Advanced Digital Signal Processing - Wavelets and Multirate

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Module No # 01
Lecture No # 42
Student's Presentation

A warm welcome, to this second session of interaction, in this course on wavelets and multirate digital signal processing; in which, for variety we now bringing again a student presentation. We have to record now a series of tutorial sessions, and student presentations, and we shall intersperse these. Largely speaking we shall have tutorial sessions, here and there very infrequently, we could have some presentations or expositions or expressions of thought by students of the course, on the theme of the course. In that spirit, today I am going to request one of the students who has attended this course; namely Toney Sebastian, to make a presentation on the excellent application presentation that he worked upon in this course. I shall not take away from him, the thunder of explaining what he did, safe to give an introduction in a few lines. I shall just introduce the broad theme of his application, and the broad theme relates to what is called denoising.

Now, denoising as the name suggests, means an operation of separation of wanted and unwanted in a mixture of signal and noise; as expected normally the noise or the perturbation is unwanted. And it is often the case that when one goes into the wavelet domain, particularly in the context of biomedical signals; it is easier to separate the wanted signal from the unwanted noise. We could have several instances of this, but what we have today, is essentially a suppression of respiratory artifacts, which Toney would explain to you on his own. So, now I introduce Toney Sebastian and I request him to make a presentation on his work, related to a suppression of these kinds of artifacts and wavelet based denoising.

Hello everybody, myself Toney Sebastian of second year M. Tech student, M. Tech student of biomedical department IIT Bombay. Welcome to my application assignment presentation on wavelet based denoising for the suppression of respiratory artifacts in impedance cardiogram signals.

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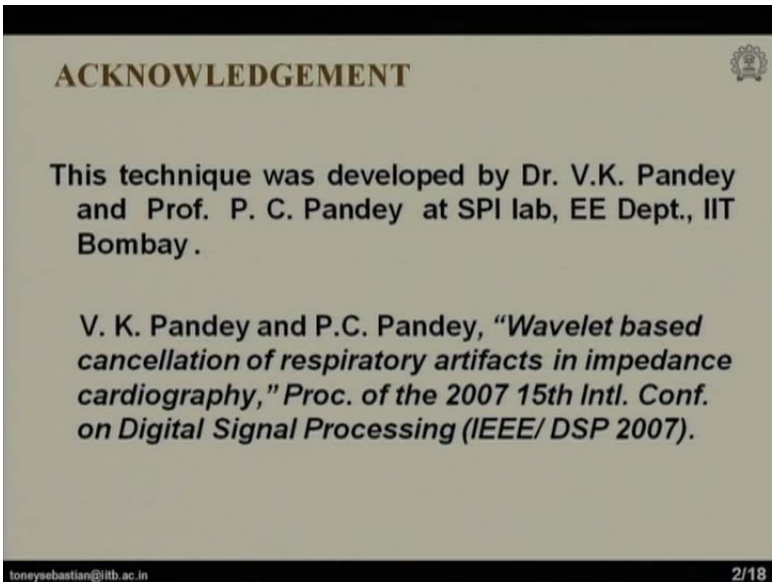

Now, the technique I am going to present here was originally developed by Doctor. Vinod. K. Pandey and Professor P. C. Pandey of EE department IIT Bombay.

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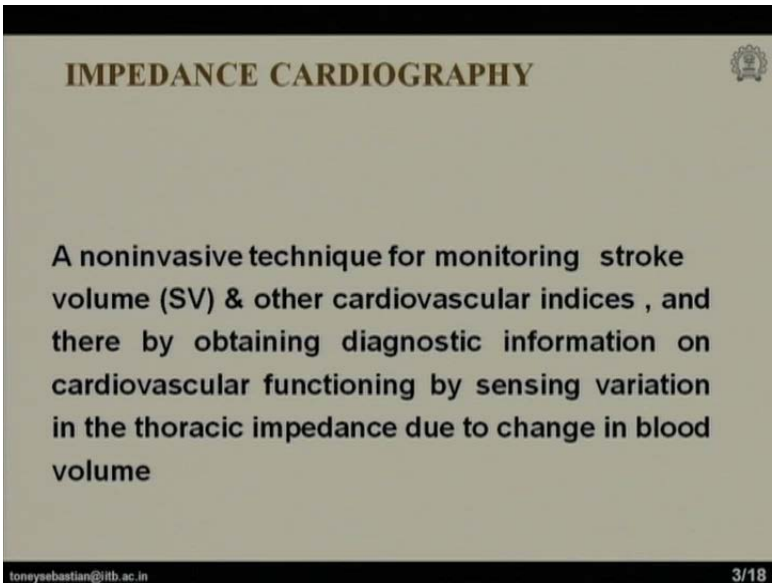

Now, what is impedance cardiography? Impedance cardiography is a noninvasive technique, for monitoring stroke volume and other cardiovascular indices; and there by obtaining diagnostic information on cardiovascular functioning, by sensing the variations in thoracic impedance due to the change in blood volume. Now, since most of you are from engineering background, many of the technical times in this definition are not familiar for you. So, it is better to have some basic understanding of the heart structure,

for getting into this definition, and hence fence for the better understanding of the project. Now, let us look into the structure of the heart.

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Now, this is the structure of the heart most of you may be familiar with, but this is not how the heart looks like. Let us look into the actual structure of the heart.

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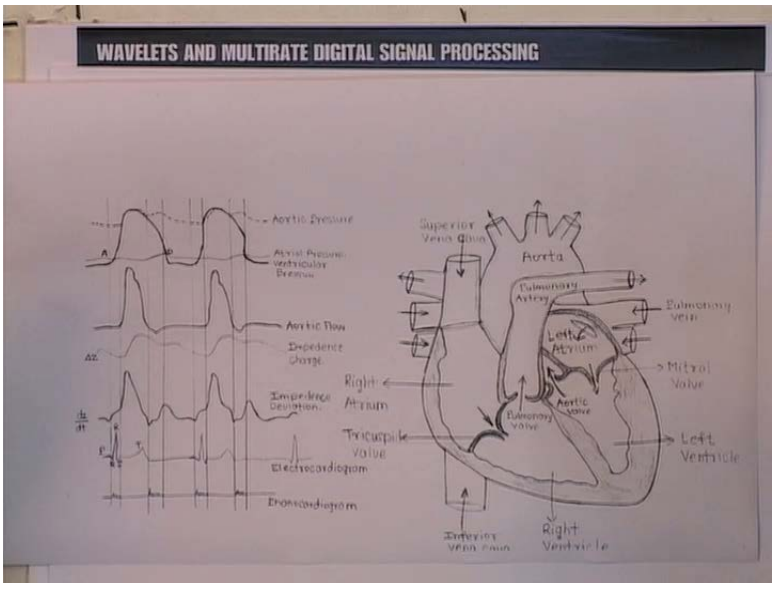

Now this is how the structure of the heart looks like. Thanks to my friend, Ajay Tijore for drawing such a wonderful diagram for this presentation, and now let us look into the structure of the heart, with an engineer's perspective. We can visualize heart as a

combination of four chambers; here you can see one chamber that is the right atrium, here you can see the second chamber; that is the left atrium. Now, here is the right ventricle, and here is the left ventricle. Now, the right side of the heart; that means, the left hand side of the picture, deals with the deoxygenated blood, and the left side of the heart, that is the right side of the picture deals with the oxygenated blood. Now, these four chambers can be visualized as a combination of as four pumps. Now, it is very similar to the mechanical pumps, the function is just to pump the blood.

Now blood from the different part of the body, will enter into the heart to the right atrium. Now, here you can see the two major vessels; that is, this one and this one. These are the superior vena cava and the inferior vena cava. Superior vena cava will be bringing blood from the upper part of the body to the heart, and inferior vena cava will be bringing blood from the lower part of the body to the heart. Now, the name superior and inferior is not because of its functioning, it is just because of the position. Now as soon as this right atrium filled with blood, this blood will be, right atrium will pump the blood to the right ventricle. There is a one separating the right atrium and the right ventricle. There is this one; that is the tricuspid valve. Now, from this right ventricle, this right ventricle will pump blood to the lungs for getting oxygenator.

As you know blood which is coming from different part of the body to the heart, has carbon dioxide in it, and we need oxygen in the blood for the body functioning. Now, in the lungs, this blood will exchange carbon dioxide and oxygen, for that this right ventricle will be pumping blood to the lungs, through the pulmonary artery. This is the pulmonary artery. So, right ventricle will be contracting in this direction, by that time this tricuspid valve will be closing. And this particular valve will be opening this particular valve is known as semi lunar one, because it is opening to the pulmonary artery, it is known as pulmonary semi lunar one. So, blood form this right ventricle, will pump to the pulmonary artery and it will go to the lungs, and from the lungs, blood will come back to the heart, to the left atrium. So, blood will come back from the lungs to the heart, through this pulmonary vein to the left atrium, left atrium is on the top side.

From this left atrium blood will be pumping into the left ventricle. There is a valve separating left atrium and the left ventricle; that is known as the mitral valve, or the bicuspid valve. Now, comes the most important part of the heart. Left ventricle out of this four chambers, I say left ventricle is the most important part, because left ventricle

will be pumping blood to the different part of the body. As you know, since our body parts for away from the heart, it has to do a lot of work for pumping blood to the different part. So, this left ventricle will be contracting with maximum folds, and when it is contracting this particular valve will be opening. This valve is again a semi lunar valve, which is the aortic semi lunar valve, because it is opening to the aorta. And from this left ventricle, the blood will be pumping to the aorta. Aorta will be taking away blood to the different part of the body; here you can see different branches of this aorta.

Now, here comes, here you can see the beauty of this cardiac design. I say the beauty because, see compare to all the other chambers, left ventricle has to do maximum work, for that this particular muscle has maximum thickness compare to other valves, other chambers. Now, another important factor here is, why left ventricle is important is, even if this arterial muscles have some problems, or even if this arterial pumps are not working, because of the gravitational force and because of the weight. This tricuspid valve and bicuspid valve will automatically open and seventy percentage of the blood will automatically fall into the ventricle even if this arterial pumps are not contracting. So, we can say, disorders related to atrium are not comparatively that much danger, compare to the disorder which is related to ventricle. Now let us look into some of the waveforms related to heart.

This upper dotted line indicates the aortic blood pressure; that is, when we are measuring our blood pressure, by using normal pressure meter, we will be getting this aortic blood pressure; that is when we are going to hospital the doctors measuring our aortic blood pressure, by using his normal pressure senses. And this blood pressure what we are normally getting for a healthy man 80 to 120; that is the systolic and diastolic pressure of the aorta. Here is the aorta you can see, because normally our doctors are measuring blood pressure in the hand. This blood pressure is slightly, whatever pressure we are measuring is slightly lesser than the aortic pressure, but it gives an approximate measure of aortic blood pressure. Now, the second waveform, is the ventricular blood pressure, and the third one is the aortic pressure. Now, at the initial phase you can see aortic pressure is little bit higher than ventricular blood pressure.

Now, when this aortic pressure is higher than ventricular pressure, this tricuspid valve, as well as the bicuspid valves is opened, and at this time, this left atrium and the right atrium are contracting, and blood will be falling to the ventricles. Now, as soon as these

ventricles start contracting, pressure inside ventricle will increase start rising, and at some particular point it will overcome aortic blood pressure. At that particular moment this aortic valve this tricuspid valve and semi lunar valve will be closing, because the pressure inside the ventricle is higher. So, this valve will be closing, and it prevents the back flow. And the pressure inside ventricles will be start again and again and building, at some particular point it will overcome the pressure inside aorta, and that that particular movement, this semi lunar valve will be opening and ventricle will be pumping blood into the aorta. This will be continuing for a moment, when this ventricle start relaxing, the pressure inside the ventricle starts reducing. When this ventricular pressure becomes lower than the aortic pressure, this aortic valve will be again closing, and ventricle starts relaxing the blood flow strokes.

Now, this ventricle pressure again will come down, and when it comes down below to the arterial blood pressure, this tricuspid valve and bicuspid valve will again opened, and blood will again come to ventricle, and this cycle will be continuing. Now, next waveform is aortic flow. As you can see, this particular point is the point at which the aortic valves are opening. The semi lunar valves are opening, and at this particular moment blood flow to the aorta starts, and it will be a pulsatile flow. You can see, if you tie at our radial aetrial or some particular points. You can see the pulsatile flow; you can feel the pulsatile flow of the blood. So, this will be pulsatile and when this particular valve is opening, blood flow will be, a sudden blood flow will happened, and it will continue for a moment, and once the valve closes flow again stops, again in the next cycle it will be continuing.

The next two waveforms will be looking a bit later and the next waveform, this particular waveform is the most common bio signal, and most of you might be familiar with this particular waveform. This is the electrocardiographic waveform, in most of the films, the climax scene will be some ECG waveforms will be coming, some ECG waveform will be coming and once the waveform will be stopping, that will be the end of the storing. So, this waveform particular waveform, this electrocardiographic signal, gives a measure of the electrical activities of the heart. This particular waveform I will draw once again and I will explain.

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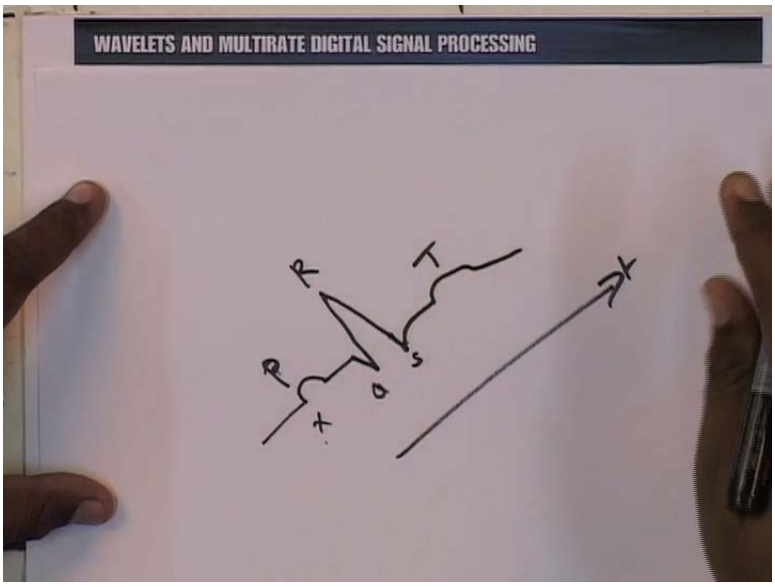

Now, in basic electrocardiographic signal will be looking something like this. So, this is the P wave, then q R s either t wave. This P wave indicates the beginning of contraction of the arterial pumps. So, as I show in the previous picture, the arterial pumps will be start convicting at this. This axis is the time axis. So, in each cardiac cycle, at this particular moment the arterial pumps will be starting contracting. And this P R s complex indicates the contraction of ventricles. So, arterial contracted, at this particular moments the ventricular pumps R start contracting, when the ventricular pumps R start contracting the upper pumps again start relaxing, at T view the ventricular pumps R relaxing.

So, by looking at an electro cardio graphic signal; this can tell how would a heart is working or what are the major disadvantage, means disorders of a heart we can tell. Now, coming back to the previous picture, so this gives m measure of electrical activities of the heart. Now, the last one is the phonocardiogram; that actually gives the cardiac sounds, cardiac sounds mean our doctors basically by stethoscope they are hearing this sounds. These sounds are actually sounds of closing of these valves, first sound is the closing of these aortic valves, and the second one is the closing of this semi lunar valves. Now, we will go back to impedance cardiography our technique.

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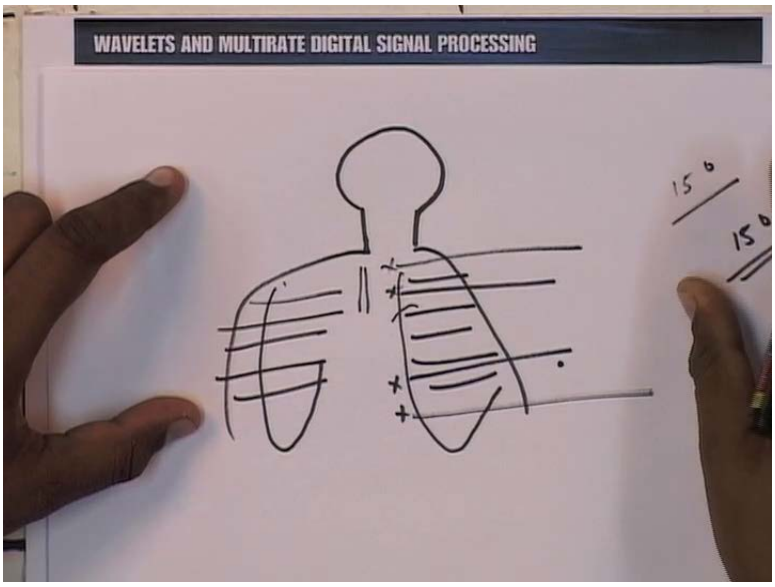

Now, for impedance cardiography, we will place four electrodes; like this in the body, and we will be injecting current through the upper two electrodes; that means, we will be basically injecting a high frequency current of very low amplitude, and we will be measuring the potential voltage difference between these two particular moments, and we will find out the impedance variation across these two particular point. This area is the thoracic region. Now, we will go back to the previous picture and understand the two waveforms which we kept aside. Now, these are the two waveforms we kept, this one is the delta is a; that means, the impedance variation, because of the blood flow, because in every body part. In the thoracic region there are basically three types of conductive issues; that is, first one is the. In this area, basically we can see, three different types of issues; one is the ribcage you can see something like this, we have ribs this side and this side ribcage bound, these are bonds these are basically nonconductive.

Then here we will be having the lungs, lungs are muscled tissues, soft tissues, they are conductive, but note that much conductive compare to blood. And next one will be the vena cava and the thoracic aorta, vena cava will be somewhere here and aorta will be here, and compare to all the other body fluids or body parts, blood is more conductive. For example, if you say a conductivity of blood is 150 then conductivity of lungs and other muscles are 1500, or 10 times lower compare to blood. So, whenever the heart is pumping, what will be happening, this aorta will be changing its dimension. Now,

because of that the voltage we are measuring changes, and we can sense, we can find out the impedance variation from that.

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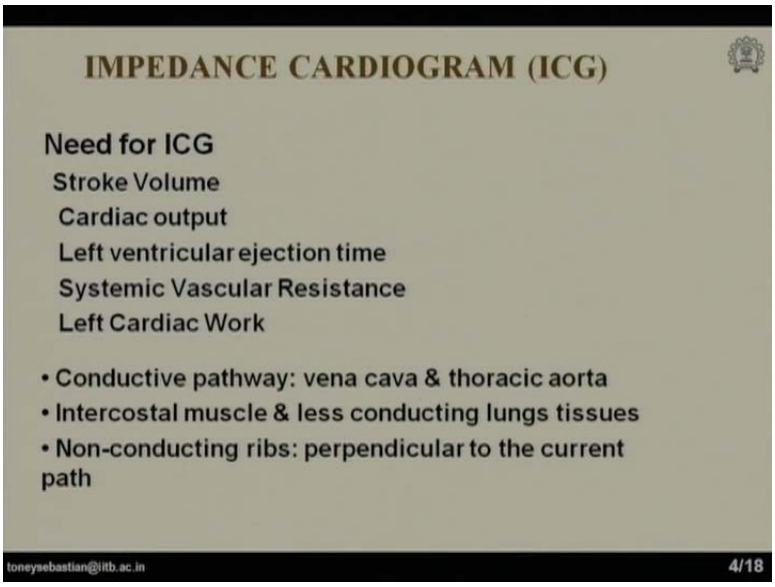

Now, this is how the impedance variation looks like, whenever the aorta is opened; that means, blood is pumping to the aorta its dimension changes, and the impedance go down, resistance go down. So, here you can see a fast change in the impedance, and it will again come down again in the next cycle the same variations will be happen. And the time derivative of this particular waveform is known as the impedance cardiograph cardiogram signal. By using certain parameters measured from this impedance cardiogram signal, we can find out stroke volume and as we told other cardiovascular parameters. The three major points in this particular waveform are; the b point, the c point and the x point. These three points are the major points in this particular waveform, and this is the time derivative of this impedance waveform, and this is known as the impedance cardiogram signal.

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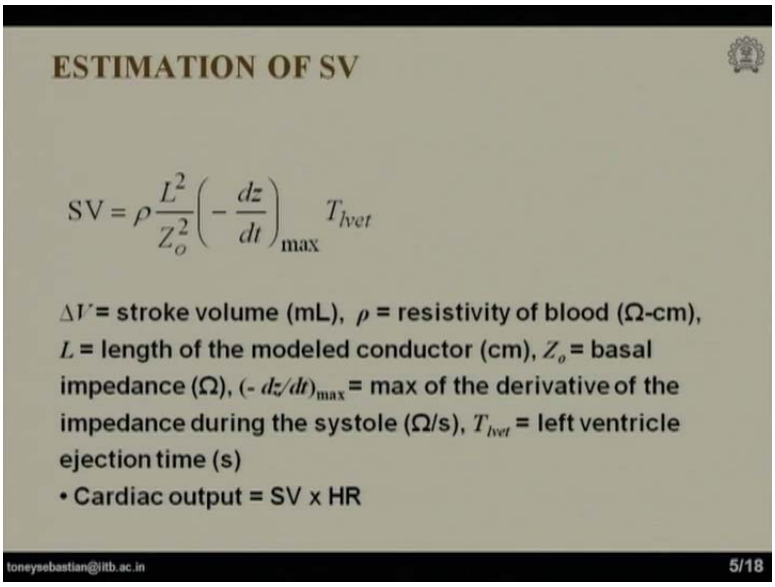

Now, coming back to the slides, for finding out how to estimate the stroke volume? Now, for estimating the stroke volume, we have a special formula developed by Kubrick et al; that formula is stroke volume here, in the slide you can see, stroke volume is equal to rho into L square divided by Z not square, into negative of d Z by d t max into T l v e t. Now, let us spend a minute in understanding this formula, rho is the resistivity of the blood, that is a constant, that is somewhere around one fifty. Then L is the distance between the electrodes, as we show in the previous picture. The distance between these two electrodes are there; that is the. We are we are actually modeling this thorax as a conductor. So, the distance between these two points is L. Now, the next parameter is the L naught; that from the previous picture, this delta Z will be above a particular base value. So, that particular base value is Z not normally it is around twenty five, but it varies from patient to patient.

And the next parameter is d z by d t max, d z by d t max, this is the d z by d t waveform, d z by d t max is note the difference between the c point and x naught x point, but it is actually the difference between b point and the c point. Now, b point what is the significance of b point and x point, see here comes the significance of the other waveform, b point indicates this particular point. This particular point is the point at which ventricular pressure is above the aortic pressure; that means, this is the particular moment at which, the aortic valves are opening and the blood is pumping into the aorta. And x point is this particular point and at this particular point, ventricular pressure will

be again come down below the aortic blood pressure. And at this particular moment this valve will be closing. So, during this period; that means, the time period from which b point to x point, aortic valve is opened and this is the particular moment in which aortic valves are opening and this is duration in which ventricles are pumping blood into the aorta. So, T l v e t is basically, the point difference between time duration between b point and x point.

So, from this waveform impedance cardiography, waveform we will be basically taking d z by d t max as well as T l v e t. Now, the other major parameters related to heart; they are stroke volume, stroke volume is basically the amount of blood pump by heart in one during one heart beat; that is, during which this aortic valve is opened what is amount of blood pump by the heart in one cardiac cycle, and the second parameter is cardiac output. Now, cardiac output is the amount of blood pump by heart in one minute; that is basically stroke volume multiplied by heart beat; that is, we can see by counting just by counting number of c points or c points will be very easy to detect, and by recounting the number of c points or by counting the QRS complex in the ECG diagram we can get the heart rate.

And then by multiplying stroke volume into that particular value will be getting cardiac output. And next parameter is, left ventricular ejection time; that is, basically the time difference between the b point and x point. Next parameter of interest is, systemic vascular resistance; that is, the resistance offered by aorta to the blood flow. And the next cardiovascular indices is, left cardiac work; that is, as I told you we are basically, among all the cardiac parameters we are basically interested in this part of the heart; that is, left ventricle the work done by this part of the heart for pumping blood into different part of the body, that is the left cardiac work.

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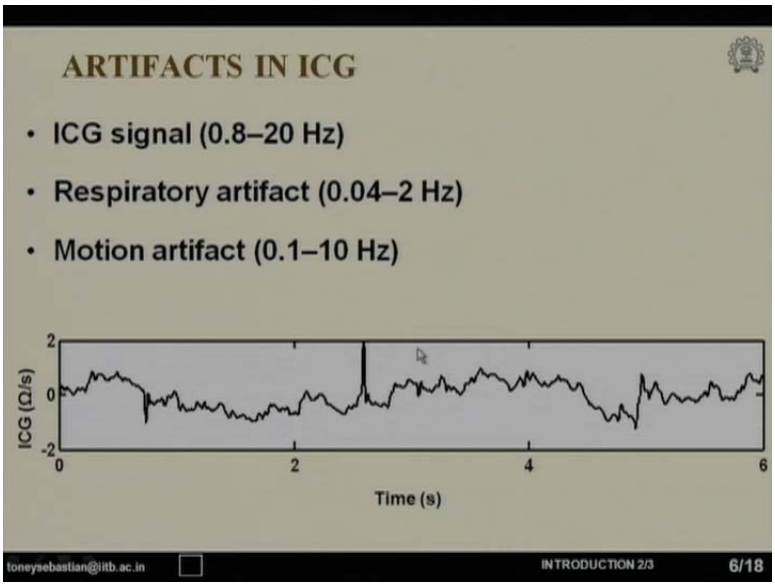

Now, coming back into the artifacts, impedance cardiography is signal, basically how few types of artifacts, what are artifacts. Artifacts are actually manmade signals, which are unnecessary in impedance cardiographic point of view. Now, we have two types of artifacts, major artifacts are the respiratory artifact and the motion artifact. Now, respiratory artifacts are very low in frequency; that is basically from point not for hertz 2 up to 2 hertz and motion artifacts are up to 10 hertz. Now, if you realize the impedance cartographic spectrum, we have signals of interest from 0.8 hertz up to 20 hertz. Now here you can see that this motion artifact and respiratory artifact, has signal components of components in the same band. Now, here in this particular presentation we are looking into respiratory artifact separation, now in this particular picture, you can see a signal in an impedance cardio graphic signal recorded during exercise.

So, this is an ICG waveform recorded from a healthy subject, during exercise. So, this particular signal has both respiratory and motion artifacts. Now, these particular peaks high peaks are because of motion, and this slow varying base line is because of respiration. Now, what is the disadvantage of this artifacts, here you can see when we are finding out d z by d t max, this particular points will be coming into picture, and they will be introducing severe errors, and because in the formula we are using this d z by d t max this will introduce severe errors, for calculating a stroke volume. Also this base length drift, also introduce errors in d z by d t max also in T l v e t calculation. So, it is

very important to saporous this artifacts, for the proper estimation of stroke volume and other cardiovascular indices.

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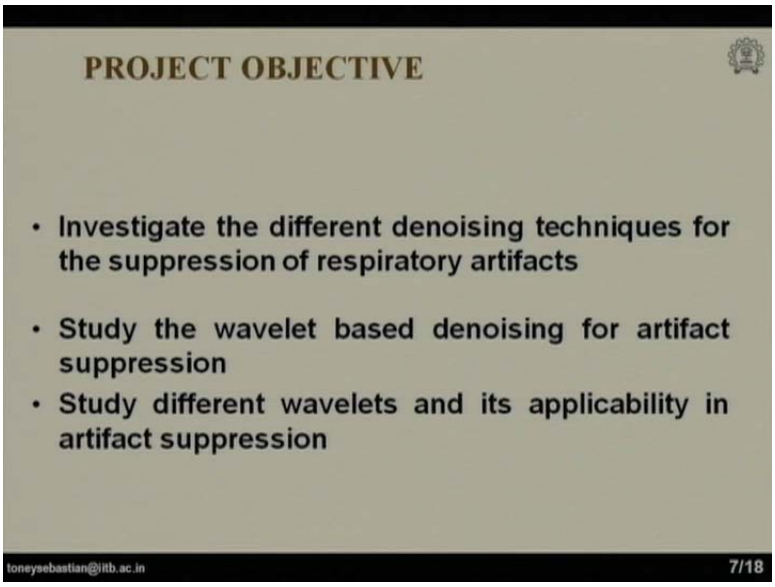

Now the project objective is to investigate different denoising techniques for the suppression of these artifacts, and study in detail the wavelet based denoising technique, for the respiratory artifacts suppression, and investigate few different wavelets, and see how this wavelets are use full in this denoising applications.

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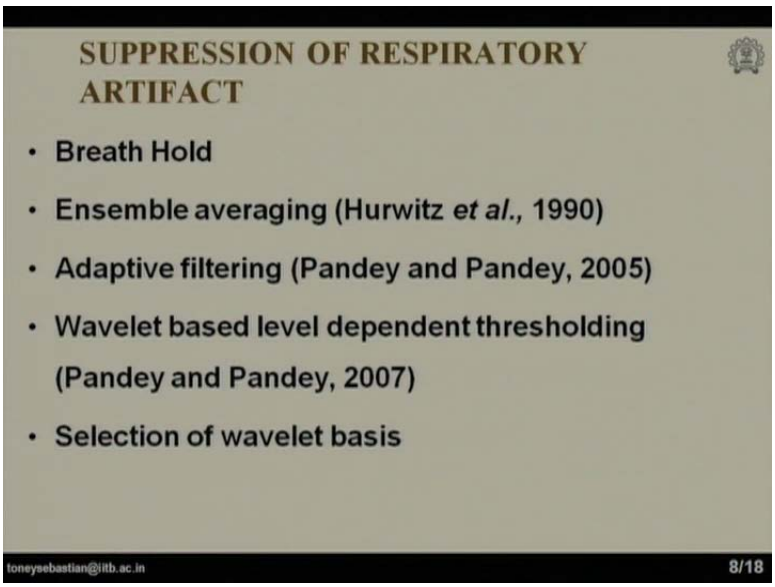

Now there are different methods of artifact separation; the first technique is, breath hold. Now, you can see the respiratory artifact is because of respiration. So, the easiest way or the simplest way of respiratory artifact cancellation is holding the breath. Now the program with breath hold is, when we are holding the breath cardiac activity will always go down. And another problem is, when we are recording the impedance cardiogram after exercise it is difficult to hold the breath, because after the exercise cardiac activity will be more, so it is difficult to hold the breath. The second establish technique is ensemble averaging. The problem related ensemble averaging was proposed by Hurwitz et al 1990. The problem related to ensemble averaging is, it will distort the waveform or it will remove the beat to beat very built in the impedance cardiogram. Actually we are interested in stroke volume as well as the variation in the stroke volume.

In each beat how much variation is coming in the blood; that makes the sense in diagnosis. Now, when we are doing ensemble averaging, it may blur this b point x point and. So, we would not get after ensemble averaging, we would not get this clear b point and x point, and hence it will introduce distortion or errors in calculating the stroke volume. Next technique is adaptive filtering, which is developed by Professor P. C. Pandey and Vinod. K. Pandey again in 2005 in IIT Bombay. The problem with adoptive filtering is, adaptive filtering is always good in bio signal denoising if you have a reference signal, but for adaptive filtering we need to have a reference signal, for that we have to keep a pressure sensor in the nostril.

So, this is again problem of special complaints, that is how adaptive filtering works, then the next technique is, the one which we are working on is wavelet based denoising, which is known as the level dependent thresholding, which is again developed by Pandey and Pandey in 2007. Now, in wavelet based denoising, selection of wavelet bases is very important, why selection of wavelet base is very important, in denoising applications, it is observe that basically in whether it is in ECG denoising or in ICG denoising. It is observed that, if the wavelet and the waveform has some similar shape, then the denoising is better, always better. So, in ECG denoising or in ICG denoising, there are some particular wavelets which has some shape stimulate by bio signals, those wavelets will be giving better denoising, better separation of noise and the signal.

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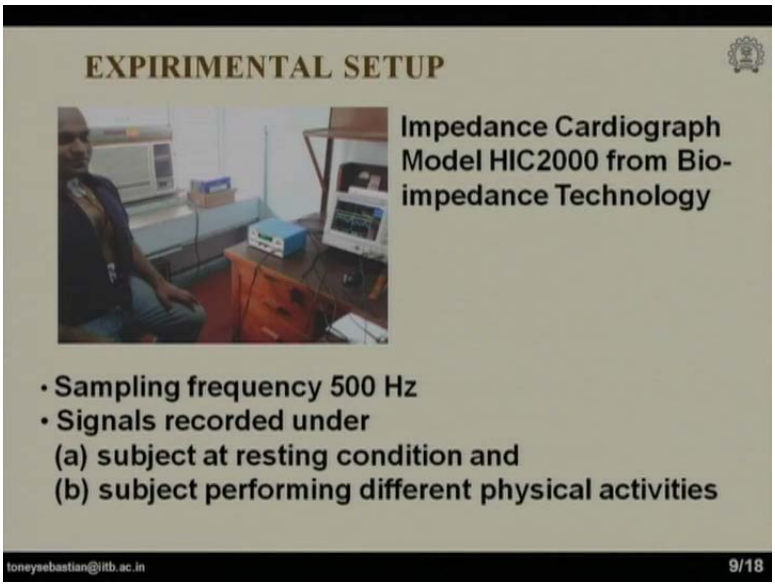

Now, let us see some waveforms. This is the experimental set up of impedance cardiography. Here you can see the recording of impedance of cardiogram, four electrodes are placed or here, two in the upper part and two in the lower part. This is the impedance cardiograph. And through the upper two electrodes, current will be injecting, high frequency current of low magnitude will be injecting, and this will be measuring the. This lower two electrodes will be used for measuring the voltage, and hence we will be calculating the impedance variation. Now, this impedance cardiograph, this particular impedance cardiograph is HIC2000 impedance cardiograph from bio impedance technology. Now, we have occurred the signal at sampling weight of 500. Signals are recorded both in resting condition, as well as signals recorded, by performing different activities, one signals which we. So, before, while performing some activity.

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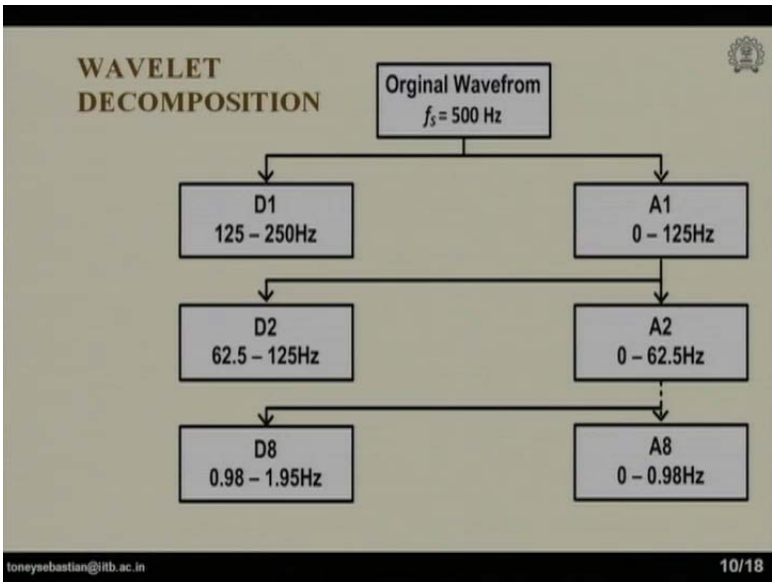

Now, this is the basic wavelet decomposition. The original waveform is sampled at 500 hertz. Now, each detail gives a bypass signal and each approximation gives a low pass signal. Now, when we are decomposing the signals into different levels; for example, if you are decomposing the signal into 8 levels or 9 levels, the first decomposed, if the sampling rate is 500, it will be having signal components up to 250 hertz, because of nyquist criterion. So, the first detail will be having components from 125 hertz to 250 hertz, and the approximation will be having signals from 0 hertz to 125 hertz. Second detail will be having components from 62.5 hertz to 125 hertz, and second approximation will be having components up to 62.5 hertz. Similarly in 8 level detail, it will be having components from 0.98 hertz to 1.95 hertz, and approximation will be having components from 0 to 0.98 hertz. Now, in this particular method what we are doing is, we are decomposing the signal into different level. And we are also decomposing the artifact into different components, and we are seeing up to what level the signals are present, and up to what level the artifacts are present.

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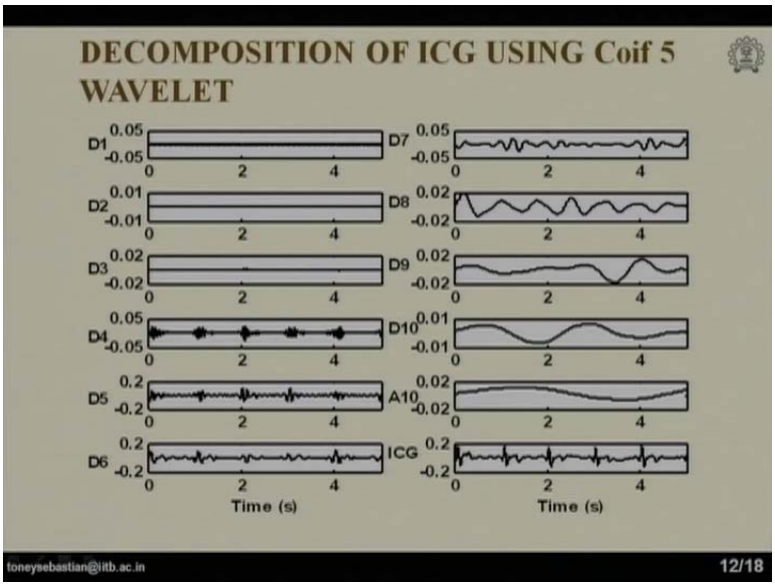

Now, we use different wavelets for the decomposition, and this is the 10 level decomposition of ICG signal which is shown here, by using the coif 5 wavelet. Here you can see detail 1, and detail 2, they do not have much component, detail 3 they do not have many components, because we do have components only up to 20 hertz. These are high frequency components; we do not have any a signal or artifact in this area. And from the fourth detail onwards, we have signal components 5, 6, 7 up to 10, all the approximation, all the detail and approximation. This is and ICG recorded under breath hold condition. So, it is not having any artifact, it is having only purely signal component. So, all the 10 detail, and approximation has signal components.

So, we cannot use this particular wavelet for the separation, because it is not capturing signal components in any particular detail, because, see 8 level detail or 9 level detail are very low frequency components. So, this will be having, if the signal supposed to have respiratory artifact. This will be having signal as well as D 9 and D 10 will be having signal as well as artifact. Now, this particular waveform is the ten level decomposition of, same ICG using daubechies 6 wavelet. Again you can see all the ten detail and the approximation has signal components in it.

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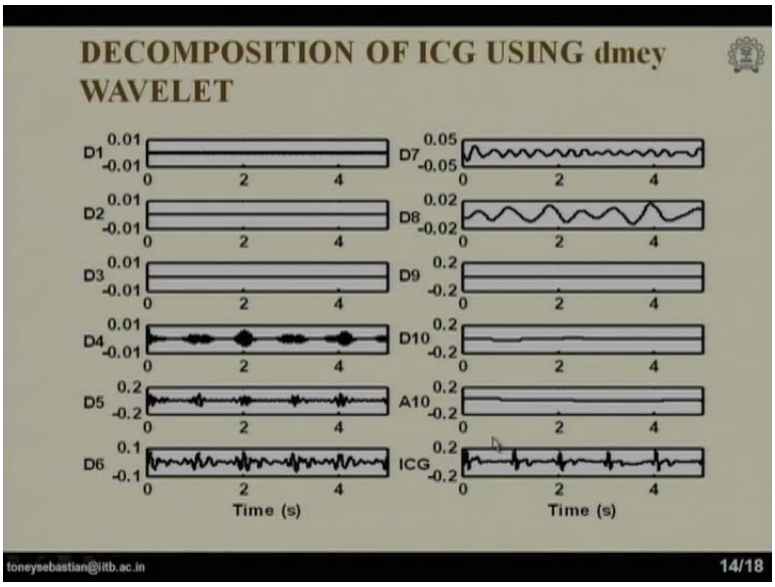

Now, here comes the one which we are interested in. This is the ten level decomposition of the same ICG by using dmey wavelet; that is the discreet Meyer wavelet. Now, here you can see D 1, D 2, D 3 as such their high frequency components, we do not have any components in that, but D 4, D 5, D 6, D 7 and C 8 has signals in it, but in D 9 D 10 and A 10, we do not have any signal components. So, this is basically D 9 is the low frequency area, that is from 02.98 hertz. So, here is basically, in this frequency band the respiratory artifacts are coming, and in this particular session we do not have any signal component. So, this particular wavelet will be very useful for separating the signal, and the artifact. So, in our denoising technique we will be basically, adding this first eight details and will be removing D 9, D10 and A 10 for the artifact separation. So, the artifacts free ICG signal is, obtained by adding D 1 D 2 D 3 D 4 D 5 D 6 D 7 and D 8.

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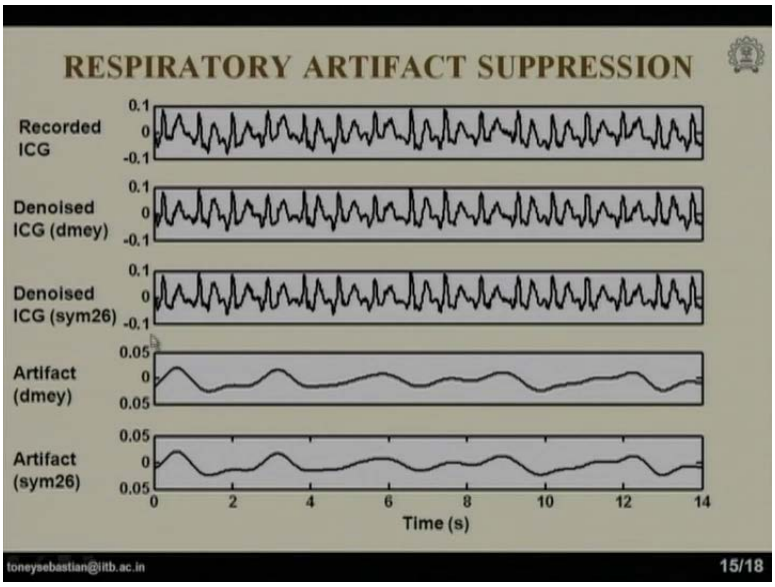

Now, further studies at (( )) showed that, similar results this obtained by dmey wavelet can be achieved, by using one more wavelet that is similar 26 wave also gives similar result as obtained by dmey wavelet. Here you can C 1 ICG waveform recorded under resting condition, but with respiration. This first waveform is the ICG recorded with respiratory artifact. This low varying oscillations are because of this respiration, sinusoidal oscillations are because of the respiration. Now, the second wave is de-noise ICG waveform, by using dmey wavelet; that is we are we have decompose in the signal into 10 levels by using dmey wavelet, and reconstructed the signal by using first 8 details. And the third one is, same procedure followed by using symlet-26 wavelet. By visually we can see both the wavelets are giving same performance. Now, fourth one is the artifact which is extracted from the ICG waveform, by using dmey wavelet, this is basically first waveform minus the second waveform; that is, first waveform which has artifact and the second one is the de-noise waveform. The difference is basically the artifact signal. And the last one is the respiratory artifact they moved by using, similar 26 wave waveform. Here you can see both the waveform, both the wavelets are capturing, exactly same multiplied and exactly the same signals.

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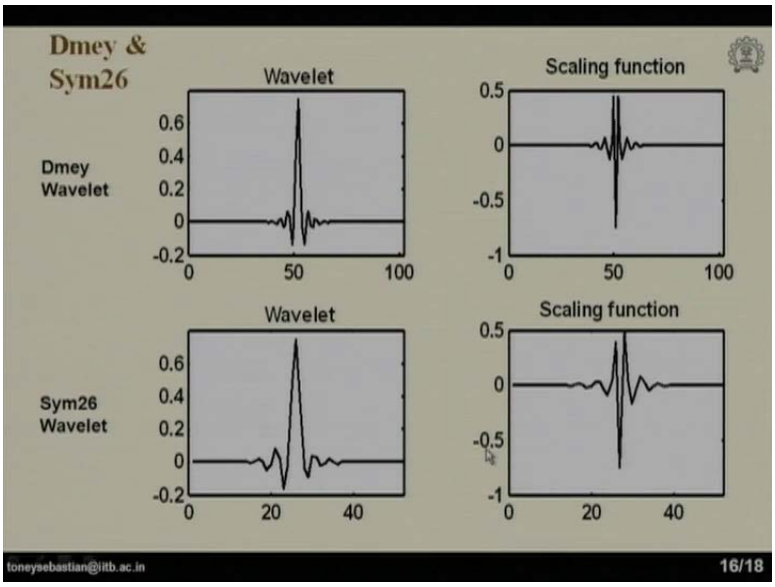

Now, why this happens, see here we can see the wavelet and scaling function of dmey wavelet and symlet-26 wavelet. Here dmey wavelet has one note two samples in the wavelets, compare to symlet-26 wavelet has 52 in it. Now, here you can see, it almost has same shape. We can see a shapes similarity in dmey wavelet and similar wavelet, both the mother wavelet and the scaling function has similar shape for dmey wavelet and symlet-26 wavelet , because of this shape similarity we are getting, same result for both the wavelets.

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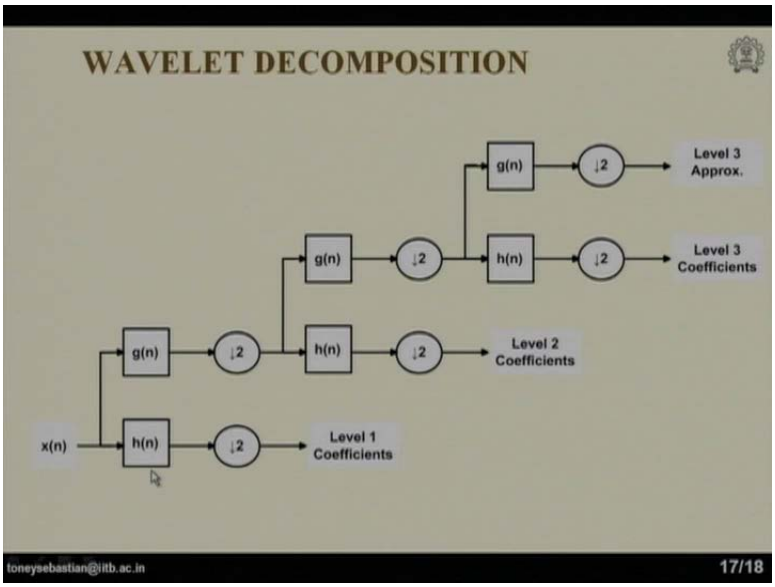

Now, this is a basic block diagram of wavelet decomposition by using filter banks. Here you can see we are using, we will be having filter is low pass filter, decomposition filter, and again here, after this here we will be getting wavelet coefficients, and for getting the details by we have to use the reconstruction filter of same length again. Here you can see, the advantage of using symlet-26 wavelet, because symlet-26 wavelet is having only 52 coefficients compare to dmey wavelet, it having one or two. So, since we are using 10 level decomposition; if we use symlet-26 wavelet, the calculation complicity will be comparatively very less compare to dmey wavelet

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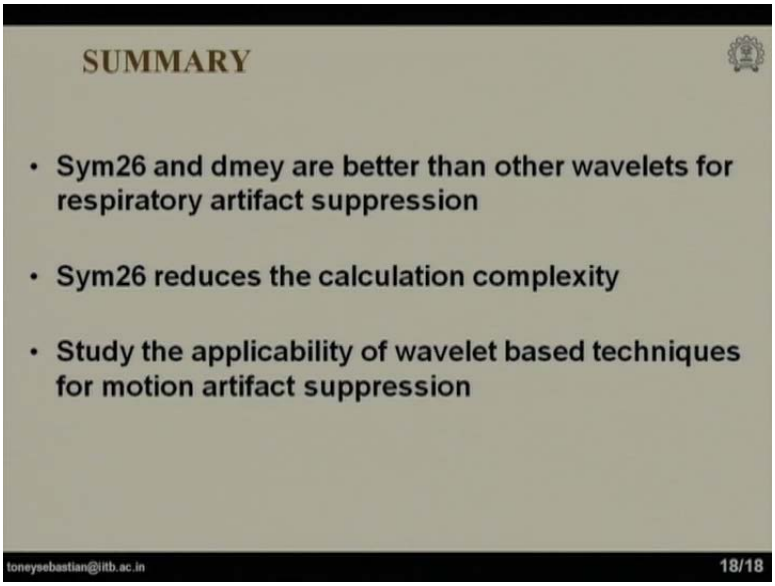

Now, coming back to the summary of the presentation; we can see that both symlet-26 wavelet and dmey wavelet are giving better performance in artifact separation, and they are giving almost similar performance compare to other wavelet, and we studied different wavelets like coiflet wavelet and the daubechies 6 wavelet, they were not comparatively that much good compare to these wavelets. And advantage of symlet-26 wavelet is it reduces the calculation complexity, because of it is having low number of filter coefficients. Now, the future work will be, we can study the applicability of wavelet in denoising motion artifacts, and also we can investigate whether any other wavelets are giving in denoising application.

What you can try is, you can use this technique or similar technique, for the denoising of ECG denoising, because ECG data files are available in MITB database you can download some ECG database, data signals from MITB database. And you can try

similar kind of technique in denoising of ECG signal. ICG signals are till now it is not that much popular compare to ECG signal, so we do not have any open database compare to ECG signal. So, you can download some ECG signals from the MITB data base, and I hope you all will try, some of the denoising techniques. May be this techniques may not be applicable, but some modification of this may help in denoising ECG signal denoising also. So, you can try that kind of denoising.

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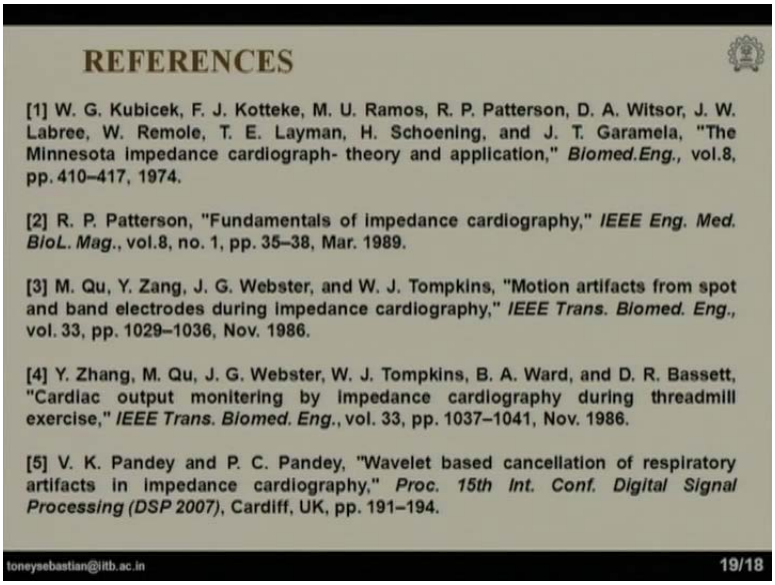

And these are few reference papers we have referred; first paper is Kubicek et al's paper, they proposed the impedance cardiograph technique itself. And the few other reference papers are denoising techniques and signal processing techniques. If you are interested in further studies, you can refer to these papers and get more information, on this a denoising technique and more about impedance cardiographic technique. That is all about in the presentation; thank you.