Introduction to Biomedical Imaging Systems
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Lecture - 26
CT_IQ_Artifact

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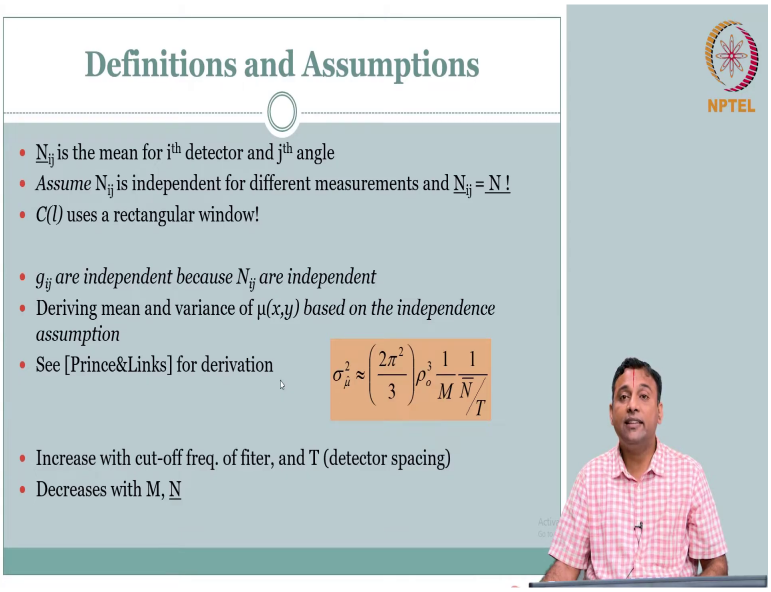

Some more definitions and assumptions because we are; what we need to do now is, we know this guy this is the randomness N bar is the mean of your i-th detector at j-th angle. So, this is the randomness right. First when we start with this is the randomness let us starts your N is a random variable. So now, what we will say is for simplicity we will assume that N ij is independent ok. What is happening in one detector or one view need not affect the other one, so we will take this independent assumption, which is not that bad ok which is ok.

Assume N ij is independent for different measurements and then you say N ij equal to N that is its a same mean is same. When will be the mean same? Number of photons that are coming through, when will it be same? If I have a homogeneous medium then I can expect whatever I sent in and whatever I receive in each of the detector for different views at least for within one view right. If it is a symmetric object it is a circle then for all the views.

They all have to be the same value right on an average the average value. Why because, it is a homogeneous attenuation in such a case we can. It is ok for the purposes of understanding what all factors play a role this is not a limiting you know assumption. So, we can always start with signal to noise ratio when we do, we always talk about homogeneous media we have many measurements what is the fluctuation.

If the signal is itself is changing right if you have in homogeneity, then it becomes you have to segregate difficult different locations and see whether the signal and noise are correlated. So, to make life easy right this is something that is routinely used. So, it is not that bad ok. So, this is the assumption. So, we can essentially talk about does not matter which detector which view angle the mean is independent of that ok. So, you can use only one N bar.

Again C l this filter function, for simplicity otherwise you will have to have hamming window or hanning window you will have to have another exponential or whatever to describe that. To make life easy we will say this is a rectangular window, so that you know less of a confusion. But the idea is you can have you can change this ok. But for simplicity we will say this is a rectangular window ok.

So, this is for the fundamental N that is going in, this is the filter function that what is that then there is a g right that goes in. So, g operates on this and that is the one that goes into the back projection algorithm. So, your g because of this we can also assume g are also independent ok. Just this is ok will say for the purposes this is fine if we were able to live with that with the N, g is random just because of N. And therefore, this is fine g is also independent ok.

Then the point is we need to get mean and variance of your mu your image that is what we want. So, we can derive this you start with the convolution back projection right, that is your algorithm, you have the input random variable, you have this one implemented as rectangular. So, if you substitute and work out based on the assumptions of independence right.

There are a few steps the even in the text it is not a detailed derivation, but there are couple of more steps that are given after these assumptions and essentially you get a expression for your variance ok. So, what is this? So, the detail of these derivations are not that important for the context of this course. So, even in the textbook only a couple of you know equations are given just before this to capture it and there and this is ok.

Why we want we do not want to get into the complicated derivation because already it is simplified. In the real context when you are working in it you have to be very diligent, but here the objective for us is to understand the factors and relate to our instrumentation and physics. So, we will not go into the details, but essentially this is an expression that you get by making these assumptions and starting out with the discretized approximation of your convolution back projection.

So, this is the variance you get, what is interesting here is, this variance is a function directly related to your rho naught. What does this rho naught? This is your, you do your filter right that is your highest cut off of your filter filtered back projection right. So, this has to do with your cut off of your filter and your M is we saw previous is the discretization right. So, more the M, M is the angular discretization. So, more the M you have more the M I have less the variance less the noise ok. More I sample, I have less noise right less variance intuitive ok.

What is this? Higher cut off. So, if I have a higher cut off, I have higher noise; why? If your cut off is more probably high frequency features are coming. So, noise lot of noise in the high frequency are coming in. And therefore, you can expect the more the cut off maybe after some time your feature is not there, but your high frequency noise is coming in ok.

So, you have to be careful about how much high frequency you want to provide the cut off. And then you have these guys what is your N dashed? Average number of photons which we kind of know increase the number of photon you shoot more photons right. If you shoot more photons you will reduce the variance which we knew from before, but downside is there right you do not want to sent too much N.

So, if you send the high energy for example, you will increase N, it will not interact much it will come out. So, we talked about that. So, again its not one-way street. And then N dashed by T so this T is actually in the numerator. So, what does this say? What was your T? T was your width right your detector it has to do with the detector ok.

So, this is basically if you there way it is written here number of photons per detector. If you increase the number of photons per detector your noise will reduce. That is what that is how it is written that is why it is written like this ok, fine.

So, we can talk about the different variables and how it influences increases or decreases. Increase in the cut off and T detector spacing right, these all increase your noise; noise decreases when you have these two. Increase the sampling right you have more finer views and more number of photons ok. So, much for your noise, but we are not really interested in noise in isolation; what are we interested? We are interested in signal to noise ratio ok.

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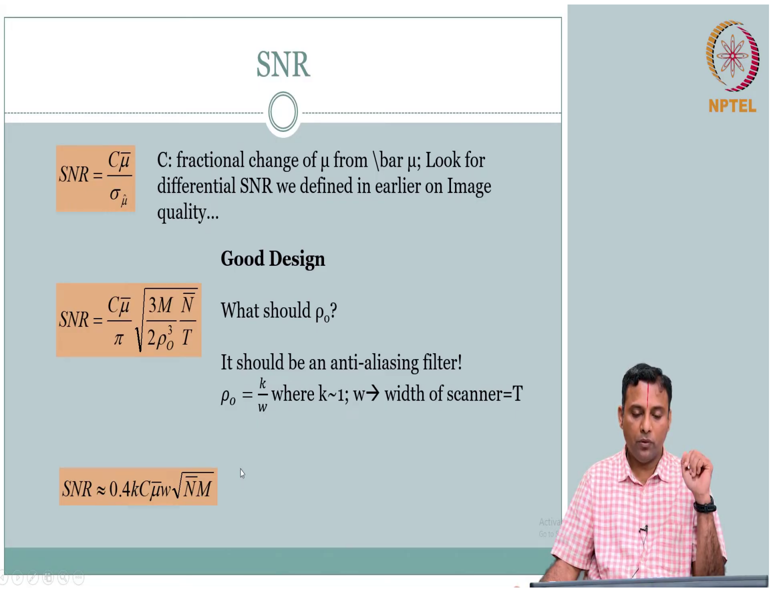

So, signal to noise ratio; what is our signal? What definition? We will use the similar definition mean two standard deviation right. We talked about mean as your signal and the variation around the mean is your noise right. So, we talked about signal to noise ratio as mean to standard deviation, mean of your attenuation coefficient.

So, it is mu bar standard deviation. So, sigma of your mu I estimate, this is your signal to noise ratio in a traditional sense. However, we talked about this local differential signal to noise ratio when we covered image quality. So, it is also common that because our interest is in looking at image contrast the signal to noise ratio can also include your C which is contrast.

So, it is a differential contrast. So, at differential signal to noise ratio is what we are practically interested right. And so, the C is nothing, but your differential contrast fraction change of mu from mu bar. So, we covered this differential SNR when we divide you know talked about your image quality introduction to image quality. So, go look at that portion if you want to know what we have done here.

So, this is your differential signal to noise ratio why because, we want to talk about this contrast that is interesting ok. So, that is your SNR. So, now, what we need to do is, identify this is a big picture definition. So, what do we know? We know what the noise is mean is not a big deal mean is just mu bar, this guy that is a problem what is the variance right? We had a variance derived right in the previous slide we will have to substitute that here.

So, when we are substitute and the rearrange you get signal to noise ratio to be C by of course, what we had was variance we like to take a square root, so you get this square root here. So, C mu bar by square root of sigma square right. So, you get this pi square root of 3 by 2 M by. So, whatever was your directly proportional inversely proportional right that is kind of changed here slightly because we wrote this as in the denominator before at least the way we wrote it, ok.

So, what does this say? This says ok I am interested in signal to noise ratio and how am I affected? Fundamentally, this is important right fundamentally C is important, if there is not much differential signal there maybe you are not going to see much, but let us not worry about that. So, this is a part that is important, but then it is this part that is going to affect for whatever you start with, this is the guy that is going to affect you ok.

So, how do you design? What are the things that are in your control to do a good design so as to get maximum SNR, right? Things that you have in controllers we talked about this cut off. So, what could be the cut off that we want to use? Well, without mentioning explicitly you already know we are talking about discrete implementation and this is kind of a right your cut off for this filter. So, where do you, how much frequency do you allow right especially the highest frequency that is the question.

So, what do you do? When you have discretization some filtering the first concept that comes to your mind is anti-aliasing filter right. You should have the filter such that; so, that when you do you have the Nyquist criteria as met right; you have to have at least twice the max highest frequency otherwise you will have aliasing which we will talk about aliasing also as a artifact.

But, so here is your control. So, you could essentially design your cut off so, that it can serve as a anti-aliasing filter. So, you cut off the highest frequency whatever you want to allow right after that you digitize. So, your anti-aliasing filter you can have your rho naught to be k by w where essentially your w is the width of the scanner. So, if you can design it like this, then you can minimize at least the artifact and you can get a good signal to noise ratio, ok.

So, that is fine. So, when you substitute that right, when you substitute that condition, you can reduce this further to because you had some values here right. So, we can reduce it to 0.4 because your rho naught is substituted right in terms of k and w; w is the width of the scanner. So, k and T k is approximately equal to 1. So, it is in terms of T. So, you can do this part and you get 0.4 k C mu right w square root of this guy.

So, the idea is this is your signal to noise ratio differential signal to noise ratio. So, you can quickly look at this and convince yourself if I want to have good signal to noise ratio the good contrast I have to increase my M I have to increase my N, but there is a square root that is a important factor, ok.

So, it is not just if I want to double this SNR, I have to quadruple this. So, you see the; I mean in some sense this is intuitive, but then explicitly putting it makes it compelling to take that look ok. So, that is what that is.

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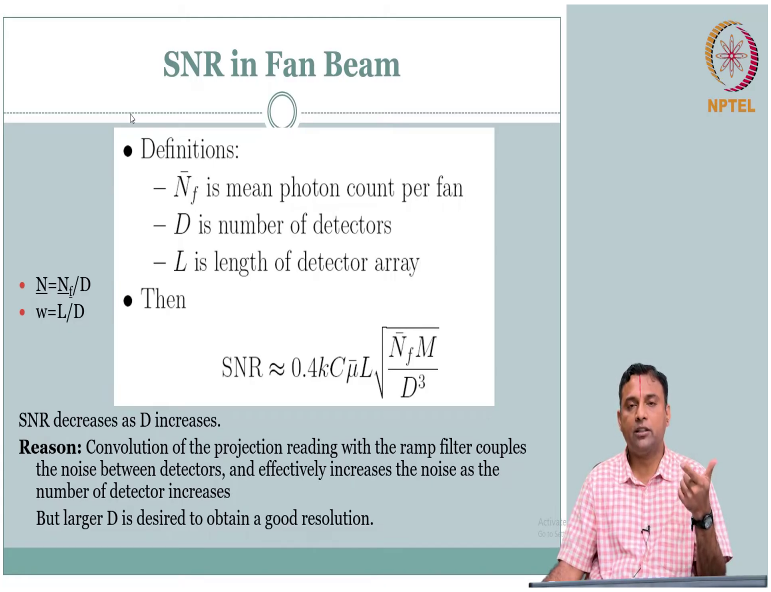

So, we will that is for parallel being. So, you can do the similar thing for your fan-beam. When you do it for fan-beam you can talk about N suffix f as a number of photons count per fan and D is your number of detectors and L is the length of the detector array. So, there is a slight change in the formulation because of this. So, your SNR is 0.4 k C mu L N of M by D cube, ok. So, your N is your mean is your N f by D and w is your L by D; length of the detector array by number of detectors is going to give your width per detector ok.

So, this is fine for fan-beam you get some similar things like this. So, SNR decreases as D increases. This is something that is right D increases SNR decreases D is number of detectors. So, this is something that is not intuitive you would have expected if you have more number of detectors you have more measurements. So, you will probably get less noise at least because you are averaging and right you are reconstructing using more number of independent random variables you would expect that the variance would have reduced.

And therefore, your signal to noise ratio will improve, but that is not happening; it turns out that the D is the denominator. So, it says that this SNR decreases as D increases why would that be right? What assumptions did we make in parallel ray we said neighbouring; neighbours do not disturb each other independence whereas, it turns out in fan-beam the convolution of the projection right you have this ramp filter that kind of couples noise between the adjacent detectors.

So, because of that your detectors are not saying the neighbouring ones are not independent. So, there is a coupling that is taking place and therefore, the noise between the detectors is coming into picture. So, this effectively increases the noise. So, more the number of detectors in this configuration, the detectors interference is there and therefore, your noise is going up ok.

Of course, you can do larger D is desired; why D is the number of detectors? So, if I have many number of detectors right then each one will be small; that means, my resolution is good. So, it is always a trade-off, that is the problem in most of the modalities. That is always a trade off, but then if you understand enough of how each parameter is affecting which are conflicting which are favourable then you talk with the clinical practitioner, you talk with the engineer on site you kind of work out a agreeable trade-off, its always about negotiating an agreeable trade off that is the important you know practical aspect that you will find in all of these, ok.

Good. So, much for SNR. So, what do we want to do? We talked about resolution, we talked about noise, noise not in isolation noise in the context of SNR not just that SNR for fan-beam also.

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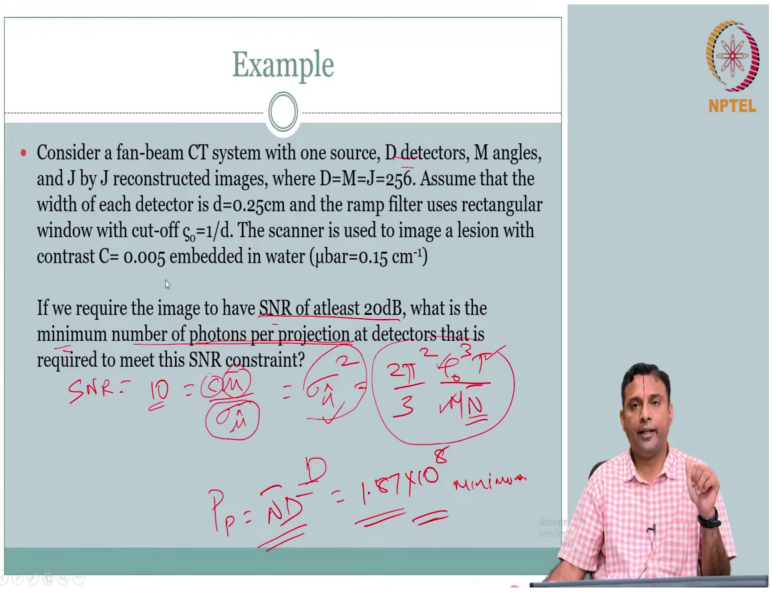

So, now, we are good to proceed further. Just before that in fact, I will not solve this just to appreciate right so, that you can relate all the parameters we talked about so far. Cconsider a fan-beam CT system right with one source; let us not deviate much from what we know. So, you have D detectors M angles and image sizes also given J by J. So, here we are treating the D equal to M equal to J equal to 256. So, it is a 256 cross 256 image. So, you have taken 256 views and in each view you have 256 detector measurements.

So, now assume that the width of each detector is 0.25 centimeters. So, 2.5 mm ok and you are using a ramp filter rectangular window. So, we will not complicate that why ok. So, we have also designed it such that it is 1 by d it is anti-aliasing. So, we are design that with the cut off that is equal to 1 by d; d is 0.25 which is your width of the detector ok.

So, now you are using this scanner to measure a lesion right. So, the contrast between the lesion and the surrounding tissue right is 0.005 or so, this is not the scanner is used to image a lesion with a contrast embedded in water. So, the surrounding is water ok. So, you are water ok; you have your mu bar average this thing is also given.

So now, the question is ok given this setup this is what I want to do you are given a constraint. I want to do the imaging, but subject to at least 20 dB I need to make any diagnosis. Only then I will be confident then saying that is a lesion is whatever it is there and I can do follow up. So, if you if we require the image to have a SNR of at least 20 dB, what is the minimum number of photons per projection right.

So now, it goes back to your settings. So, you based on your signal to noise ratio desired you are going to come up with the exposure. So, what is the question is, what will be that, what is the minimum number of photons per projection that you need? How will you go about right? So, first and foremost you are given a requirement for SNR in dB, but what we derived in the previous slide? You had SNR as a ratio. So, first thing that you can do is convert this a dB to ratio; how is that done? 20 log off right SNR log base 10 right. So, go. So, first thing you can get SNR alone not in dB what will be that if it is 20 dB right?

So, this will be the ratio. So, that will be log of 10 by 10 20 log of 10 by 10 in TB. So, if it is ratio is 10, log 20 log base 10 of 10 will be 20 dB right. So, SNR will just 10 ok. So, I know my SNR what do I what else do I know? I need to get number of photons per projection ok. So, I know my SNR. So, that is the signal and noise ratio. So, I have some formulation for noise, right. Sigma square I have some formulation that you can quickly look through in the previous slide. So, I have that.

Then of course, this SNR is what? We go by your formula you had C times mu bar correct C times mu bar by sigma of mu hat this is what is the definition. So, I have my C that is given, I have my mu bar that is given what is that? We have some formulation for that, but that you can measure from here from the given information.

So, if you can measure sigma mu hat, I can estimate sigma square. What is sigma square? That you can look into your formulation from before right. So, sigma square is 2 pi square by 3 rho naught cube T by M N dashed bar M N bar. So, look back to your previous slide, you will see this formulation. So, I can calculate my sigma from here. So, I can calculate the sigma square so I know this, what else do I know? Now I have the right hand side several of which I know.

I know M, I know T, I know cutter cut off frequency this is just 2 pi square and I know left hand side. So, I can get my N bar ok. So, you can go do that, but what is asked is; what is asked is there is the photons per projection. So, if I have D detectors, then I will have to multiply with D. For one projection if I get N, then I have to multiply with D ok. So, you can actually work that projections per thing is N dashed into D N dash you can get from here. So, you can calculate this.

Just go do this it is not, it is just substitution after this ok. So, you will get some number like 1.87 into 10 power 8 that is your; that is your minimum right minimum number of photons ok. So, the objective is not so much on the calculation the details of how you punch the calculator.

About how we understand the question appreciate that ok if there is a requirement constraint from the end user on the acceptable image quality, how do we work our way around, because this is important right. Based on this answer, you are going to acquire ask the technician to acquire the image so, that you can make a diagnosis.

So, you should know the end requirement and how that controls the data acquisition settings, this is the important. So, in the context of covering the physics, instrumentation and image quality, I hope you will be able to swiftly go back and forth and understand how to connect all the three concepts. Most of the time it will be from the end user some requirement will be there, some from the image side.

So, how do we go from that and see if we can improve it is, there a fundamental improvement possible? If possible then how do we acquire that at of at a fundamental level? So, the raw data itself you have to acquire using that insect, using that condition ok. So, that is so much for our signal to noise ratio and how we can use the information of setting and your context of recon right to calculate those.

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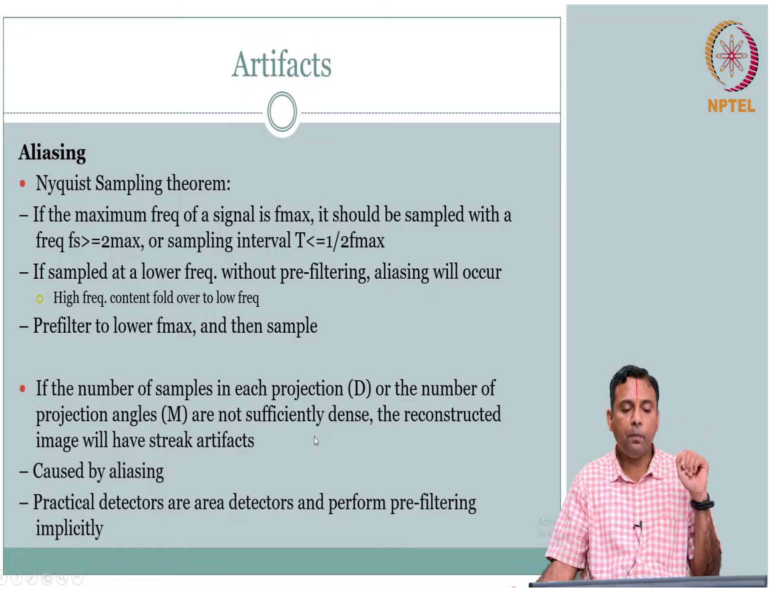

So, now, what we need to do is artifacts ok. So, we talked about noise, but in the image artifacts are also distractors ok. That confused the doctors from the actual object that they are trying to understand if there is something that is distracting them that is a no. So, its not a noise per se, but then it is a distractor ok. So, it has to be reduced.

So, where all can artifacts come from? So, in the process that we have done so far first and four very easy to spot from our backgrounds is your discrete location. So, the continuous function. So, your distribution is continuous right I am in, but then I am making these measurements in discrete locations.

In fact, I am doing two discretizations, one is the view angle the other is the detector the number of detector each one is separate right along the l it is discrete, along the view angles that is also a discretized. So, we already saw that. So, how do we arrest that? So, that is going to be your sampling whenever you have a sampling you have to worry about aliasing.

So, how do you reduce this aliasing? You have to do right you have to do anti-aliasing filter. So, in some sense aliasing if you have not sampling if you are sampling less than the Nyquist state what is that? Twice the highest frequency content that is there right. If you are sampling any less than that you are going to get aliasing; that means, what? Your high frequency content might be wrapped into your low frequency. So, you might write that will be the effect.

So, how do you avoid that? We need to do some anti-aliasing. So, in this case how ok so; that means, highest frequency. So, the highest frequency if you can apply this filter with some cut off f or f max before you this right then you sample, then you are ensuring that wrapping around is not taking place.

So, in our context we were talking about number of projections right number of projection angles. So, if you actually you can do this. So, you throw some angles right you start with it, you get several projections, but then in your sinogram right you have all the angles just throw some angles do the reconstruction using only say every other step size or every fourth step size and you will start to see the effect ok.

So, what do you mean by effect is, you will vividly see this as a street as streak artifacts right you will see the it will not be smooth it will have lines ok. So, you will see streak artifact. In fact, we will just show the image and you will recognize the streak artifact, but from before also we did this, but now what is expected is when you see that you will know where it is coming from.

First time when we showed streak artifact I said we will cover it later, but now hopefully you should be able to visualize the effect and say I know where this is coming from this is because I have discretized. So, if I go back and change the number of angles, I should see the streak pattern changing right. So, you should be able to do that.

Of course, in some sense already the detector right because it is a area detector its not a point detector it is averaging out. So, it is already having some effect implicitly some pre filtering is happening ok; averaging is kind of your low pass right. So, it is already doing that to some extent.

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So, here is a example of the variation of your number of angle number of projections right and samples per projection. So, you can notice that I mean even this is actually pretty you know you see one object here at the centre which is supposed to be the case, but you notice this star right. So, you can have this star artifact people say.

And in fact, when we talked about also we talked about when this can happen when you have sampling under sampling, but we did not really tell what it is. Now you know under sampling means in the context of either you can under sample in the views or you can under sample in the number of projections in that views right number of detector limits in that views.

So, either case has its own effect; and you see the aliasing when they say ok and you can see the effect ok. So, this is streak artifact. Then what are the other things that we talked about before? This is streak artifact due to sampling there is one effect what is the other effect in our we cannot we assumed.

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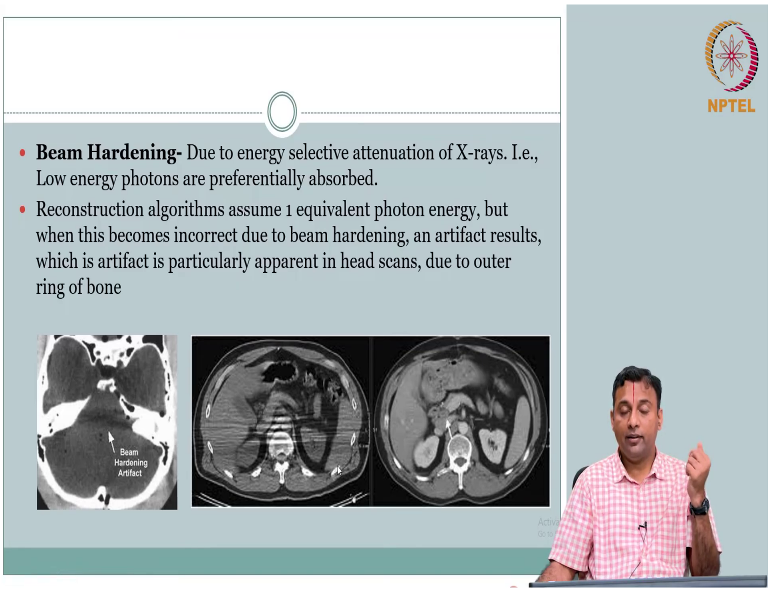

We will assume something about the energy, we used mono energetic. In fact, when we sent energy in we already said unlike projection in C T we are going to set the hardened beam what did we mean by hardened beam or beam hardening? That means the narrowing right that is what we said.

So, we said that when you do beam hardening, the spectral spread is reduced you give only a narrow and therefore, mono energetic is fine or at least reasonable. And therefore, all are reconstruction algorithm used this assumption of mono energetic right. But then that is not entirely true because beam hardening can also happen after you do all that and you send it into the body, what you get at the detector right.

It is still the beam hardening is also happening, but then it can be amplified depending on what material is in its path. If you have a strong absorber right. So, then strong absorber at that frequencies, then you are going to have behind that part you are going to have a different spectra. So, what enters is already a hardened beam, but then due to the interaction the you know the energy is lost right.

But then if you have some strong attenuator in the path those locations you can have attenuated effect right and that will kind of or what preferentially absorbed that we know. So, this could actually come back into the image. So, reconstruction algorithm we assumed this, but when you have effect of the beam hardening showing up then artifact results.

So, typically where do you have these effects prominent? We talked about bone. So, it depends on the location for example. So, if you take a head scan, you have a bone skull and then you have soft brain right. So, the attenuation is kind of different there. And therefore, when you have something like this, the amplification or the hardening of the beam is drastic because of the bone that is hitting, and you have to penetrate the bone before you go into the brain right.

So, whatever you send from out which is supposed to be beam hardened beam compared to your projection radiography, its already a hardened beam, but then when it goes through the skull, your bone is attenuating far more and then you get the behind that you get your soft brain tissue. So, in such cases you have lot more predominant effect of your it is a beam hardening artifact.

So, this is kind of a tricky artifact somebody who is working in the domain they have done lot of scans, they understand the organ they may know. So, they allow to you know work on the dose, they have to try to reduce this ok. So, they know what to interpret what is a beam hardening artifact. So, this is a tricky artifact though right. So, you could get this artifact in other regions also I mean this is a head scan, but you could get it at other locations also right abdomen for example. So, it depends.

So, if you have a bullet right I mean somebody gets shot there is a implant it is a different material. So, there you have to be very careful in its interpretation. Beam hardening artifact and so, you are sampling, beam hardening what else did we talk about when we talked about introduction to artifacts? So, when we come to CT these are very prominent.

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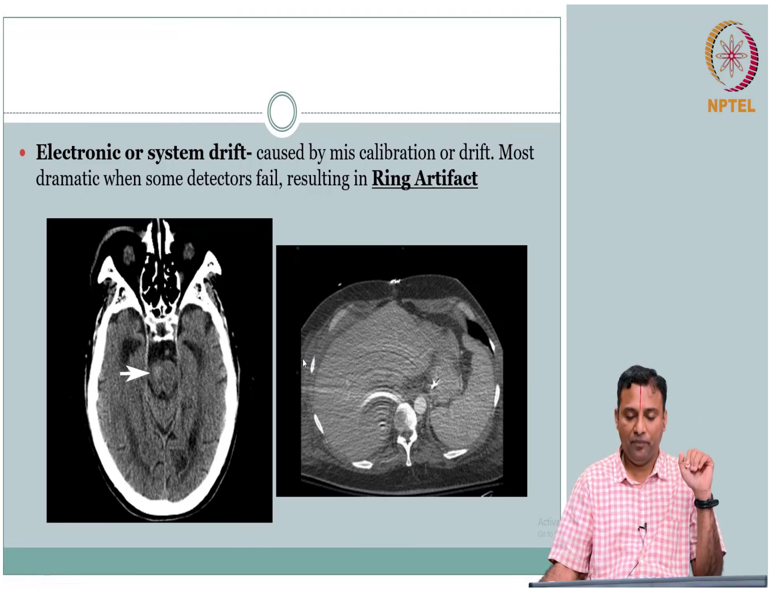

And then you have your you have a detector, regular electronics is there electronic drift all those things are there, but more importantly we have detectors if one of the detector goes bad right. What does that mean? That means, it is whatever it is going to always have a zero value right.

What does that mean? Physically that means, everything that came in along the line of sight is attenuated absorbed by the body. So, it is going to say very high attenuation value will be projected along that path ok. But then what is the thing? You are going to rotate right different angles you are going to do, but the detector is a malfunctioning detector. So, every rotation wherever that detector is there along that line of the detector, it is going to project back and say this is a high attenuation everything is absorbed in the medium right.

So, when you organize it in theta and some what is going to happen? You get what is called as a ring artifact. So, the size of the ring right. So, it is more prominent here I think you can you can see the effect what is the. So, the size of the ring for example, could tell you the radius of the ring could tell you which element from the isocenter right; centre of the detector right you have the source you have the centre and then its width.

So, if a detector is gone bad the location of the detector from the isocenter right from the centre of the detector that radius you will see the ring ok. So, ring artifact is again something that take an spot; I mean it is not really a pattern that is there inside you can have so, not a pattern, but at least one ring if it is there is it a circular lesion or some circular growth or is it because of malfunction.

Again, domain expertise and experience comes into picture, but this is kind of a very if you get nice circular symmetry you know; all likelihood it is going to be because of your reconstruction algorithm, you have projected it back based on the theta for full 360 degrees. So, you are going to get likely that it is an artifact. Nature is beautiful, but maybe it is too good to believe that you have a perfect concentric circles that are coming in the object ok. Again some amount of domain knowledge is important, but this is these are sparely understood well ok.

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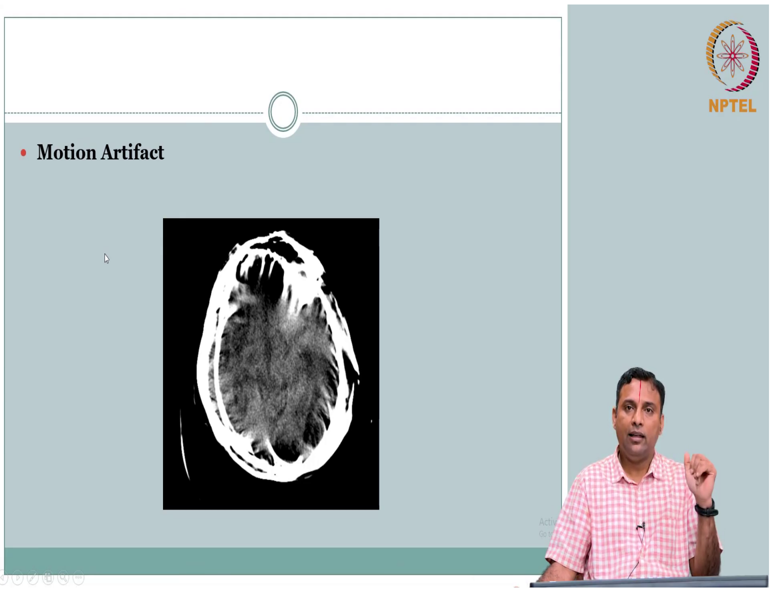

So, one another common thing is your motion artifact. So, we talked about different generations and that time also I kind of cautioned you. So, if you have motion during the data acquisition, you cannot do much right you are going to project that back. And so, motion artifact is common most of the times you will have to rescan ok. There are settle times for example. So, here for example, you have to rescan, but the advantage, but it depends on.

So, it is anatomically image if you want to hear right you can ask put a fixture and have the head stable. But for example, if you are going to do a C T of your heart right it is always going to move there is going to be. So, one is fundamentally you have to do high frame rate, but after that what do you do? If you want to see some dynamics that is moving much more than your frequency of temporal frequency right your scan frequency. What do you do?

Well say for example, heart what they do is you have what is called as ECG getting right. So, they can have the ECG and they can collect the data and then go back synchronize it with the ECG and say ok every time right this data we got next time also at that location only I got; I will synchronize it with what they call as ECG gated that is one common way they try to do it.

So, you do multiple acquisitions over different cycles and then go back synchronize it with the ECG which is very good temporal resolution and then take only those frames that are all in certain time interval in the cycle that you want ok. So, that is one common way they do to. So, to reduce motion artifact here vivid artifacts is when you rescan, but sometimes intrinsic when you are really dealing with intricate organs, where there is a motion, but you would still like to look at image without motion because you want to measure the thickness of the valve right.

If you have blurring and thicknesses because of the blur is certain value you lose out. So, you. So, there are critical applications where you may want to minimize the motion blurring and the motion is not because of your outside motion that is controlled, it could be inside. Breathing you can hold to some extent, heart is a good example it is going to do its job. So, motion artifact there are ways to correct it, but this can be corrected at the acquisition stage.

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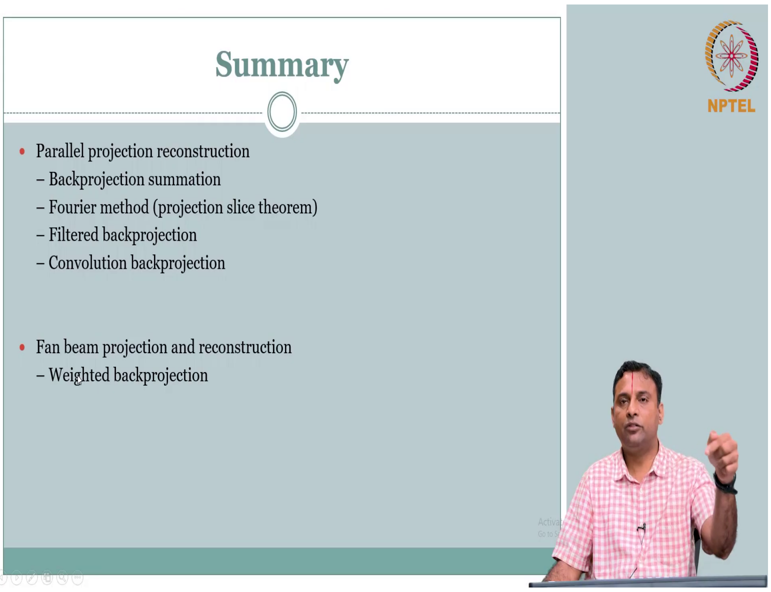

So, to just summarize what we have covered in the whole idea module of X ray CT; X ray computed tomography. We started with parallel projection reconstruction ok, and that is a simple intuitive paradigm to understand. So, where we talked about back projection summation first this is the intuition way.

Just project back the average sum, but then we kind of made it a little more formal because the image were blurry we started looking at mathematical correctness. And then we notice there is a projection slice theorem and that projection slice theorem was a Fourier method.

But then we said this is not that popular most popular is your filtered back projection, but filtered back projection also if you have to implement you know it is the you have to do couple of frequency. You know go from Fourier domains back and forth. So, more practical one would was convolutional back projection. So, you do your convolution in the spatial domain right. So, it is also filtering.

Then we talked about fan-beam projection and reconstruction. So, here what the take home message was its very similar to what we had before only thing is start to imagine that was what is 1 by d dashed square. So, that adds a weight. So, you start to think as weighted back projection otherwise it is a back projection only ok. Same filtered back projection, but you have one more 1 by d square term. So, that is your weighted for the distance from your source to that point.

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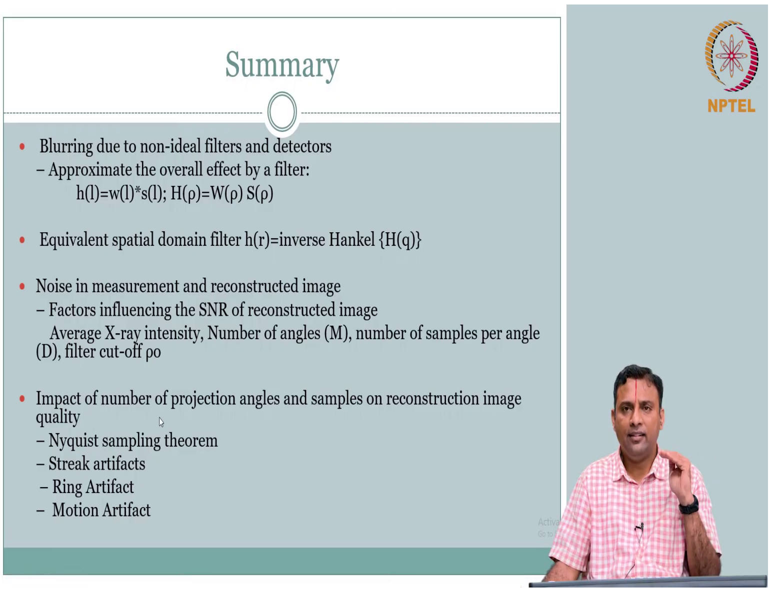

Then we talked about image quality in the image quality we talked about blurring and the blurring introduced due to your filtering the non ideal filter and the area detector. Not a point detector there is a area detector. And therefore, we introduce that as the blurring that introduces a blurring effect. And so, we talked about this and equivalent filter that you can get for the blurring we obtained using inverse Hankel transform h of r right. So, this something that we did then we talked about noise.

In the noise we each talked about not just noise, noise in the context of differential signal to noise ratio and we talked about how the factors some of the factors that are influencing these to be the X ray intensity, number of view angles, number of angles per right the number of samples per angle and your filter cut off anti-aliasing. And we also talked about different artifacts ok.

So, I think this is a like I said this is supposed to be a introductory material for this module, because we are covering different modalities. But what we covered here is fairly at a level where if you understand this and you have some self-learning motivation because you are working in this area or you plan to work in this area or your worked with some image processing of you know CT.

And you would like to understand more, I think you are you; will be able to catch up to the state of that in quick time after you start to work on this do some programming of implementation of the recon. That will be a suggested strategy to master this material, ok.

So, thank you.