Biomedical Signal Processing
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Lecture - 53
Tutorial – III

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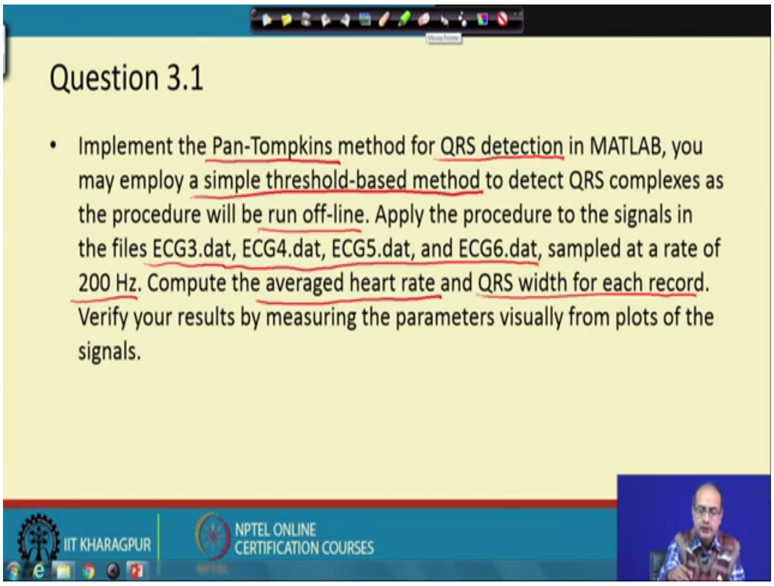

Now, we will start the tutorial number three and the first topic of it would be Pan-Tompkin algorithm ok. So, we will use the Pan-Tompkin method for detection of QRS complex using the MATLAB platform and we will use a simple threshold based method we know that Pan-Tompkin method has a very sophisticated that thresholding technique which actually requires that that multiple pass through the same signal and adoptive thresholding will simplify that we will use a single threshold to detect the QRS complex ok.

And it is a actually offline procedure that because we have collected the data and then we are actually running it. So, in that way, we would actually do this job and for that a multiple number of files are given ECG 3, ECG 4, ECG 5 and ECG 6 dot dat and each of them, they are sampled at a much lower frequency 200 hertz; that means, we can have the frequency content between 0 to 100 hertz.

So, at using the Pan-Tompkin will find the QRS algorithm and from there we have to find out the average heart rate for the different cases and the QRS width of each of this record the average QRS width that also comes as a good parameter to know that how the QRS complexes are whether they are normal or not. So, these two we would take ok.

So, and then we will check that that how they are actually appearing with the plots ok. So, this is the task and for that.

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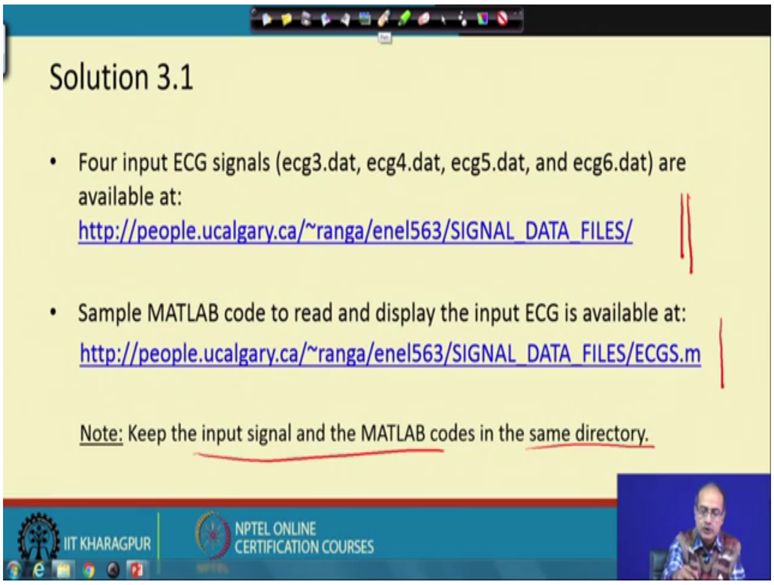

First, we have to look at the data that data is given here in this folder we get all the data. So, we need to collect them and we need to collect the MATLAB file to read those data and we need to keep the input signal and the MATLAB code in the same directory that is the working directory of the MATLAB.

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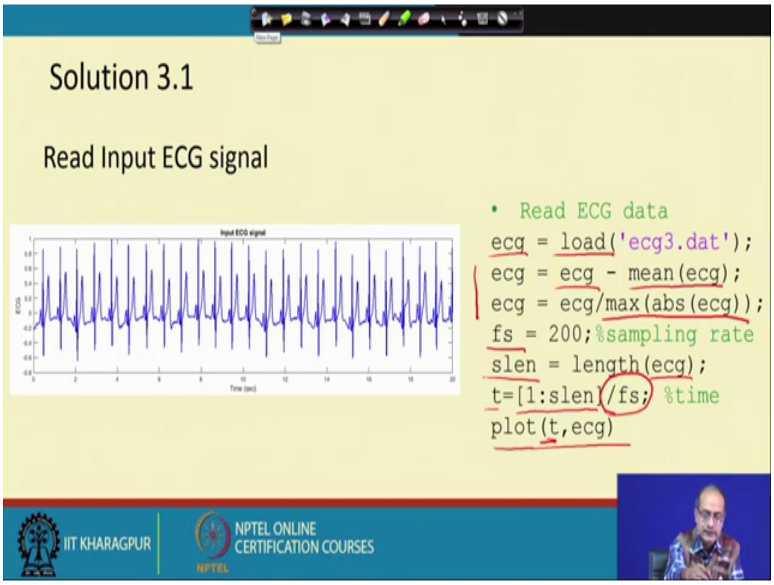

So, with that we start our work and the first thing would be that we have to read the data to appreciate that how it looks like. So, here first we load the data in a variable named ECG and then we try to normalize that. So, the second and third line that is for the normalisation first we make them 0 mean. So, we subtract the mean from the ECG signal, we make it 0 mean and then we are actually dividing it by the maximum absolute value ok. So, the ECG signal now it has to be restricted within minus 1 to plus 1 after this operation.

Next that we note that what is the sampling frequency and look at that how many samples are there s length is gives a number of samples in the vector ECG and then we create that time index required for the plot and time index first we write down the sample number then multiply it with 1 by f s to get the time instances ok. So, that gives us that that the plot that we get that is signal that the time index and we use a plot command to get the plot. So, here we see the plot the plot looks like that we have 20 seconds of data.

So, we have shown it for only for here one signal ECG three the same way, we can actually see for all the cases.

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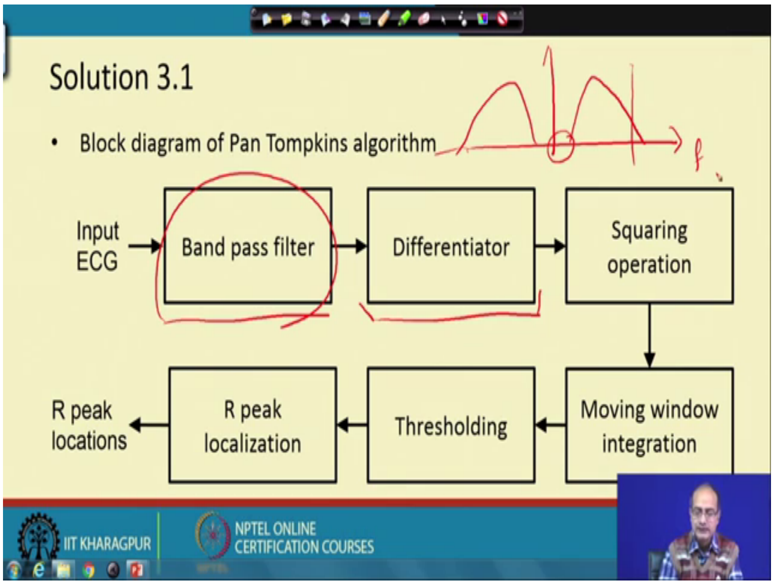

Next let us look at the Pan-Tompkin algorithm that what are the steps in the Pan-Tompkin algorithm the Pan-Tompkin algorithm, the first step is the band pass filter followed by a differentiator differentiator is to accentuate the QRS complex which is having the highest frequency in the ECG signal; so, we use the differentiator which is high pass filter to accentuate that and because the differentiator is actually susceptible to high frequency noise. So, we need to do some filtering before that. So, that is what we are doing here.

Why we are doing band pass filtering that the band pass filtering first of all that here if you look at that this is the frequency axis and this is that this is the amplitude and this is the frequency then band pass filter is somewhat like this. So, and symmetrically for the real signal that here also that symmetric components would be there. So, first this region we are actually eliminating to avoid the low frequency artifact ok, like baseline wandering and the cut frequency here chosen in such a way it will the in the high pass band it will not only take care of the high frequency noise it will also eliminate the power frequency noise.

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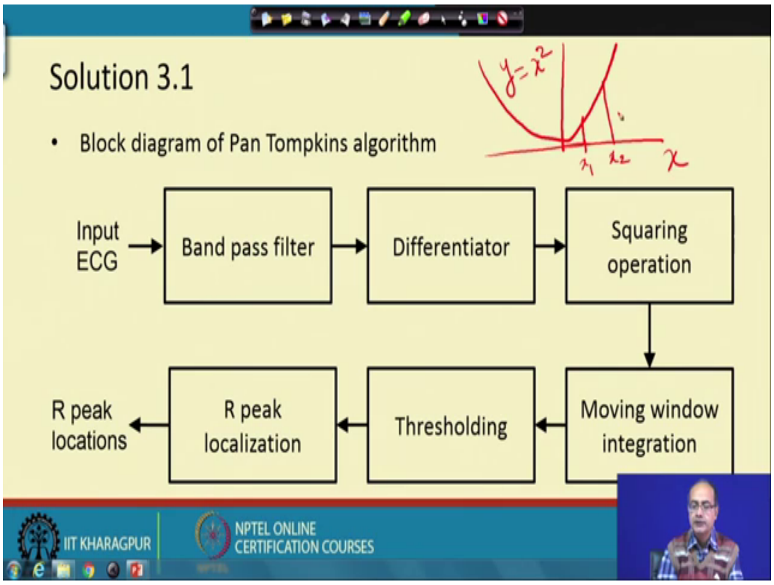

So, band pass filter that is the purpose it serves, then followed by the differentiator. And after that comes the squaring operation now what happens after the squaring if we take the plot that we have the value here x and here we take the axis y equal to x square when we take that square first of all for the both positive and negative value will get a here parabolic curve and both will become positive, instead of taking absolute value, if we take the squaring operation; that also helps us to get only the positive result.

So, after the differentiation we may get the positive and negative value. So, that becomes positive after the squaring operation at the same time it has another benefit that if we look at two values say here and here say one may be say value x 1 and another x 2 such that say x 2, we take cations x 1. So, if you look at that what is the difference between them compared to that when we take the square the difference actually increases ok. So, that is the beauty of the squaring operation.

So, we actually want to get wide separation of the high peaks from the small peaks. So, that is the job also held by the squaring operation next we look at the moving window filter that is for low pass filtering and followed by thresholding and then find the heartbeat. So, these things we will keep on explaining as we move ahead.

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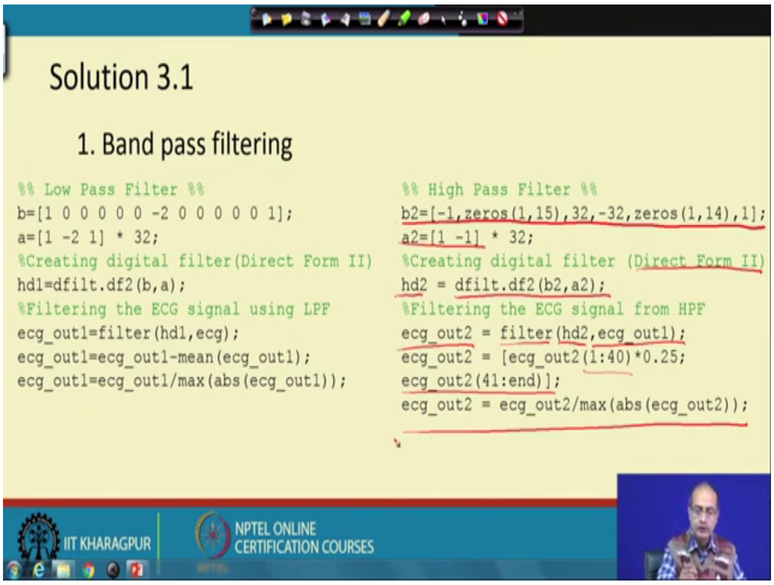

So, now let us move ahead with the work first we find that the by the band pass filter in this case the Pan-Tompkin has actually suggested a low pass filter followed by a high pass filter that give a band pass filter and for the numerator we find that these are the coefficients. So, here we have thirteen coefficients and with that and in the denominator we have three coefficients multiplied with 32 means there is a term called 1 by 32 a constant scaling is there. So, to take care of that that numerator polynomial is multiplied with 32.

So, once we have that a and b the numerator polynomial and the denominator polynomial then we can create the filter here for that we have chosen the direct form to filter structure. So, that is the command d filt that d f 2 b comma f provides as the filter in the direct form two. So, we get the handler of that hd 1 and using that we are first performing the low pass filtering.

So, we use the command filter provide the filter coefficient followed by the signal ECG and we get the output ECG out one now ECG out one this signal again is normalized that we take out the mean and divide by the absolute max. So, that the signal is content again in between minus 1 to plus 1 and remains 0 mean.

So, after that that we have to do the high pass filter. So, let us look at the high pass filter we have the polynomial coefficient b. So, it consist of a bigger length minus 1 followed by 15 0s, then 32 minus 32, then 14 0s and 1 ok. So, we have a big length here. So, 1 plus 15 plus 1 plus 1 that is 18 plus 14; 32 plus 133. So, that is the overall length of the numerator polynomial and in the denominator we have actually just two coefficients and again 1 by 32 is there which is actually incorporated as a in the multiplicand in the denominator filter.

And again we chose the direct form two structure here and we get the high pass filter hd 2 ok. So, the hd 2 that high pass filter is created and next that the hd 2 filter, it is applied on the output of the low pass filter using the command filter and we get the ECG out 2 that we can take as the output of the band pass filter consisting of the cascaded low pass and the high pass filter.

And within these signal what we get that the first few coefficients they have actually that high value first 40 coefficient. So, they are actually suppressed because of the transient. So, we are suppressed value is made one fourth and rest of it that remain the same rest of it remains the same so, that the first few data they were unusually high because of transient, they are just suppressed.

And then we perform that the operation of that scaling because it is a high pass filter that already it is a dc remove signal the input. So, we are not doing any that the mean subtraction though if you do that there is no harm in it that is not required. So, that is not applied here ok.

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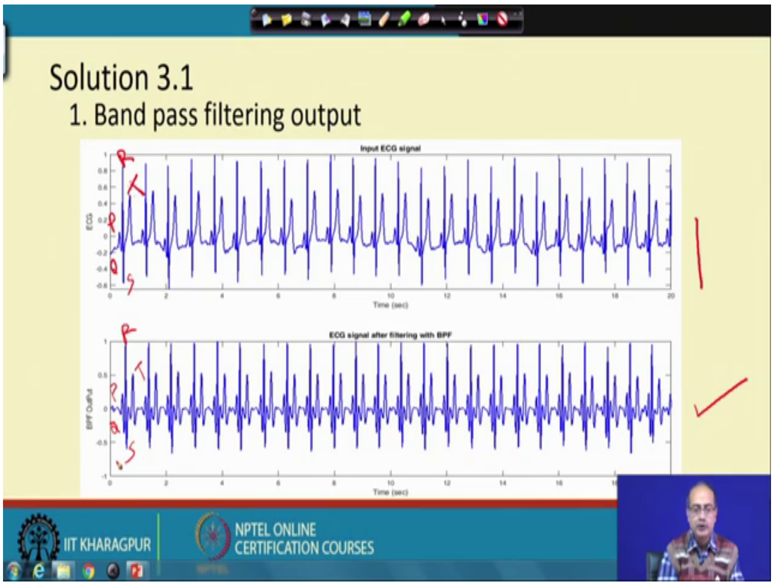

So, now let us move forward let us see that how the outputs will look like. So, here we get the at the top we are getting this is the signal ECG 3 and below we get the band pass filter output. So, band pass filter output what we notice that here the compared to the that R value here there was the R there was the P, there was the Q out of that sorry that the last one, this is not the Q this one would be the T signal ok. So, this T signal is the nearest to the R ok.

Now, after doing the band pass filtering we see the difference has a increased P has got completely subdued; however, the other two things that Q and S out of that that Q has become more prominent that is away from the 0 line, I would say and S is also has become prominent ok. So, overall the QRS complex is emphasised by the band pass filter here as the signal input signal did not have much noise. So, we cannot see that impact in terms of the noise removal here in this picture.

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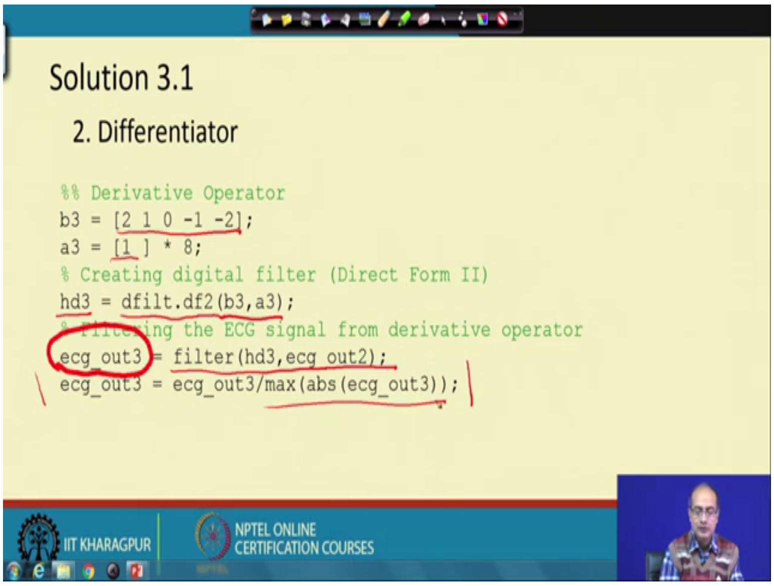

So, next we look at the derivative operator the derivative operator is not a the simplest form here we have 5 that coefficients in the numerator. So, that the 5 coefficient means it is a sophisticated derivative operator, it is doing sum the along with the derivative some averaging to take care of the high frequency noise or to make sure that very high frequency noise is not accentuated and we have a scaling function that 1 by eighth that we have introduced in the denominator that we have taken one coefficient multiplied by 8 in the denominator.

And again we form the that filter is d three is the filter and London, we use that the MATLAB function dfilt dot d f 2 for the direct form 2 that filter that that filter and we provide the b three and a three that numerator polynomial and the denominator polynomial for creation of this derivative filter.

Now, the next task is to apply the derivative filter here using the filter operation and the two that the terms we need to give as input to this filter that one is hd 3 that we need to provide that filter and second that in the signature that second variable is the input signal here that what we get out of the band pass filter that ecg underscore out 2.

So, at the end of it, we get the derivative of the band pass filter here and after that we are doing the normalisation and please note that normalisation easier only that we are dividing with the maximum absolute value of the output again that we are skipping that part that we are not subtracting the mean again the reason is that derivative filter itself good enough to remove the dc bias and our input also did not have the dc component. So, is doubly sure that no dc component would be there in this signal. So, that is why that part is not actually used.

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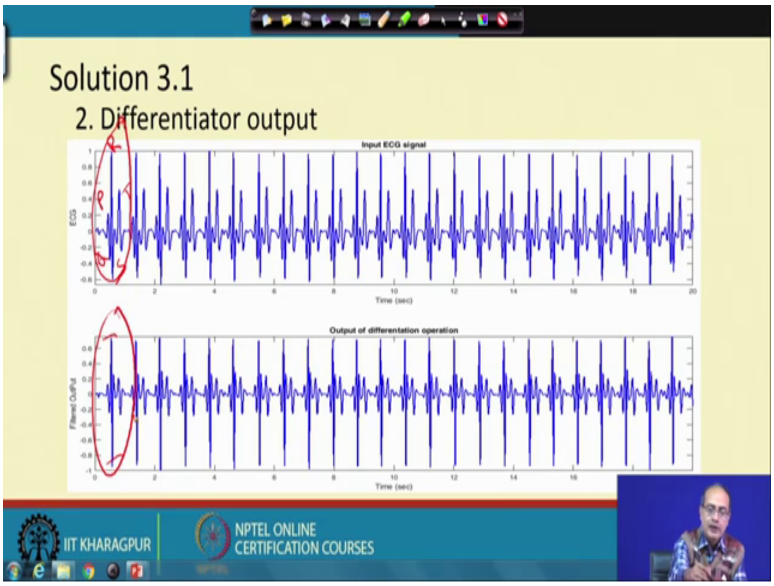

So, here now we get the output of the that differentiator filter and what we notice here that if we look at signal waveform here we look at the corresponding output of the difference filter we see that P and the T wave ok, this thing has got subdued that QRS they have got modified, but they are accentuated. In fact, here the R was bigger S was comparatively smaller. Now that R and S both have become high ok.

So, we can say overall the QRS complex has become much more prominent and well separated from the, that P and the T wave, but now what we get that after the differentiation operation the signal is actually ranging from minus 1 to nearly plus 1 so, in that case; that we have to use double threshold if we have to separate them out ok.

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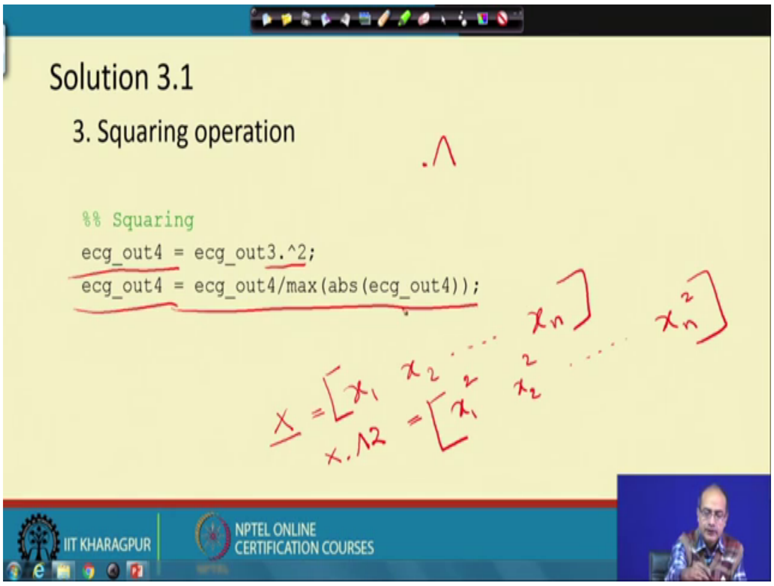

So, to avoid that we go for the next step we do the that the squaring operation and for the squaring operation we are using these command that dot hat the meaning of it is that if we have a signal say x with values x 1 x 2 dot dot dot xn ok, if it is a here we have shown a row fill vector it could be a column vector also.

Now, if we perform that x dot 2 hat 2 what will happen, it will create actually the that element y square it will create x 1 square x 2 square, then x three square and all at the end xn square. So, that is exactly what we have performed here and we have written that output into ecg underscore out 4 and again we normalise it. So, that the things are within the bound. So, we normalise it again with the value with the maximum value ok.

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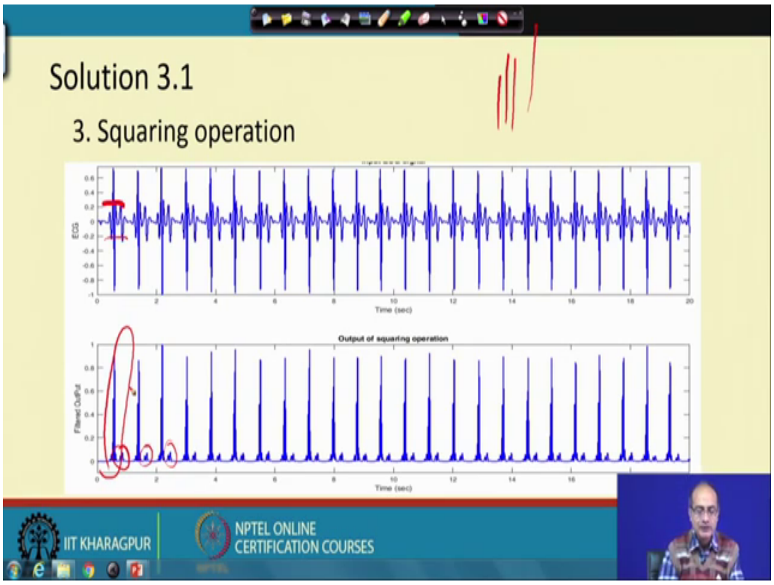

So, after the normalisation; let us see how the image looks like. So, after the normalisation of the signal that here at the top is we are giving the signal after differentiation and below we are showing that what is the output of the filter here we see that after the squaring first of all it has become positive that is one good thing. So, one single threshold we will do and what we again see that the small the peaks, they have got subdued here we see them that like small stuffs ok.

So, the difference with the high peak and the low peak that has actually stretched and that is another good thing that has happened by squaring now once you do the squaring one more thing has happened though both the negative and the positive peaks they have become positive, if we look carefully and if we could stretch this signal a single actually cycle at a time, we could see that here that output it looks like multiple peaks ok.

So, multiple peaks will make it difficult that to detect instead of one we will get multiple actually values above the threshold. So, then it would be a challenge to find out that which is the location of the R wave because we know here only one actually R peak is there. So, we need to take care of that situation.

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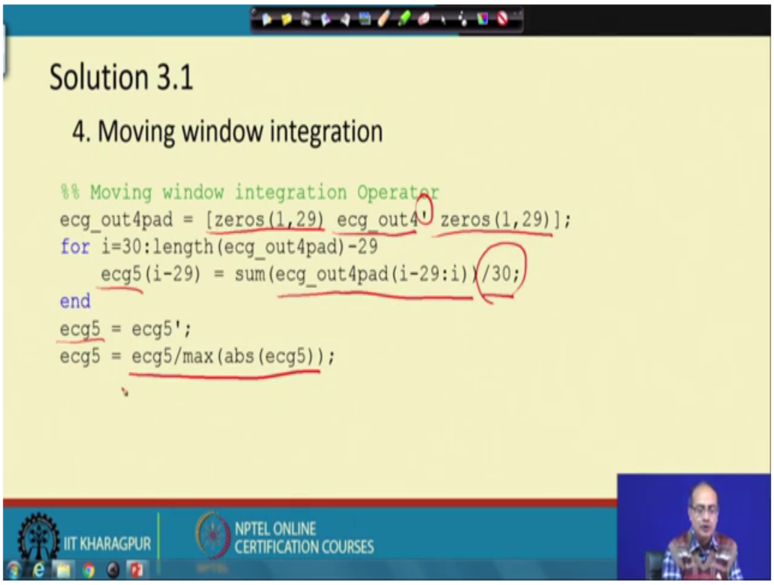

So, next thing is to use that moving window integration operation or moving that averaging ma filter what we call. So, using that what we try to do all these positive peaks we want to merge them together a to a single peak which will look like a post. So, here what we have done or rather, let us say that Pan-Tompkin has suggested rather than we are doing anything we are just following Pan-Tompkin; Pan-Tompkin has given that we should have an moving average of length 30 ok.

So, we should take the signal last thirty points we should take and do the averaging. So, it is divided by thirty ok. In fact, for real time implementation you may avoid these point because later on the scaling is done it is not a actually offline operation. So, here we are doing the scaling. So, we could avoid this one, but we try to keep the form proposed by Pan-Tompkin.

And to do this operation faithfully we need to pad the signal with zeros in the both the side we should have 20 nine more zeros in both the sides of the ECG out for and this operation is actually transposed operation we had a column vector we have converted into it into a row vector and padded both the side with 2009. So, that when we take the average we can actually have the output for all the elements corresponding to the that ECG samples otherwise what will happen that will go out of range and it will give an error.

Now, after this operation at the end the output what we get we have again transposed and made a column vector and again because it is a that it is a offline operation, we have this luxury, we are again normalising, it had it not be in a offline operation every place where we have used this command that taking out 0 and normalising with the maximum this would not have been possible ok.

So, now we have the moving average filter now let us appreciate that what is the impact of it.

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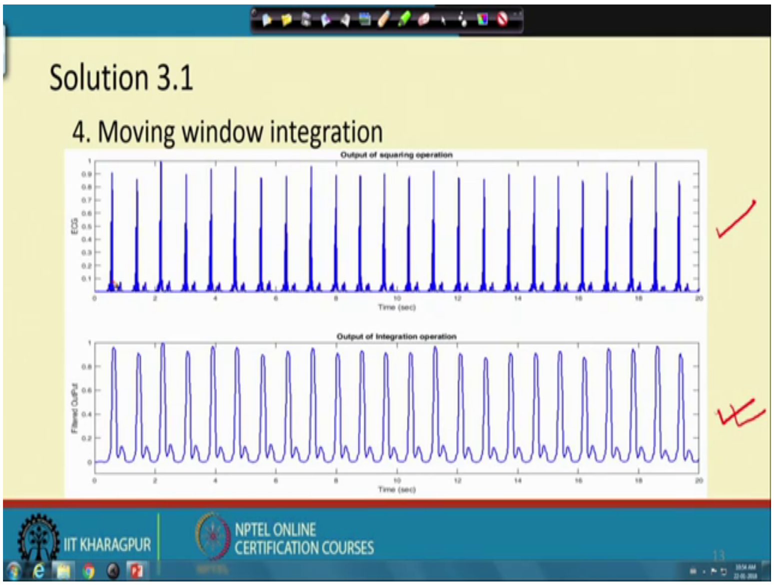

So, at the top. we are showing that this was the this was the output of the that our ECG signal from what the output we got from the squaring operation and after ma filter this is what we get ok. So, the ragged peaks here in become a post like structure, but one good thing happen that it becomes a single post. So, for each QRS complex we have one post. So, that is the advantage we get here following the step of moving filtering.

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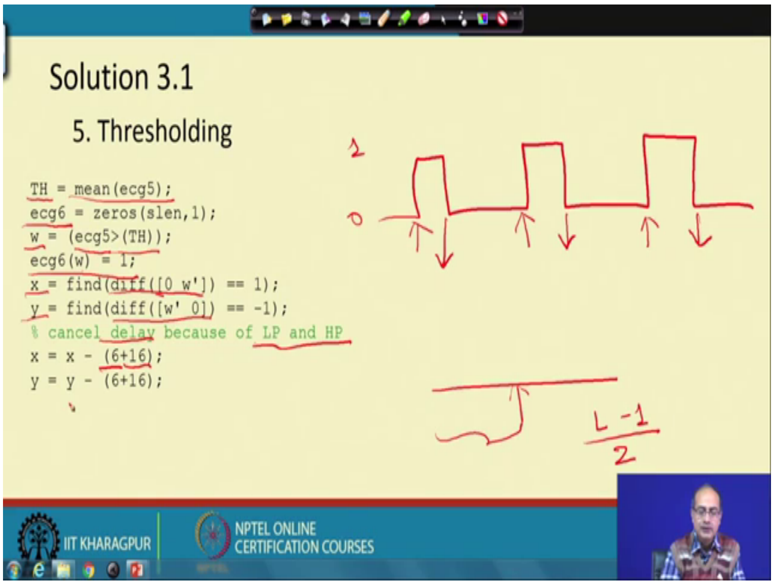

Now, let us go for the next step the next step is to threshold the signal and the thresholding help us to find out the location of the peak. So, what we have done we have taken again we take the advantage of the fact that this is the offline operation we have the signal at hand. So, the threshold th is taken as the mean of the ECG file; that means, the signal with the post we take the mean value and next we create a signal of the same length as that ECG signal the only difference is this is filled with 0s.

Next what we do that we take out those a vector the index w that for which for which indices that ECG 5 the post are greater than the threshold value and that we note actually here and this index is used here to write the signal one ok. So, what we do; that means, ECG 6 will give one when the post value in ECG 5 is above the chosen threshold ok. So, ECG 6 I having value 0 and 1.

And now next point is that we would do the differentiation for that we pad the first value we add one 0 here for forward difference and here also we do it for the, that n value with 0 that. Now in the ECG 6 what will have we will have signals like this at the location of the posts ok. So, the value here is one here it would be 0. Now after the differentiation operation we are trying to catch that what are the places it is becoming a transition is happening from 0 to 1 ok.

So, we are catching those parts or those indices here in the vector x and wherever it is becoming 1 to 0 that is not in that is caught here and collected in this vector y ok.

So, once these two are collected then we know that where the post is starting and post is ending next task that is to correct actually the location now. So far, we have apply number of filters and out of them the major filters where the low pass and the high pass filter which has actually that given as the band pass filter, why I call that they are major they are major in terms of the delay that high pass filter of 32 tab. So, sorry 33 tab in the numerator it introduces a delay of 16 samples.

The low pass filter having thirteen tabs in the numerator introduces delay of 6, now how do you get this figures because the if we have a filter the midpoint is the centre. So, what we get that this is the amount of delay it has introduced that is the length of the filter minus 1 divided by 2 ok. So, by that we get that both the x and the y vectors they have got a delay of 6 plus 16 that is 22 samples. So, we collect that thing to align the location with the QRS complex ok.

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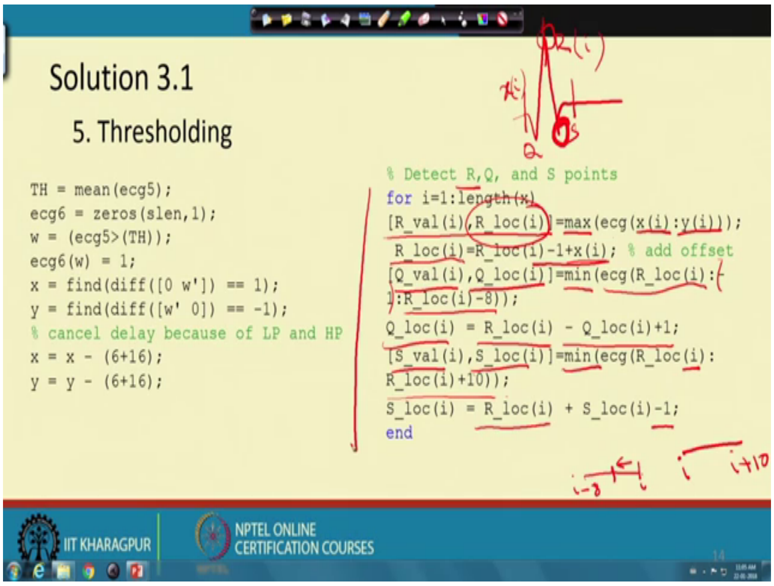

So, next is we would like to find out the location of R wave first, then we hope you recall that QRS complex that it looks like this; this is Q, this is R, this is S and x and y is giving us the bound within which that peak is line. So, first we look for the R value, it is done with a simple operation with x i that is ith peak is located within that x i and y i. So, we find out the maximum value within this range that is giving us the R peak ok. So, that locations; they are kept in this vector that location is kept in R underscore loc and the value is kept that R underscore loc value.

Now, if we look at now we are running in for loop to get these actually all the values now after getting these we need to keep in mind this specially this location is actually is disturbed how it is disturbed that we have calculated the location within a small range between x i to y i ok.

If the signal has few 1000 samples, this could be may be few tens of samples. So, the location is with respect to that starting from xi. So, we need to if we have to give it a global location we need to have that adjustment at that offset along with the location. So, we add x i minus 1 with that location. So, that is how we are getting the location R underscore location i which would be aligned with the ECG signal.

The next task is to find out the Q what we know that Q is before R and we already have found the location of that and here is x i and we can say this is arrive it is within these two it is a minimum point within the R and the beginning of the QRS complex. So, we find out the minimum in between R location i and R location i minus eight; that means, minus 8 samples maximum difference could be there instead of going up to x i.

We are limiting the window further that for the 8 samples and here we look at this term minus 1, here we are decrementing; that means, that we are starting from if this is a vector this is the location i; this is i minus 8 we are starting from here and going this way and finding out the location here somewhere the minimum is occurring the value of the location is kept here and the value that Q value is kept in queue underscore value and the Q location is kept Q underscore loc loc.

Now, again we have to correct it we have to take care of these with respect to that R location this is so many samples before. So, we are actually adding one minus the Q underscore location ok. So, we get the Q location next we look for the S location which is again that from i to i plus 10 R location i to i plus ten; that means, that if the R is here the 10 samples.

After i that R location we would check to find out the minimum and we store the value here S value and S location keeps that index, but again it is within this 10 samples. So, we need to use the offset that R location minus 1 we need to add that to find out the location with respect to the original ECG signal. So, all this things; it would run in a for loop here number of times that how many actually this terms we have received. So, with that that hopefully we could get all the R, Q and S points.

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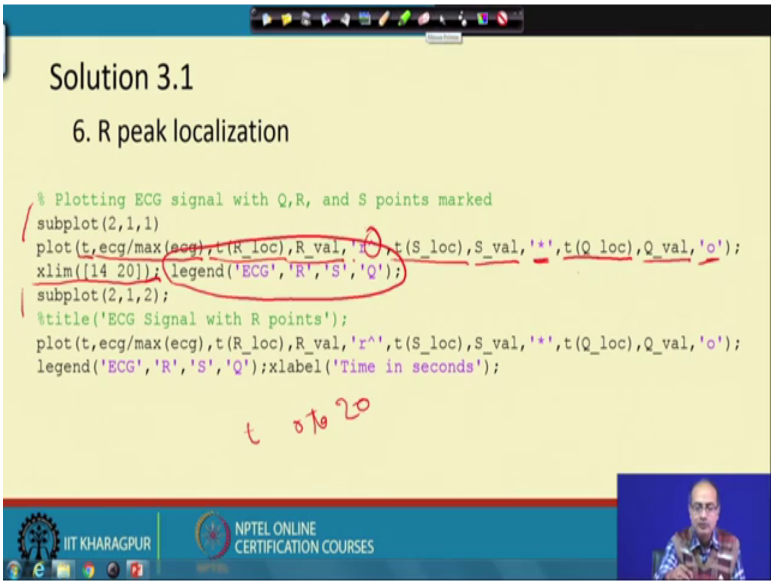

Next, we would like to actually plot them to visualise that signal. So, how do we do that first we use that subplot command which we are using so many times to create actually the space. So, that we can see the signal more carefully that side by side we can see the two first we with respect to a time we draw the ECG signal divided by the maximum of a that is normalized signal because you see the signal is what we have read. So, we have normalised that if you have already normalised that we need not have to do that thing.

Next that we show the points that tr location will give those points or indices where the r point is there and corresponding value is given here r value. So, we get the x and the y coordinate of the r point and that is marked with a symbol hat here and R stands for rate ok.

Next same way we draw the that the s values s location and the s value and with the help of star that is designated next is Q the location time we are getting here and the value of the Q in y axis, we get here and we use the symbol o to give that location and that whole plot this is limited between 14 to 20 seconds ok, the time starts to 0, T starts from 0 to 20, out of that we are taking only 6 second so, that we can get a clear picture of that ok.

And again in the subplot two we are doing the same thing here we are showing the full signal ok. So, at the top we are taking a part of it. So, that we can separate the points QRS and we can appreciate that and another thing we have used we have used something called legend ECG r and s that different symbols what we use that is actually could be given there.

So, let us see now that how successful we are in drawing that plot ok.

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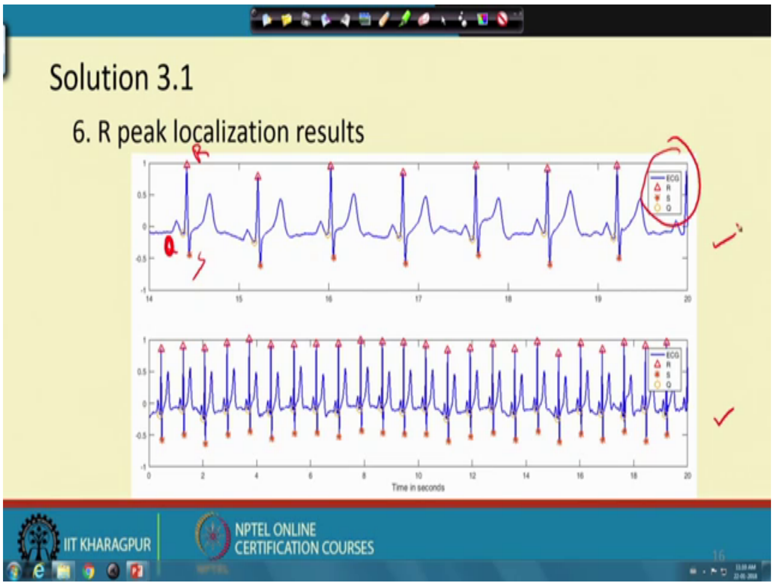

So, let us first look at the legend here ECG drawn with a blue pen it is given here r we have specified that there is a small hat that we have drawn a small triangle for that then s is drawn with a different symbol star and for Q O is used. So, that different symbols are used here to designate them separately.

And here we are showing that with respect to the signal we get a nice view that for each of this case that QRS is nicely picked up and all of them they are rightly marked now below, we are showing it for the whole signal the 20 second signal and in this particular case, it seems it is successful in getting all of them the only problem that here the signal has become cramped.

So, we could not differentiate the, that time location clearly for QRS ok. So, this is the whole signal this is the part of it. So, we get that with Pan-Tompkin in this case we are successful in getting the QRS locations.

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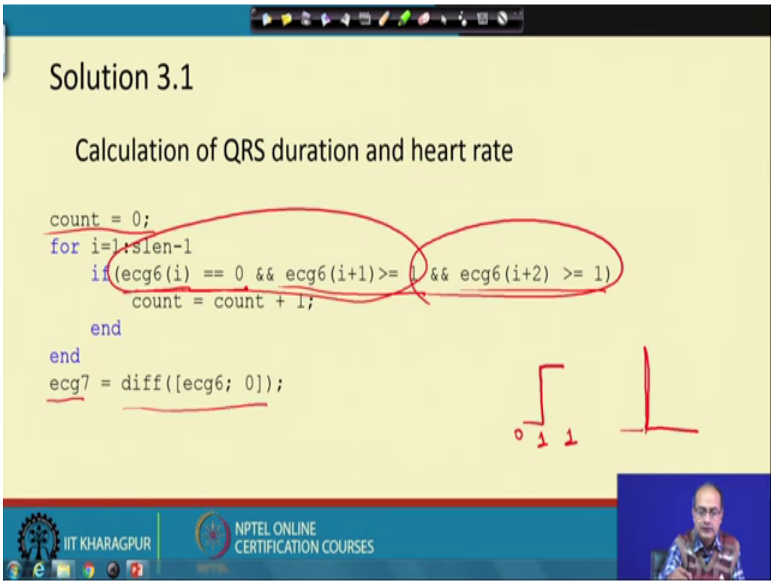

Now, we have something more that is left we need to calculate the QRS duration and the heart rate ok. So, for that what we do we go back in the signal ECG 6 which had actually the values? So, what we are looking at that the first value if it is 0 and second value is one or more than that and next value again is continuing to be one; that means, we are talking about a jump like this; this value is 0, then one followed by one ok.

Why we are taking all this things the first thing is giving the this; this part is giving a transition and it should not just come like this and again go to 0 it should be a post to check that that the next and condition is added that it should have some continuation. So, if it is there then we increase the count by one which was initialized the 0 at the beginning. So, we go through that signal and find out that how many such transitions has happened and that will help us to give us the count.

Next see that recall that we have ECG seven by taking the differentiation here we have added one 0 at the end so that that after the differentiation we get equal number of samples as the ECG 6 ok. So, that will give us that the output of the differentiation and let us see that how we make use of that ECG 7.

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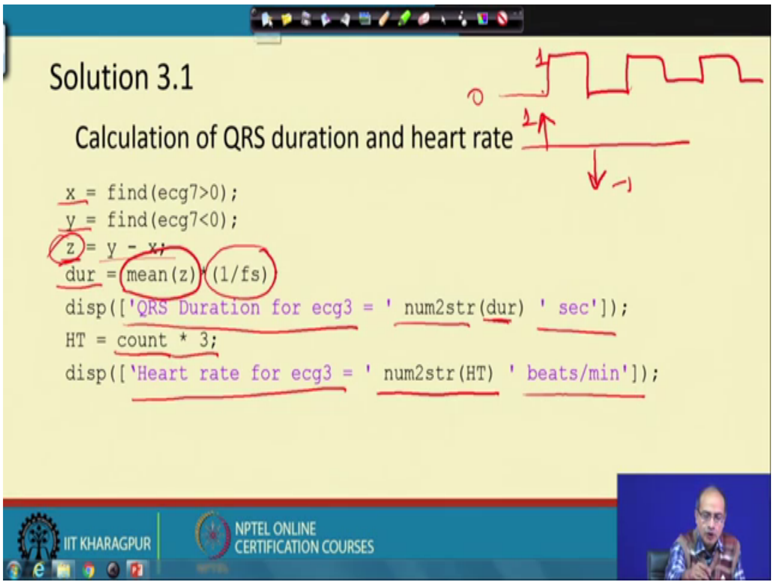

ECG 7 will have actually after the differentiation of the signal of looking like this with 0 and one it will be consisting of spikes like this that it will have here one it will have here one minus 1 and rest of the place, it will be 0. So, we are finding out that where it is more than one sorry more than 0; that means, having a transition and where it is minus 1 that is the starting point of the post and the end of the post in the time.

And once we have all those indices please keep in mind x and y, it is not just single value, but as we have multiple peaks we are getting all of them. So, we will get two vectors once we take the difference of this two vectors, we get another vectors z which gives the difference between the consecutive that two points that starting point of the post and the end point of the post. So, we get the width of the corresponding post in the variable z ok.

And these value is we need to keep in mind that we are getting it into that number of samples. So, to get the time or the width of the QRS complex or the post here in time what we have done, we have calculated the mean and multiplied it with the width of one sample or the inter sample interval 1 by fs that gives us the duration of the post and this duration of the post is taken as the width of the QRS complex ok.

So, here we find out that here we now go for that display that QRS duration of the ECG three that for that we need to convert the that number dur from number to string, it is calculated in terms of seconds and the count what we got that is for 20 seconds to get the number of counts per minute we need to multiply width with 3 to get the value for estimate the value for 1 minute. So, HT has the count for one minute. So, again we use the term number 2 string to get the heart rate for ECG 3 in terms of beats per minute.

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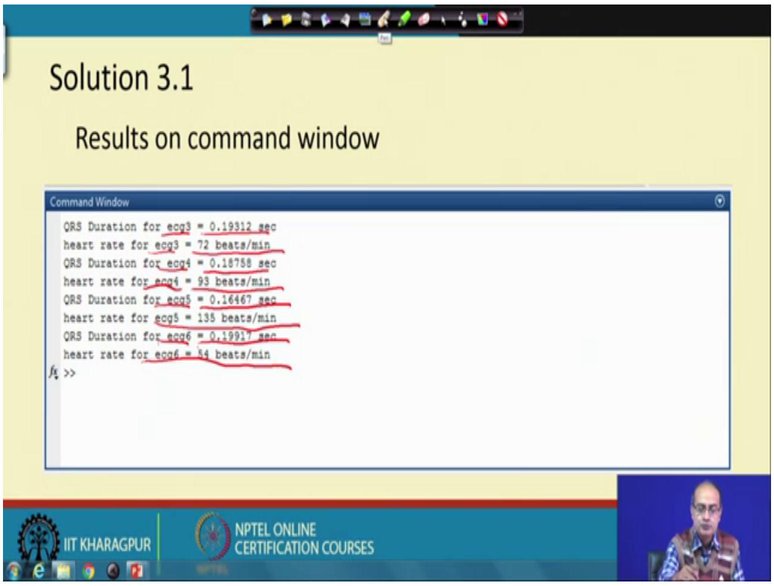

So, here we get them in the command window the corresponding the values the first one for ECG 3, we get it is point one nine three second the corresponding heart rate is 72 that is absolutely normal for ECG 4 that QRS duration has reduced a bit 0.18758 corresponding to that what is more surprising that number of beats has increased this become 93, 93 beats per minute.

For ECG 5 the duration has further decreased 0.16467 second, again and heart rate is abnormally high 135 beats per minute for ECG 6, what we get the duration has the highest among these ECG signals, it is about 0.2 second and the heart rate corresponding to that is much lower is very low 54 beats per minute; that means, it is certainly having bradycardia that unless this person is a sportsman ok.

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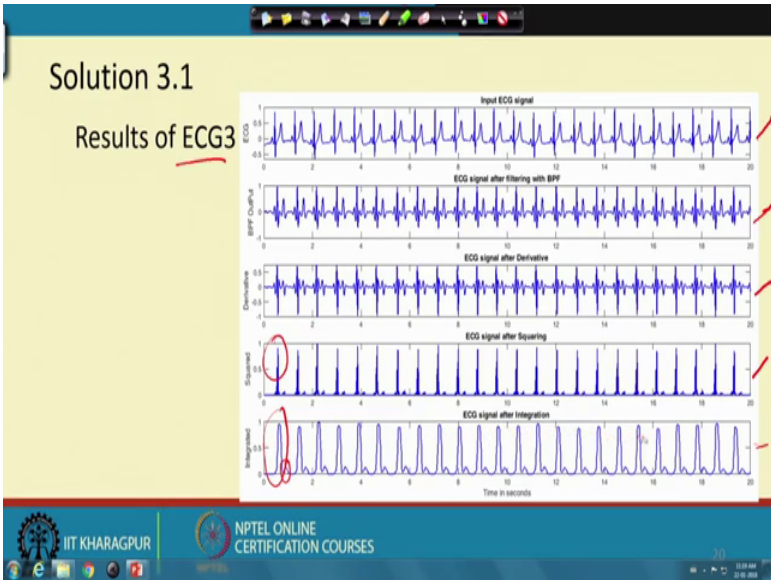

So, now let us see that the output in each of this case this is the first case for ECG three first we show the ECG signal at the top followed by that band pass filter output which suppresses the P and the T wave and also suppresses the noise then after taking the derivative operation we get QRS complex is accentuated.

Then after taking the that square operation that output of the derivative has become positive and the difference between the high peaks and the low peak has got reduced; rather accentuated the separation has increased, but it has number of peaks. So, we have passed it through a master filter and we get post like structure and clear separation between the small peaks and the high peaks here ok.

So, here we get very uniform kind of view that if you look at the post heights they are more or less same ok. So, it is a very nice signal, we could get all the QRS peaks here without any error.

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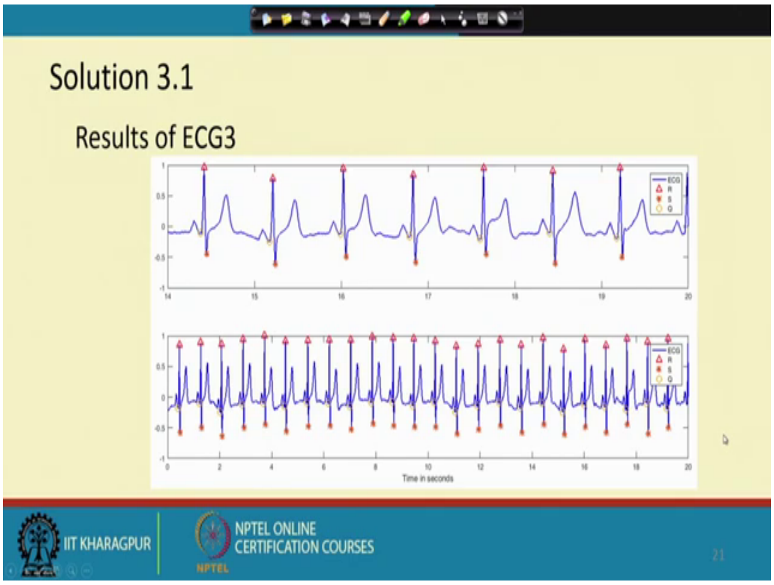

So, this is the markings; we show that how we could mark them; this is for the, that 14 to 6 the 20 second; this is for the whole signal of 20 second that we could get all the Q, R and S points

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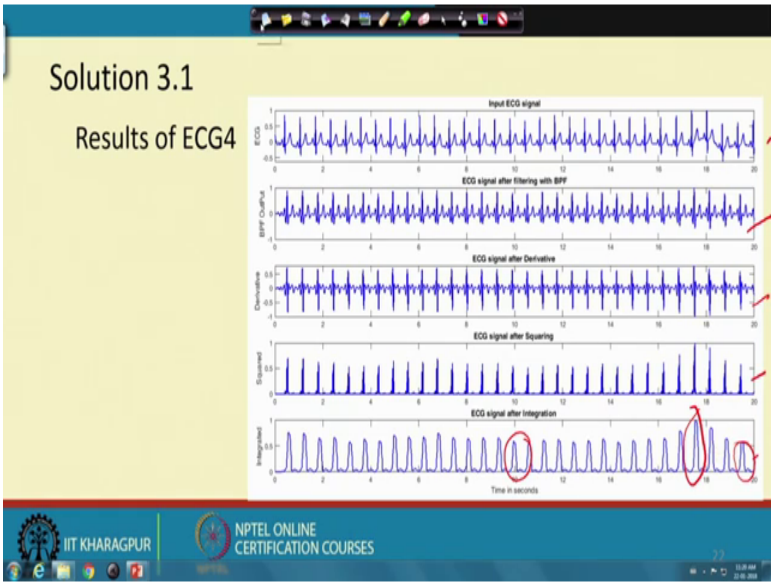

Next we go for the ECG four we do the we show the same set of values first starting with the signal, then band pass filter output, then output of the derivative filter, then output of the after the squaring operation then after the integration here we see that the post here is a little higher here there much lower. So, there is uniformity is not that much ok.

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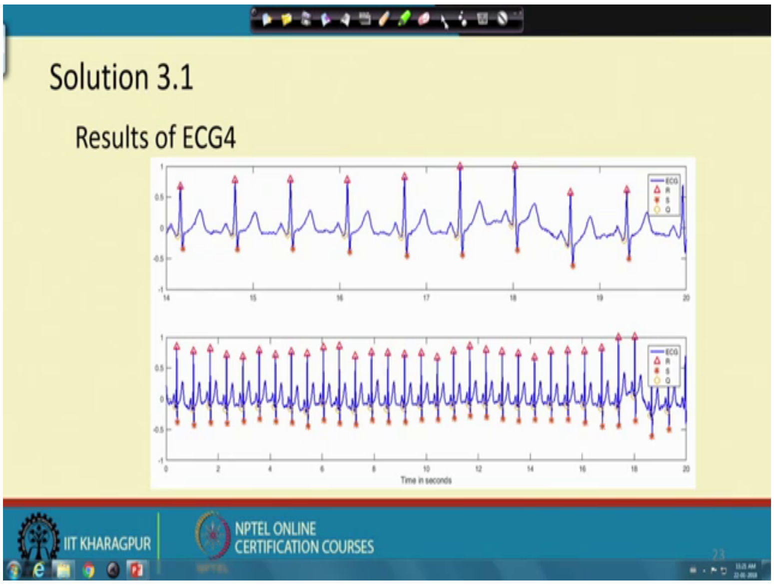

So, let us see that how successful it would be after the thresholding we get that here in this case also that it seems that all the QRS complex Pan-Tompkin algorithm is able to get.

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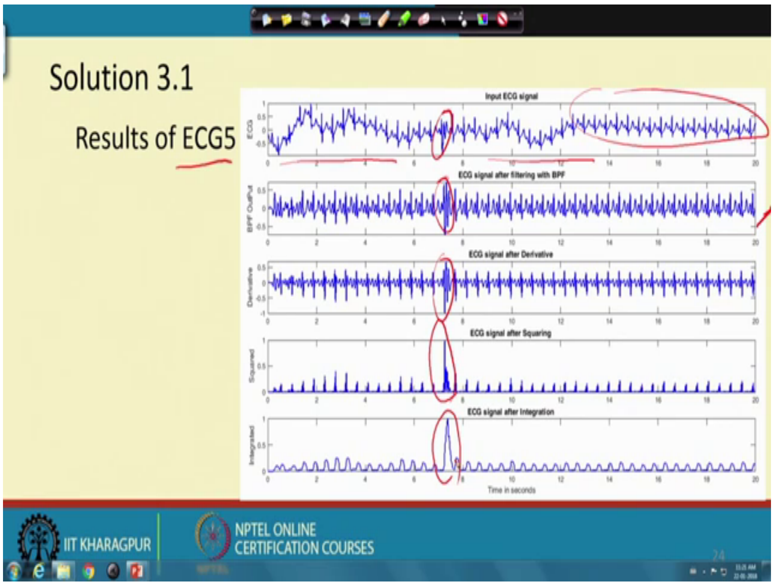

So, next we go for the ECG 5 signal ECG 5 first time we are seeing that baseline wandering here are the places baseline wandering are very prominent this portion the baseline wandering is not there so much.

Now, after the band pass filter what we get that baseline wandering is removed and here we had a jaguar peak that is giving a high output after the derivative filter is also highest. So, after the squaring operation this remains to be the highest one here we see all the other QRS complex, it seems to be much lower than that ok. So, it is dominating the scene.

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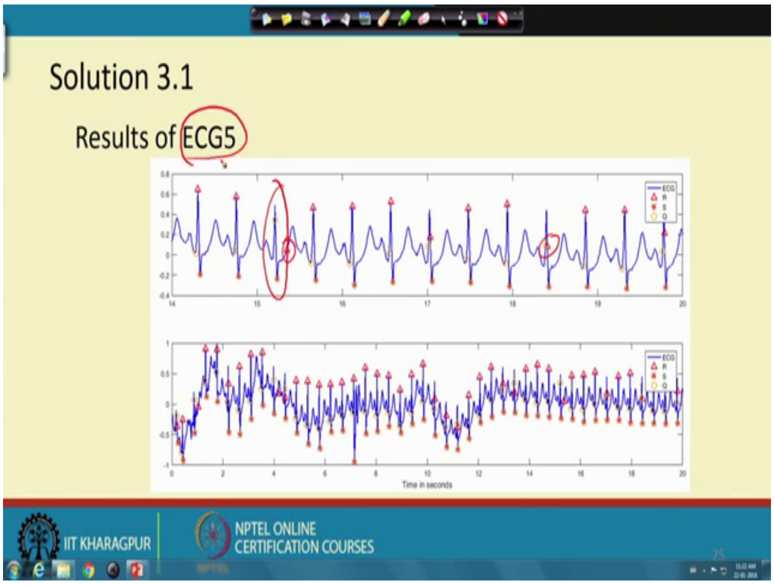

So, let us see that what would be the impact of it after the thresholding. So, after the thresholding as that one very high peak was there that is pulling the threshold above what has happened that some of the peeks are missed. So, this is one such example that R wave is missed ok; R is mark here wrongly here another place that R is missed. So, several such misses are there,

So, ECG 5 what we get for the, this one that the signal that the Pan-Tompkin algorithm in this.

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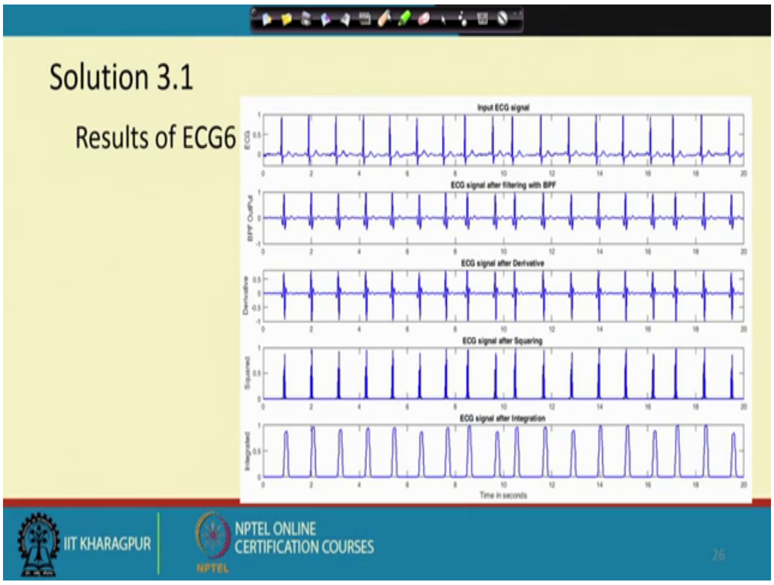

Form it could not give a very good result again for the ECG 6 the last signal that that is having the low heart rate we get the signal here and then we get that the band pass filter output derivative filter output the squared output this is the that post we get.

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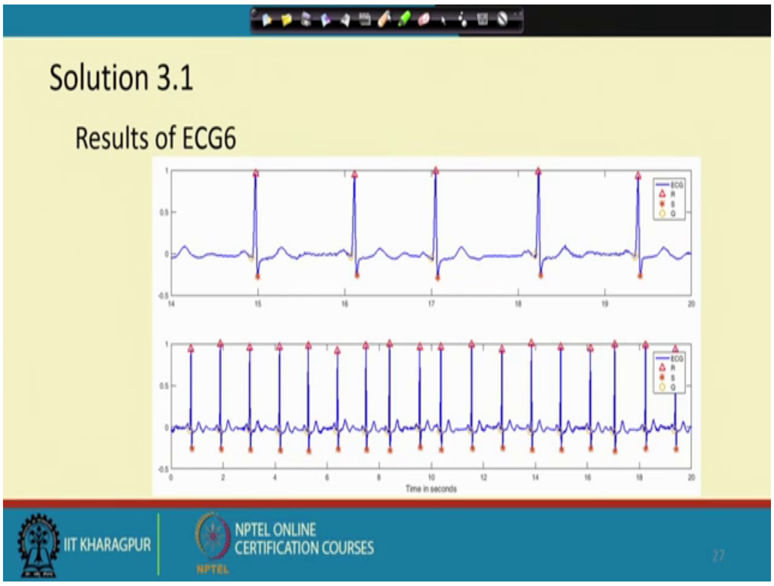

And this is the QRS outputs we get that it is working fine, we get all the QRS complex.

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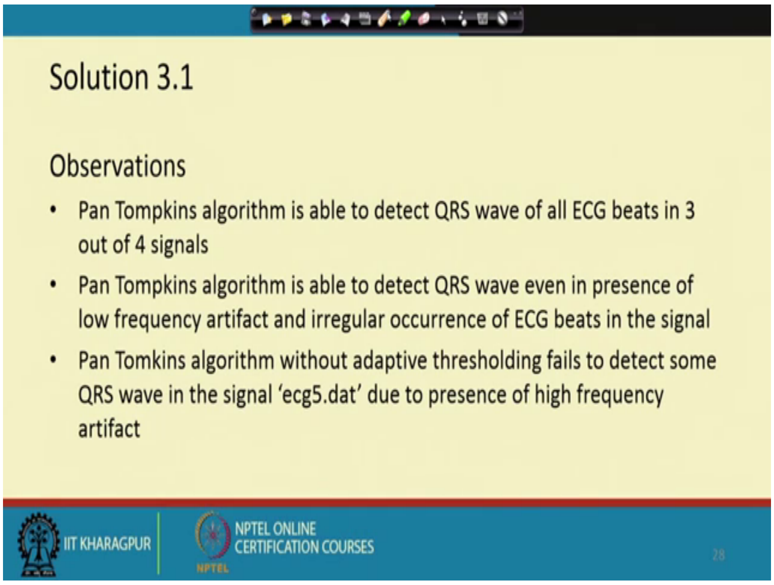

Now, we would conclude with our observation the Pan-Tompkin algorithm is able to detect all the QRS complex in three out of four signals Pan-Tompkin algorithm is able to detect QRS wave even in presence of low frequency artifact and irregular occurrence of ECG beats in the signal Pan-Tompkin algorithm without adaptive filtering fails to detect some QRS wave in ECG 5 due to presence of high frequency artifacts. So, this is the end of the Pan-Tompkin algorithm.

Thank you.