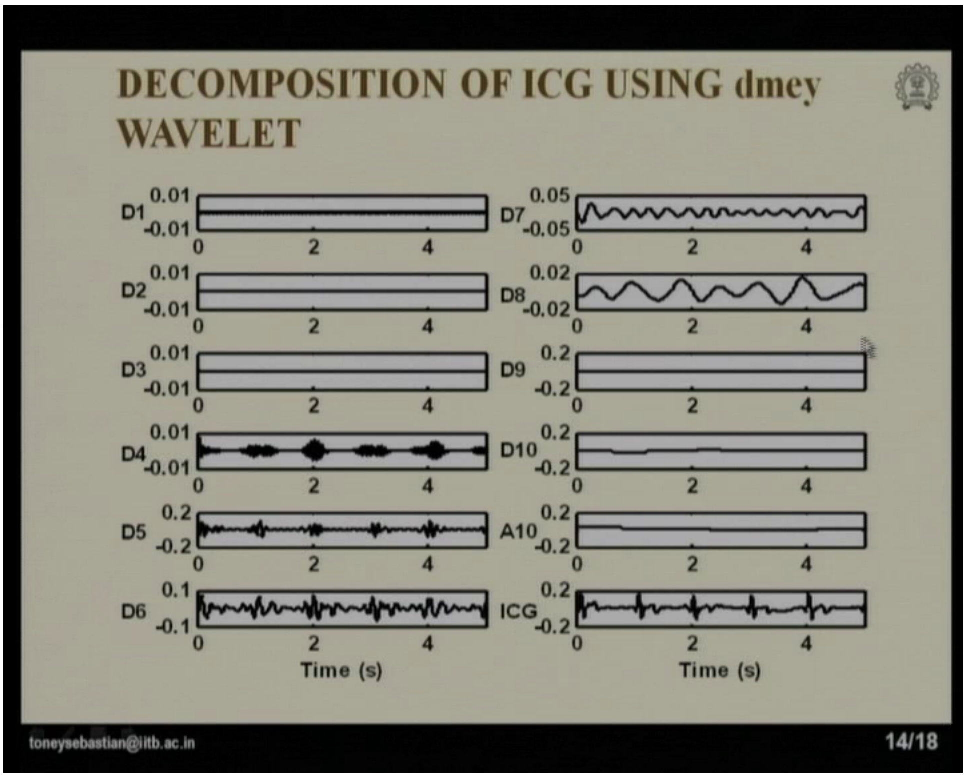

Figure 8: **10-level decomposition of ICG with 'demey' wavelet**

4.1 De-noising Results

Further studies at SPI lab EE department at IITB showed that similar results can be achieved by using 'demey' wavelet can also be achieved by using one more wavelet known as 'sym26' wavelet.
The first waveform in Figure-9 is an 'ICG' signal under resting condition but with respiration. The second waveform in Figure-9 is an denoised 'ICG' signal using 'demey' wavelet *i.e.*, 'ICG' signal is decomposed with 10-levels and the reconstruction is done using first 8 details. The third waveform is obtained by following the same procedure using 'sym26' wavelet. We can visually see that both the wavelets giving the same performance. The forth waveform is the artifacts which are extracted from from 'ICG' waveform by using 'demey' wavelet. This is basically first waveform minus second waveform. The last waveform is the artifacts removed by using 'sym26' wavelet. Here we can observe that both wavelets capturing exactly the same artifacts and same signal.
The question may arise in one's mind that why this is happened. The shapes of wavelet and scaling function of 'demey' and 'sym26' are as shown in Figure-10. We can see that both have same shapes and matches with the shape of ICG signal and hence these wavelets gives better artifacts suppression performance over other wavelets. All the de-noising experiments are performed with Matlab using wavelet toolbox.

4.2 Summary and Future work

- 'Sym26' and 'demey' are better than other wavelets for respiratory artifacts suppression.

- 'Sym26' reduces the calculation complexity compared to 'demey' wavelet.

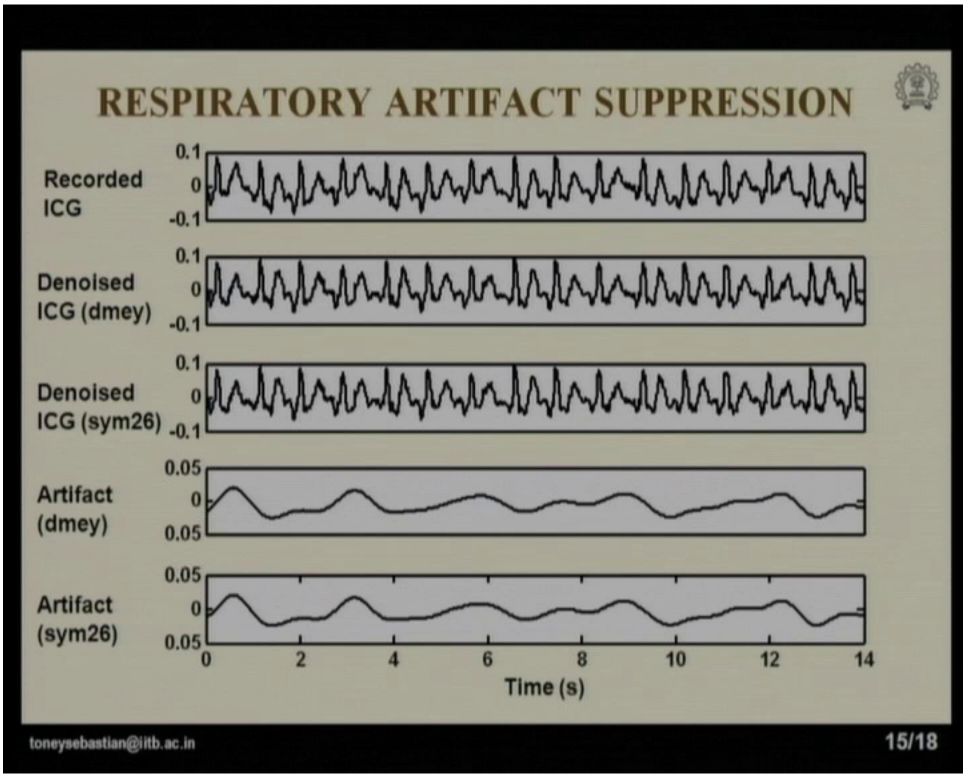

Figure 9: **Respiratory artifact suppression with 'demey' and 'sym26' wavelet**

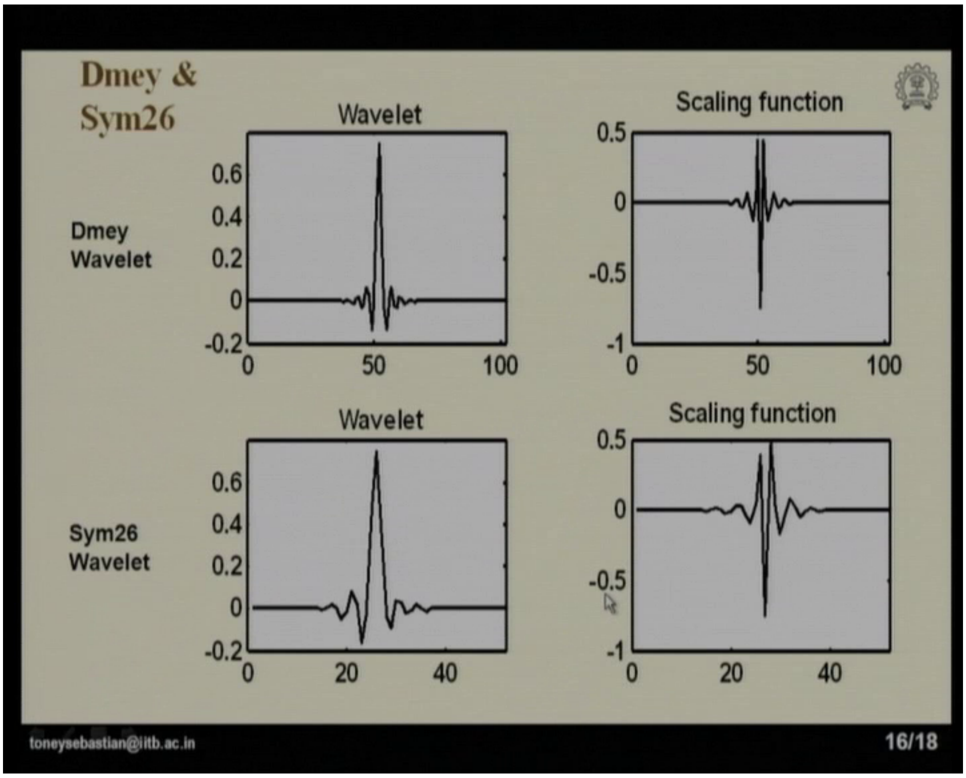

Figure 10: **wavelet and scaling functions of 'demey' and 'sym26' wavelet**

• Study the applicability of wavelet based techniques for motion artifact suppression in 'ICG' signal.

• Study the wavelet based techniques in 'ECG' de-noising applications.

5 References

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