Biomedical Signal Processing
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Lecture - 46
Modelling of Biomedical Systems (Contd.)

So, now we will go for the summary of this session that the modelling of biomedical systems.

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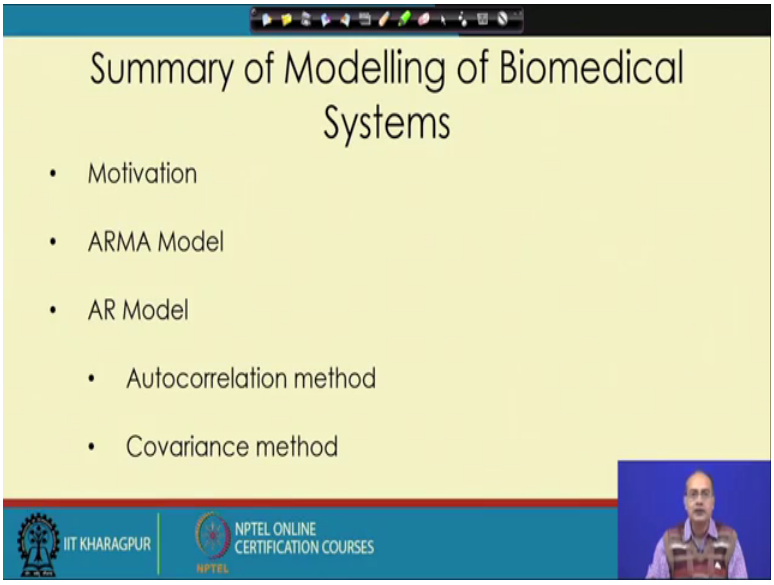

So, first we will look at the motivation behind it that we have seen that there are number of examples starting from EMG signal. In case of EMG signal, say we want to lift and weight and we are actually asking the muscles of our hand to exert that force to leave that weight.

Now, for that that again and again those muscle fibres they need to be energised to give that input to contract and give that force. So, what we have seen that again and again same set of muscle fibres, they are energised with the help of neuron and we get a train of signals which we can model as impulses that that is giving the signal to the muscle to contract again very similar kind of thing, we have seen that when we look at that our book order or our speech whenever we are uttering a vowel, we have that the pulses coming out of the that glottis due to the vibration of them and we get the vowel sound.

So, essentially if we think that the glottis gets a signal and excitation to give that glottal pulse, then we can get again a pulse train as an input to the overall system of our vowel sounds a little different from that, but again a very similar kind of model is for the consonance where we see that that we have a transfer function of the vocal track and it is excited by the turbulent air coming out of the lung.

So, all these things; they motivate us that all this models, they have some similarity and we can think them in terms of some filter driven by some kind of input and for that; we have chosen one is point process where the impulses are impulse train; rather is the input and other is ARMA model. So, in these two cases, we thought of some modelling.

Now, let us look at the theoretical part of it. What is the motivation for going for these models or rather for parametric modelling?

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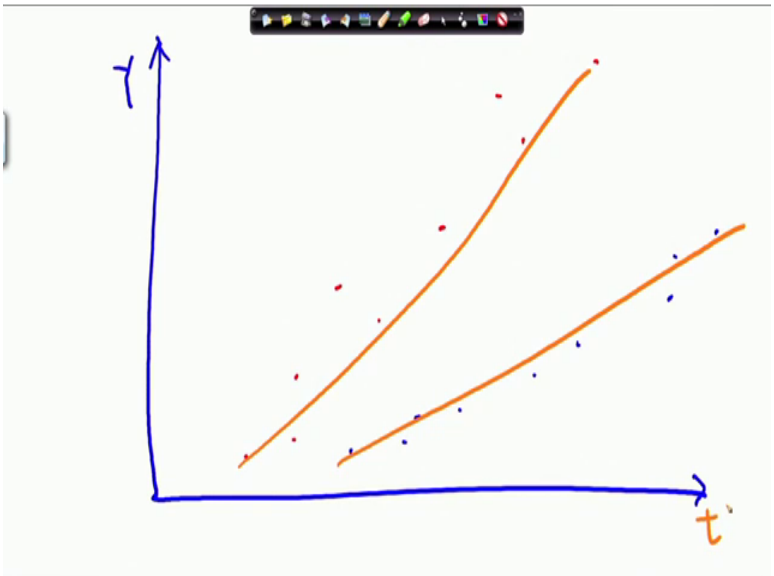

Let us take some example that we have some points. Now, we have may be another scenario, may be this is the normal condition and this is the abnormal condition ok, let us change the colour to distinguish that. Now this two set of points red and blue; if we do not have any information, we can think them as a cluster two different clusters.

But if we know there is a relationship between the two axis to be specific, in this case, say two variables, if I take that x and y and there is a functional form between them to make it, simple, let us take that that they are coming out of some linear model ok, if we assume that; then the things becomes much more simple; first of all from a cluster when we talk about a straight line, we need much less of information and when we have much less information, then we have saving in computation, when we try to compare, then lot of assumptions actually you can make use of it.

If you look at those points; what you will find that whatever the divisions and they are from the straight line they are errors; that means, they do not give any useful information to us. Again, if we assume that one of the valuable say that what we have taken as x that we may take that as time and say our timekeeping instrument is pretty accurate, we do not suspect any error there in that case the error is limited only in the variable y. So, do you see that; we actually get more and more control over the scenario and we can reject some of the things whenever the error is there, we do not say that the error is all the variables we know, it is just in one variable because our the clock is pretty stable.

Now, what is the benefit in that? We told that coinciding the information gives value when we look into this scenario instead of now trying to find out the difference between the two clusters, as you boil down to the two lines. Now we can compare them, those two lines in terms of the equation of the lines. We can look at the slope and the intercept form; for example, and we can simply compare these two variables and tell that which is the normal scenario and which is the abnormal scenario.

Now, all these things; first of all gives a shift in actually time that earlier we are talking about the observations. Now from the observations, we are getting into the model and once we get that model, we simply ready to forget about that data because the data was important. So, long we could not get that model. Once we get that model, data is nothing, but it some outcome of that model. So, there is a change in actually the thought process also and that gives us a lot of benefits.

So, let us look at again look back at that ARMA model. ARMA model is the simple linear prediction model that prediction is based on the present input, few past inputs and few past output values and out of that whatever we the output, we get in that case that when we run it in the practical scenario, most of the time we do not have that input.

For example, we can collect the ECG or EEG or EMG from the skin; that means, in a non invasive way, we can collect those signal, but we cannot get actually that the signal for the actuating signal for the EMG that is coming through the nerve or the input given by the s a node to create the ECG signal all those things if we have to capture we have to go in a invasive way. So, it is not possible to actually go for them. So, in those case, as the inputs are not available, we look for a simpler form of ARMA model we keep only the AR part where the prediction is based on the past outputs and the present input, but as the present input is not there; what we do with the help of the past output, we try to predict the present output and the error what we get we try to minimise that error for the best fit of the model.

Now, that give rise to scenario; what we get that the error, it is actually coming orthogonal to the space span by the previous observations of the signal output signal rather now and that is why we call that equation as a normal equation and when we have a model like that and we said the parameters in an optimal way, then that error becomes actually white noise and we know AR and ARMA process are also driven by white noise. So, during the analysis we find out that model and the actually we get the error as a white noise and that is why we call it as a whitening filter.

And let us look at the ways, how I can we can find out actually the AR parameters the two dominant techniques, we have discussed first is autocorrelation based technique where the idea is that whatever data is there, we try to make use of all the data all possible samples, we could do we want to use it because autocorrelation definitions arrays that we should take the summation from minus infinity to plus infinity, but in reality we have the only have a finite set of data and from these are very proceed, we get some nice form of that equation which gives rise to a matrix that autocorrelation matrix where all the diagonals.

They are actually having the same value and we can call it also a circulate matrix. The same set of actually values as you move through a rows, you will find that they are actually getting a rotation by ones actually space that and it is a symmetry matrix that overall structure of it is called Toeplitz matrix and using that property of that Toeplitz matrix, we have the Levinson Durbin algorithm which can help to reduce the computational complexity.

And we get actually something called reflection coefficient which helps to get the AR parameter and those reflection coefficient. They make sure that the filter is a stable one all the time, what it does? It actually reflects the pole, even if it is not a that output signal is not a minimum phase signal it reflects the poles because it is the AR process only no that ma part is there or 0s are there. So, the reflect within the unit circle and we get a stable realisation of the filter.

Now, these are the good part of the AR process using the autocorrelation method, but while trying to actually use that every bit of sample do estimate the autocorrelation function we have a small problem there as we increase the number of lag, we see the number of actually summations that keeps on decreasing in a linear way; that means, for the 0th lag, if we have n summations when we go for the pth lag, we will have n minus p summations.

So, essentially, we are actually reducing the number of summation and the accuracy is going down or we are imposing unintentionally a triangular window on it; now as such if you ask that; what is the problem in that, we heard about the problems while studying the periodogram the number of problems we know that the accuracy goes down. Now that accuracy going down, it does not affect that much in case of the parametric on model, the primary reason is here, we take that model order p that is usually much less than the total number of samples say capital N.

So, that the error or that whatever the inaccuracy we are talking about that actually is much less and that whatever we get we get it much better than the AR process. So, rather periodogram without the number of lag what we use that is very limited which is unlike the periodogram where we need to use number of ACF and as we increase that value only, then we can get better resolution in the that spectral domain.

However in this case the spectral domain resolution does not depend on the number of autocorrelation functions, we used that is the primary difference between these two and here as a result that autocorrelation function using that AR process that whatever the PSD; what we get that PSD is much more smooth; that means, having less variation and it gives actually prominent peaks. So, it becomes much easier to understand that signal to get where the energy is lying and we get a much more simpler structure.

And another point here, we should mention that though the initial attention to the parametric model was to model the PSD of the signal later on people found that although parameters in the parametric model and all those PSDs, they have some one-to-one correspondence. So, the PSD become less important in many places and people actually could do all the task with the help of those AR parameters.

For example, that if you want to compare the two techniques or rather two kinds of signal one is normal and abnormal, you can directly look for that AR parameters like the example tau example, we have taken there, we have taken two straight lines and in that case we could use that slope and intercept to compare the two lines.

Now, it is not always true that the AR parameters will give good separation in those cases because what we get that there is a lot of non-linear transformation is going on in between the relations and not that simple from the PSD or from the signal to the AR parameters. So, sometimes the other parameters come into play which exhibits the change much more better way one of them is the Cepstral coefficient specially for the speech processing Cepstral coefficient, they have a place of their own and what we get Cepstral coefficients; they have direct relationship with the AR parameters.

And if we know the AR parameters, we can directly compute the that first p Cepstral coefficients from the that p AR model coefficients and for that we need not have to take the trouble of doing the log FFT inverse FFT inverse log or that taking care of the phase that is phase unwrapping. So, all those things we can avoid directly with a set of equation we can compute the Cepstral coefficient. So, that is the beauty of the that AR model and primarily it is done because in speech signal what we found that Cepstral coefficients show the changes in a much more prominent way than the AR coefficients.

So, it is better to go to the Cepstral domain in that case and compared the different cases. Now we have seen another variant of the that autocorrelation method that is the covariance method for estimating the AR parameters that different between these two is that when we go for the covariance method the change is that the summation for we can say that autocorrelation estimate in this case, the change is motivated by the fact that we should have same number of terms for all the lags.

Unlike the previous case where for the 0th lag, we have more number of actually samples to sum and when we the lag increases we have less and less sample for the summation in this case, we take equal number of them, but because of the change in position, what is happening? the total number of actually summations what we get we are going for a conservative way; that means, for 0th lag also. Now we are taking summation which is n minus p.

Now, what is the effect of this? In this case, the function what we get in that way that we take the summation actually not in the autocorrelation function the starting point is the sum of square squared errors. Now that interval of summation actually we have change and from there, it is flowing down to that function whether it is autocorrelation function or the auto-covariance function.

Now, the form of the function is change and that is why we call it is a auto covariance method and when we write the matrix to solve the equation, we can the see the change in a much better way first of all. Now the diagonal terms, they are not actually exactly the same, there is some small change from one diagonal term to the other because that is a small change in the points that they are summed up though the number of summations are same for all the lags and all the places. So, that gives rise to the different form and we can say now that we are not doing injustice to any lag that by that method, we lose the structure of the that Toeplitz matrix. So, that is the way, we pay that we cannot use that efficient structure for computation of the that AR coefficients and it can give the results.

And another interesting point as we are talking about that spectrum here that what we get that this spectrum, we compute to the AR process does not suffer from that problem of negative output like the periodogram, it can never be negative. So, these are the beauties of it.

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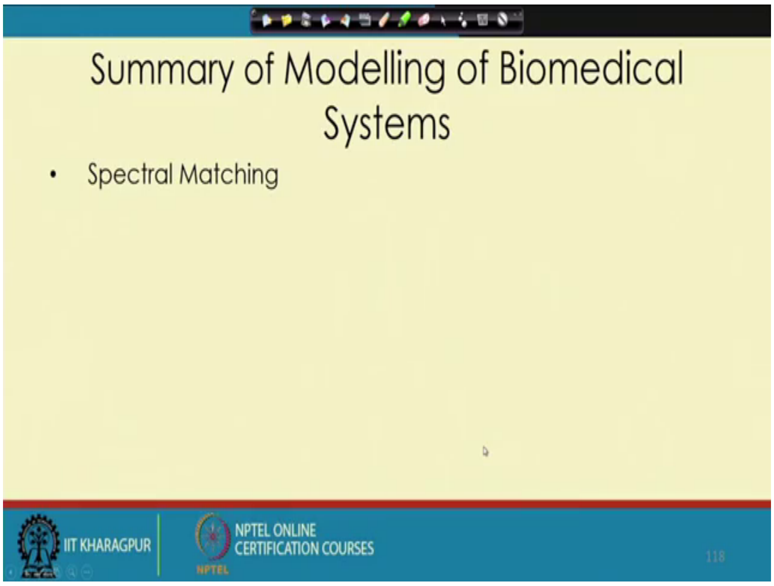

Now, another important thing we discuss that is the spectral matching spectral matching means what we have seen that as we are using the autocorrelation function of the signal to get the model parameters; that means, we are actually assuming that the autocorrelation function of the signal and the that model autocorrelation function, they are the same.

Now, as we increase the model order; that means, more and more autocorrelation functions of the model will become same as that of the signal. So, in that way; by increasing the autocorrelation function number or to put it in a simple way, the model order of the autocorrelation function, we can go closer and closer to the signal spectra because as we are matching the autocorrelation function, we know the spectrum or PSD is nothing, but the Fourier transform of the autocorrelation function. So, they have a one to one relationship.

So, if we equate more and more autocorrelation functions of the model and that of signal that model PSD goes closer and closer to the signal PSD. So, in that way, by choosing appropriate model order, we can go more and more close to the signal and that way; we can get actually one good support that whatever may be the signal, initially, we may not know that signal is really coming out of AR process or not, but if we take AR process and appropriate number of actually poles or model order, then we can actually approximate that signal to the desired level of accuracy whatever may be that desired level of accuracy in our mind.

So, it gives us that hope that the initial simplification what we have done instead of ARMA model, if you go for the AR model are we loosing anything actually we may not lose first of all the studies have shown that AR process gives a peaky PSD very well and ma part gives actually that the good shape of the valleys and all this process if we look at that they are actuated by some repeated events, whether it is train of impulses in case of EMG or signals of the s a node which is exciting the ECG signal or our that our case that where we are looking at the volcadore model that glottal impulses, they are giving the vocal sounds or voice output, they are dominant in some frequency and give rise to peak at some frequency which is very similar to the AR process.

So, there is a natural synergy also in that case and a very ma components is there by increasing the model order, we can actually take care of that fact and to get that model order also, we have discussed several techniques primary using the prediction error as you know by increasing the model order the prediction error will reduce.

Now, as the prediction error is going to go down, from that we can get that if we become sufficiently know that we have already got that model order; however, that when we are talking about sufficiently small this is pretty subjective that depends on that signal in the hand, then the amount of production is there, say for example, if there is white noise added to it, we will not be able to predict it. So, increasing the model order; we not help much in that case, but when we are modelling it as we do not know we would just perceive that the error is large and it is not actually coming down well; that means, a very slow decreases there because for the random noise white noise, we will not be able to model that unlike we go for infinite model order.

So, to take care of that; there are more sophisticated technique, primarily, they are using some biased, they are giving some penalty for increasing the model order and the techniques are suggested to take care of that and the best technique from them is the akaike information criteria or in short aic.

So, using that we can get that appropriate model order of the signal and which with the help of that we can get a good PSD and by good, we mean that we have seen that the problem of over fitting in many places, we can avoid actually that problem of over fitting because when we are talking about the parametric modelling or modelling of this signals which are primarily random in nature.

We actually assume that the signal is a stochastic process. So, if we study that process, we will get another sequence, though the model remains the same the n symbol changes. So, we should not give much weightage on the idiosyncrasies of the data, we should look at the overall nature of that signal more. So, these are the main benefits of the modelling and with that; we would like to end this chapter on the biomedical signal modelling.

Thank you.