Introduction to Biomedical Imaging Systems

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Lecture - 20
PR_Image Quality

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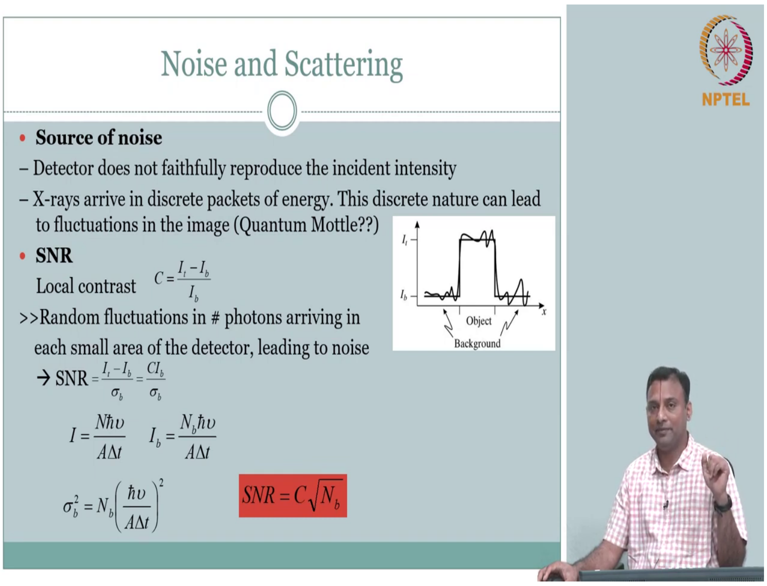

Let us get to the business. What is it? When we talk about image quality first and foremost, we want to talk about what do we mean by noise and scattering ok. Scattering because it was a named one, you might easily quickly spot it right; Compton scattering. So, we will come to scattering after we completely deal with noise right; scattering will be the towards the end of this module.

So, noise; what is noise? What we have pretended so far is I have this physics, the X-ray tube generates photon, it comes through it in; through light, you do the filtering restriction, it goes through the body, interacts with photon for photoelectric effect. Compton scattering, we said scattering will delay the discussion after completing the noise part. So, essentially, you had the signal part right, the photo electric effect and then we said that signal goes hits.

You have your intensifying screen, collimator goes hits the film. So, essentially, we have pretended whatever falls on the detector right is truly faithfully reproduced at the output optical density which the doctor is interpreting. But in reality, what do you think? In reality that is not as simple because you are measuring this all this is fine. But then, when you do the measurements, there could be fluctuations, there could be randomness right which will contribute to the source.

In our case, we need to identify what is that source where that fluctuation could come from ok. So, now, is the time to recall, where could it come from. From the physics of it, just think about from the start of this process of imaging. Physics right ok; I have photons that are coming out.

So, essentially, what we have talked about is X-ray photons, n number of photons are going through, it is getting attenuated; reduced number of photons are coming out that falls on the detector right. But how is this photons generated? Photons are packets of energy electromagnetic photons or electromagnetic X-ray is what we are talking about right, interaction with the material. Those are essentially packets of energy right.

So, is that all nice and clean or could there be randomness? In fact, we did talk about the time arrival right, when you generate this X-ray burst, the n that comes out right, it has a statistical property right. What does it model does? The time arrival on to the detector, we showed one of the random variables, what was that?

Poisson, , so now, we can essentially say detector does not faithfully reproduce the incident intensity. Why is that? Because you have randomness; where is that randomness? The X-rays arrive in discrete packets of energy ok is a random moments, so burst of X-rays. So, given that, I could have the same material, but adjacent locations may experience different n number of photons.

Because the burst creates a population of energy of that photons and each one arrives at different time instance. So, therefore, even though it is a same material adjacent locations right, you may get different n; slightly plus or minus the neighbour. So, there is a fluctuation around right. So, that fluctuation, we also used the term called quantum mottle right, this fluctuation. So, because of that, what you have is this fluctuation is your noise. So, what we will do is we will take now the question is we will have to define this little more carefully.

So, we understand where the source of noises. Now, we need to model that. It is not going to be new. We have actually we have an idea on this randomness, so you know where we are going. So, let us take a condition right here. So, you had just simplicity, we have taken a profile. For example, we have a we had a square object right. Remember the prism slab.

So, leave alone other stuff right. When you have the detector, it comes out. So, on the detector, you have a square cross section right. If I have a rectangle, I have a rectangle cross section. So, this is my object right. This is my object; my palm alone right, this is my object right. I am keeping it like this; this is my object.

One side is X-ray coming, other side is the detector. I am keeping this detector, this object on the detector to avoid magnification all those blah blah blah. So, that means, my shadow is going to be like this right. This is the region on the detector that is going to be hit. So, if I take a profile, if I take one line of this right, no value, no value, no value, high value, high value, low value, low value right.

So, this is your ideally, this solid line is what you would have had. But given the randomness, you are essentially going to have what is going to be picked up is going to be having fluctuation right. So, now, the question is fine we see this how do we now study this further and talk about the image quality, how do we define the image quality for this based on the measurements.

Same definition, fluctuation is your noise; meaning, your standard deviation, variance right. What is your signal? That is, so, signal is defined in the context in our context here. For example, what is our signal? We want to see how tall this target is standing out compared to the background. I want to spot this target in the background; I want to identify this structure right.

I want to identify this target from the background; tease out this target from the background. So, that means, my signal is how well I can see the target from the background. So, my signal in this case, I am defining as the difference between I t and I b. So, this is where I want you to be careful ok.

So, we are going to talk about always when you talk about noise, noise itself is not I mean you need to know what the noise is; but it is always in the context of signal that we are worried about the noise. So, it is always the signal to noise ratio that will be analyzed.

So, when we talk about signal to noise ratio, it is very important, you read the material to see how they define signal and what is the source of noise. This even though everywhere, they will use signal to noise ratio, contrast to noise ratio, contrast, you have so many matrix and the definition for signal to noise ratio could be different.

So, last time when we use the signal to noise ratio, we just talked about mean to standard deviation which is a very standard way of doing it; whereas, here if you notice, our signal we are defining it as actually how much can the target be seen compared to the background.

So, our signal, we are defining it as difference between your target and background right. So, you are defining your signal in terms of local contrast. So, local contrast is I t minus I b by I b. So, your signal is defined in this terms ok. So, now, the question is fine, what is my noise? Noise is just the fluctuation in the background right; fluctuation in the background or the standard deviation square root of variance right.

So, random fluctuations in the number of photons arriving in each small area of the detector that leads to noise right. So, what is that? Do we have a model for that? Yes, we do right; we do. Remember, this random fluctuation; so, if you know the characteristics of this random fluctuation, how do we know that?

We know the probability right, distribution function, you saw the probably density function that was this. We know that it was Poisson. What is the characteristic of Poisson? Your mean and variance are same; correct? So, you can write your signal to noise ratio as I t minus I b by sigma b. So, I t minus I b kind of captures your local contrast; of course, it is normalized to be I b here, the local contrast. But your signal is we want to capture this difference.

So, your signal is I t minus I b, your noise is sigma of b whatever is the background fluctuation. So, I know I t minus I b, this is a local contrast that we had defined. So, we could write your signal in terms of the local contrast C times I b by sigma b. So, this is your signal to noise ratio fine. So, this is my signal to noise ratio. But how do I you know work this further?

So, I need to bring in my signal and noise more explicitly because my noise comes from and the signal comes from your number of photons right. So, how do I expand this? We are just going to say we have population of status right, number of photons that are arriving.

So, your signal will be mean and your mean of the number of photons, the standard deviation will be your variance will be your same as your mean right because of the statistics. So, I, I know which is my N h mu by A delta t. This is the definition. Of course, be careful. Why we talk about I is equal to N h mu by this is the regular formulae.

But then, where does the you know fluctuations come? The fluctuations come here in N right. So, the number of photons, the fluctuation in the number of photons, the statistics of this gets to your intensity fluctuation as well. So, your I; so, your N is in the background you are going to have N b h mu by A delta t; your sigma square is going to be N b right; your variance is same.

So, if you recall your standard deviation right, so now we can substitute this. We did similar thing before right, but that was just signal to noise ratio, mean to standard deviation. So, mean was so standard deviation was square root of variance and we said Poisson distribution, your mean and variance are same and therefore, we got this square root of N in our generic introduction for image quality right.

So, here, we are customizing it right with putting the N b and you have this h mu square by A delta t. So, you can get the similar thing. SNR if you substitute a C square root of N b nothing. So, the C was not there before, when we did our intro because we defined our signal to be just mean; whereas, here we have defined the signal to be local contrast. And therefore, your signal to noise ratio captures C here and then, square root of N b right. Clear? Straightforward.

So, the idea is this is nothing new. The way we have defined our signal in this context is capturing the local contrast and therefore, your signal to noise ratio is in terms of contrast C and square root of N b. So, this is where I think you need to be careful, when you read interpret some measures, you need to first make sure means ok. First you have to make sure that your understanding of signal to noise ratio, the definition is same as what you are going to use.

So, several literature, we defined contrast to noise ratio which is not really captured in this modules. Here, we are talking about signal to noise ratio. The signal is capturing the local contrast. There are some other measures, I will just the contrast ratios; signal to noise ratio, contrast to noise ratio, contrast ratio. So, there are several ways people try to capture it.

So, you have to understand the definitions right; how they define and what they capture. The term may be same SNR, but here notice the signal is defined as capturing the local contrast ok. So, how do I increase my signal to noise ratio? Well, proportional right. So, I can increase the contrast or I can increase my N b or both; beautiful. So, what contributes to contrast? Well, we talked about inherent contrast right.

We have to be able to this is all inherent, we need to be able to capture the contrast that is there already. So, for example, in our case, if you look at the plot that we showed, we had bone, soft muscle right. Sorry, muscle and fat right, soft tissue that was exponentially decaying and we notice. So, x axis had energy level, y axis had the attenuation coefficient right, relative attenuation coefficient and so, we noticed that that is the inherent contrast.

The attenuation property of your bone is different at different energy levels, but that is more different from your muscle behavior, which is different from your fat behavior. So, contrast when you talk about for any given energy level, you are talking about the difference in their attenuation property. So, this is inherent intrinsic.

So, how do I increase my intrinsic contrast? You have a choice right, you can take the energy. So, if you recall that plot, you had lower energy, you had very good intrinsic separation. As you increase the energy, the intrinsic separation or the intrinsic contrast came down or started diminishing. So, if how do you increase the C? Maybe I can use lower energy right.

If I lose lower energy, I have inherent contrast over a larger range. But then, what is going to happen? What is going to happen? Well, if that is the case, we notice that the X-ray energy will probably get observed; the intrinsic contrast is there, but then we are interested in the contrast coming out to the instrumentation to the display image right. So, if it is low energy, we know that it gets absorbed and you know you do not really get the number of photons will reduce.

So, if I try to use low energy to increase C, my N b will go down; number of photons that are coming out will go down because there will be lot more attenuation. It will be attenuated fully. It won’t come out, lot more interaction right. So, I mean nothing is straightforward.

That is the fulcrum. I mean you need to understand that nothing is a one way street, this is the challenge that you will face. We talked about I understand the image quality, I can characterize the signal to noise ratio. Now, I know the physics, I know the instrumentation, so I will say increase the SNR, I increase the C. But how do you increase the C?, I know how to increase the C, I will increase the you know decrease the energy.

But then, if you decrease the energy, not your C is better, your intrinsic contrast is better; but your N is going down. So, you have to be carefully orchestrating., One way that we already saw which is beneficial is put contrast agent ok. So, there is this added effort of putting a contrast agent tailor making it, but that helped us right. So, you can increase the contrast by putting contrast agents so, that was a.

So, you can manipulate the contrast. So, otherwise what is going to happen? Ok, I can increase N b. How do I increase N b? The problem is if I increase N b, so maybe I can take a particular energy level, whatever contrast is up acceptable right which I can tease out, but then produce more photons.

Well, that could help; but the problem that is not just image quality, bio safety; that means, we increase that exposure and number of photons, then there is problem with radiation dose dosimetry right. We talked about radiation dosimetry. So, nothing is free.

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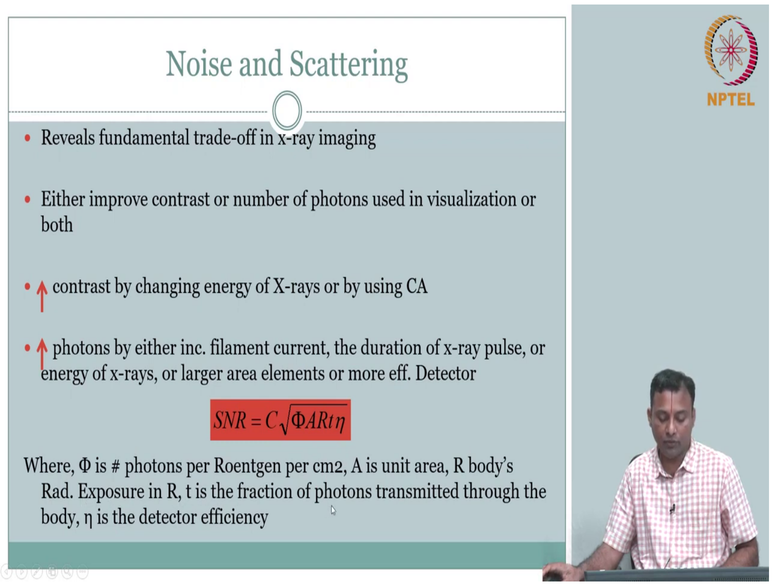

So, you will have to play with this. So, what we will do is this is an important fundamental trade off. Trade off because you cannot get both as for the reasons that we discussed. So, either you can improve the contrast or number of photons in limited case depending on how it is for example, you can have a contrast agent and use little more photons you can get.

So, you can play with this ok. So, increasing contrast like we talked about depends on the energy level, you can change or using contrast that is one way of doing it. Increasing the photon, again X-ray tube, you can start from the X-ray tube right. So, filament current duration of the pulse, energy of the X-ray or large element; what do we mean by large element?

That means, I will compromise the resolution. My detector, if I have smaller detector, then I am able to localize a location right. So, then, I can say this is the location, the line through which it passed and came, this is my pixel size. But if I increase the detector size, I will catch more photons because the area is increased.

But what is going to happen? If I increase it, then I won't be able to localize, my resolution is poorer. I will you know if my pixel is 1 mm cross 1 mm; I know I will say that this came along 1 mm cross 1 mm line of sight in front; whereas, if I make the pixel 5 mm cross 5 mm, yes I will catch more photons.

But then, I will have to say this came from 5 mm cross 5 mm region in front. So, I have lost the resolution. So, there is always this tradeoffs. But given all that that is fine, all the inherent tradeoffs are there it also depends on more efficient detector. So, we did talk about film screen, we talked about film characteristic right; but still maybe this is something that we need to explain little bit further.

So, everything else set apart, how do I understand or use a more efficient detector? If I can use a more efficient detector, I definitely can get better signal to noise ratio for all other compromises access right. So, we need to work on how do I characterize, how do I talk about the performance of; what do I mean by detector efficiency, how do I improve the detector efficiency right.

So, the idea is we can put our signal to noise ratio is contrast, we identify the noise right the number of photons N b, square root of N b right, the number of photons is can be done by any of these factors. So, we are just instead of writing it as N b, we have written it in terms of all the factors that contribute to N b right.

So, your phi is your number of photons per roentgen per centimeter square; A is your unit area right; R is the exposure body's Rad; t is your fraction of here right, t is the fraction of photon transmitted through the body; most importantly, your detector efficiency. So, all of these contribute to increasing n.

So, you can play with all of this to increase the n. So, what we will consider is all the other things, we already talked about. It all has its effect on you know increasing the X-ray tube current or radiation dose all that we already talked about. So, can we just talk about little bit more on this eta, that is your detector efficiency. If I can increase the detector efficiency, I can increase my signal to noise ratio for all other system parameter settings being same. So, we need to understand what is this detector efficiency.

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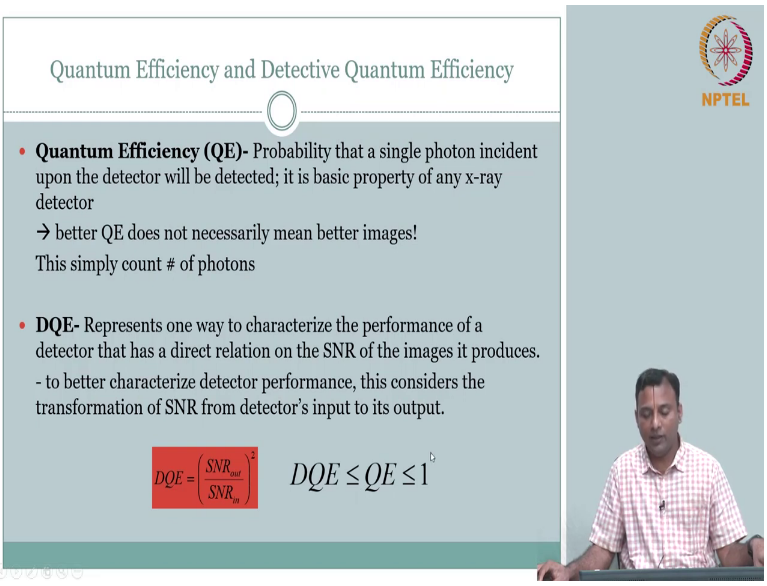

So, to in order to talk about detector efficiency, we first have to talk about quantum efficiency. What is quantum efficiency? Well, what is the whole process? The process is I have a photon right; X-ray photon is coming in. In the detector, what is going to happen? This X-ray photon has to be converted to light photon right.

We are interested in this with the intensifying screen that is the paradigm that we are talking about. So, this light X-ray photon has to be converted to light photon. So, what is the chance that this will get absorbed, interact with the material right; what is the chance that if I send 1 photon that photon is going to get interacted right, get absorbed take part with this material and create a light photon, what is that probability?

So, if it is just going through coming out without interaction, you are not going to get anything right. So, this quantum efficiency is in some sense, it is going to characterize the ability of the detector to interact with a photon and converting that to a light photon. So, quantum efficiency is the probability that a single photon incident upon the detector will be detected; meaning, will be detected as in it is going to interact with the material right and so, it is a basic property of X-ray, any X-ray detector.

So, now the question is ok, when you say probability, we can have this number right. So, I can have some number for efficiency 30 percent, 40 percent, 20 percent whatever you can think of, does it really say that if I have QE right. If I have a better QE numerically, if I have a larger QE, does it mean that is the you know that is the best or that is the detector that we want to use right? So, better QE does not necessarily mean better images, what we want is the quality of the images to be good.

What this is saying is quantum efficiency is just detecting, the probability of this interaction; but not necessarily that if you have a good QE, it will translate to better images. In other words, if I give you two detectors having the same quantum efficiency right, but you know that one of them, it has the same quantum efficiency.

But one produces right, the conversion and localization of the photons with less randomness than the other. Then, intuitively, you will say look I want to go for the first one right because it has less fluctuations. So, its ability to convert this probability might be true; but there is a randomness right when you do the multiple measurements, there fluctuation that could be a problem.

So, therefore, we will not without telling any further even though the QEs could be same, if this is the description, then I would rather go for the material or the vendor with the QE might be same; but then, the one that has less fluctuations. Correct? What you see in the image is the noises because of this fluctuation. So, I would rather so you can say that the QE does not necessarily translate to better images. What that does is it just simply counts the number of photons ok.

So, if there is a fluctuation in the number of photons, you will see the fluctuation. So, that is what we mean. So, that means, this is ok; but not really this is important, but does not really fully capture. So, I need some way to say that introducing this detector is not spoiling any further right or in other words, I have some intrinsic signal to noise ratio because of the physics and other things that is coming in.

Now, I have a output image and that output image has a signal to noise ratio. You want the detector right to efficiently transfer the input signal to noise ratio to the output. So, the output signal to noise ratio should be as close as possible to your input signal to noise ratio. So, your detector should not spoil that right.

So, detective quantitative efficiency right, quantum efficiency is your this performance characterization of how much of the signal to noise ratio in the input intrinsic signal to noise ratio is preserved in the output. So, represents one way to characterize the performance of a detector that has direct relation to the SNR of the image, it is produced right.

So, what we really want to characterize the performances of this detector is it able to transform the signal to noise ratio that is inherently there, how much of it is it able to capture? So, DQE is SNR out by SNR in square of that. So, typical values you can get like this DQE is less than equal to QE is less than equal to 1 ok.

So, what do we what can we tell from this? Well, we can see that we already talked about quantum efficiency; quantum efficiency is also less than 1, but your DQE is even less than QE, why? In some sense, we talked about having same QE if it is not able to localize if there is a fluctuation, then we talked about the image quality will be different right, it will be lower. So, your QE is the upper limit; meaning one is the best case, usually your QE is less than 1. Your DQE is a further degradation right. So, that is going to be less than your QE ok.

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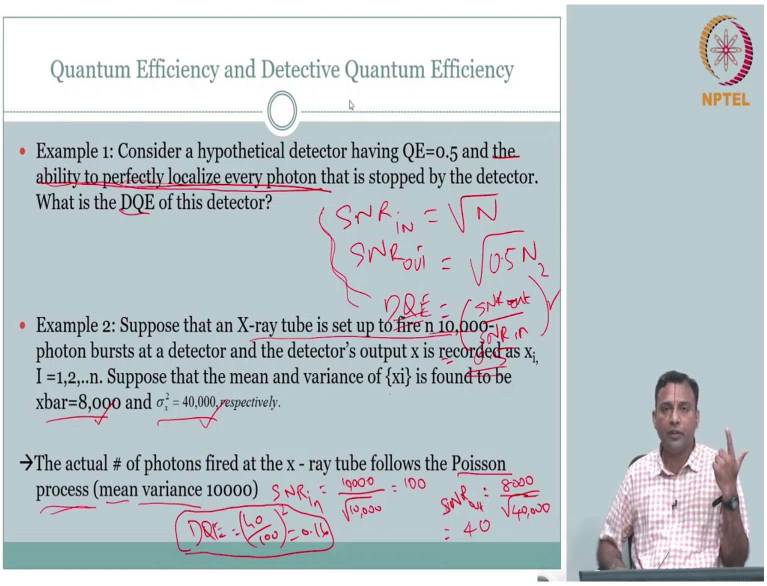

So, now, let us take an example right. Consider a hypothetical detector having a quantum efficiency of 0.5 and the ability to perfectly localize every photon, what is the DQE of this detector ok? What is the DQE of the detector? So, what is DQE? Well, DQE is intrinsic signal to noise ratio right to signal to noise ratio at the output right, square of that. So, what do we have here? QE is 0.5 that is given; but more importantly, look at this.

What does QE represent? It require, it represents the ability of the detector to stop photon right. So, that is one thing and then, what did we say? The ability to stop alone is not sufficient. You could have two detectors with the same QE. But it may have some randomness right, it mean but here what is it saying? QE is 0.5 and it has the ability to perfectly localize every phantom, sorry every photon. So, what does it mean?

That means, I do not have any more degradation right; I do not have any more degradation in the performance. So, how do we talk about that? Well, what we know is what is your signal to noise ratio intrinsic right, SNR, what is intrinsic?, We talked about this right. Number of photons signal to noise ratio if just signal being the mean of the signal variance, if it is a Poisson right we talked about. So, that is what we are talking about here right.

So, you have intrinsic is your square root of N. So, we are not talking about contrast here, do not get confused. We are just talking about 1 photon; 1 location right. So, we are just talking about signal and the variation around the signal. So, signal is your mean, variation is fluctuation around the mean.

So, your noise is your standard deviation or square root of sigma right; square root of your variance. So, signal to noise ratio is your square root of N; this is your intrinsic. So, what will be your if this is given, this clue is given right, what will be my output; I mean so if you go N input QE is 0.5. That means, in my output right, I have to calculate SNR out right.

What is that going to be? That is going to be square root of the number of photons; the random number of photons, how much is the number of photon, average number of photons? It is going to be 0.5 N because the quantum efficiency is that. So, 1 photon right, you are going to get 50 percent out.

So, the output you have 0.5 N and the so we have given perfectly localize every photon. So, that means, your SNR out is square root of 0.5N. So, what is your DQE? DQE is nothing but your apply your definition right, DQE is this guy; SNR out by SNR in square. When you substitute this, what is it that you are going to get? You are going to get 0.5. What does it say?

Wow, we talked about DQE being less than equal to QE less than equal to 1. What did we find out? Here is a case where your DQE and QE are same; of course, they both are less than 1 because QE is less than 1. So, what does this say?, this says in this case right in this hypothetical scenario, your DQE is equal to your QE; meaning, there is no further. So, that is this is the key.

When we rule out the other possibilities, other variations, noise, then your DQE equal to QE, but typically that is not the case right. Typically that need not be the case, this ideal perfect localization other things may not happen. So, there is going to be some fluctuation. So, your DQE in general will be less than your QE. But in this hypothetical scenario, you can see that DQE equals your QE clear.

So, let us take another example. Here what do we do? I mean first we took a hypothetical case. This is kind of little more closer right to reality than what we did now. Suppose, an X-ray tube is set up to fire 10,000 photon burst at a detector. So, you have a detector on the input side, you have 10,000 photon burst that is coming. The detectors output x is recorded as x i.

So, the output is random variable x and it is recorded as x i, you have n photons right. So, so now, this measurement right x that you have measured the output that has a mean and variance like this. Found to be xbar equal to 8,000 and your variance to be 40,000. Now, the question is same thing, how do you calculate the signal to noise ratio? So, DQE right. So, how do you get the DQE? So, DQE, we saw here also right; you need SNR in SNR out.

So, what is my input? My input is n 10,000 right. So, input side is relatively easy, why? Because I have given that this random variable 10,000 burst are on the input side. So, we know what is the actual number of photons fired at X-ray tube follows a Poisson process. So, the moment we recall this, we can quickly talk about mean and variance, both equal to 10,000 ok.

So, that means, this is not a big deal right. So, I can get my SNR in is 10000 divided by this is variance is 10000. So, what do I need? Standard deviation, so it is square root of square root of 10000 right. So, this is about 100. Wow, this is my input SNR. What is going to be my what is going to be by SNR output? You are given mean and variance right. So, you can write your output to be 8000 divided by square root of this 40,000. What is that? That is going to be some 40. So, what is your DQE? DQE is SNR out by SNR in by the whole square.

So, in our case, it is going to be 40 by 100 the whole square which is 0.16. Clear? What does this say? What does this say? This says, , in the previous example, we saw 0.5 as your QE and your QE and DQE were same; whereas, here your DQE is only 0.16; meaning only 16 percent of the photons are correctly identified, detected. So, right. So, that is what this tells.

In other words, when we talk about the signal to noise ratio out by signal to noise ratio in and you know how much it transforms the input signal to noise ratio, this kind of tells you that its only about 60 percent detector correctly. That is one way of interpreting this; clear? So, this is more straightforward to interpret. So, QE is fine, but it is a DQE that can be used to select the detector performance, efficiency right ok. So, so much for signal noise ratio, what we need to do quickly is signal to noise ratio is fine.

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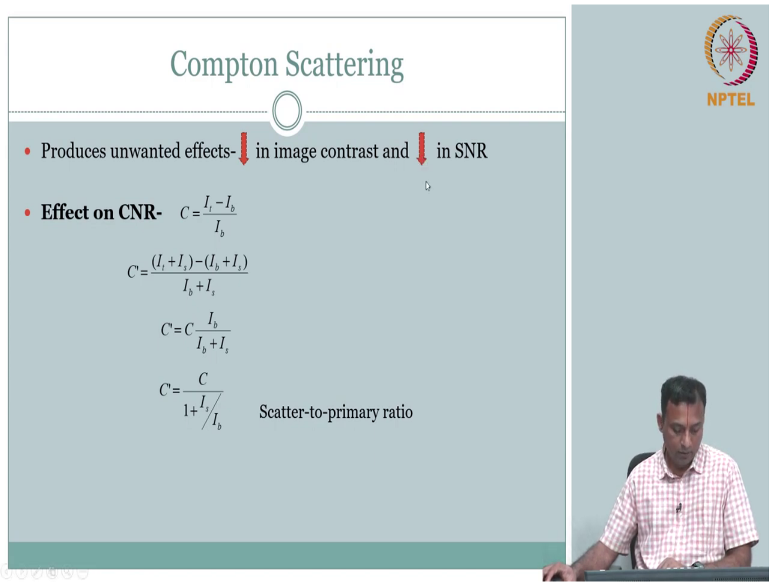

We need to talk about Compton scattering right. Compton scattering; what is Compton scattering? Again for what we did so far, the randomness came from the noise came from the physics of the number of photons that are distributed right, the time arrival difference; whereas, always there is going to be Compton scattering with due to the physics right. So, what did Compton scattering do?

Compton scattering essentially sent out some photons with reduced energy and it could come at angle ok. So, that was Compton scattering. So, you have a signal that came from photoelectric effect, number of photons due to your photoelectric effect; but on top of it, you also get some other photon from a different location which is a Compton scattered.

So, what it does is it produces reduces the image contrast and also, reduces the signal to noise ratio. How does it reduce the image contrast? I hope you did this exercise, when we did the introduction right for your image quality, I talked about how I think I did this experiment of taking my phone and switching on the torch and saying whether can you know if I add, there is a contrast between my if I remember right, that is the example we did right.

Contrast between by shirt and skin, if I put a white light both on skin and my shirt, did the contrast go up or go down, I had actually asked you to try it at home and get a feel for it. We will do that mathematically now. So, produces unwanted effect where the image contrast is reduced, we will see why it is reduced and it also decreases the signal to noise ratio. So, we will see these unwanted effects, we will write out this unwanted effect. So, in order to do that, first we will talk about the effect on contrast to noise ratio ok.

So, what is our contrast? I t minus I b by I b. So, now, we need to talk about Compton scatter, effect of Compton scatter. What is this Compton scattering do? Compton scattering essentially added right both high scattering, it added it to the target, it also added it to background. So, every pixel, remember every pixel now gets additional intensity because of the scattering. Remember, we I hope you now recall what we did or at least what I asked you to do.

So, C dashed is I t plus I s minus I b plus I s by I b plus I s; whereas I have added the scattered intensity to all the pixels, both in the target and the background. So, if you do that, what is the new contrast? So, you can manipulate this, you can get new contrast in terms of old contrast by a factor. So, more conveniently, we can write this as C dash is equal to C by 1 plus I s by I b.

So, if there is no scattering, then no problem, your contrast is not reduced. If you have scattering right, if you have scattering, so there is this 1 plus some value right. So, this is denominator that is greater than 1. So, your original contrast will be reduced; C dash should be less than C because of scattering that is what we mean by decreases the image contrast ok. So, C dashed C; so, this I s by I b is given a term called as scatter to primary ratio ok.

So, if I have more scattered to primary ratio; that means, my contrast is going to reduce in this form because it is inversely related. So, if I have scattered to primary ratio increases, my denominator increases and therefore, my C dashed becomes less than my C. So, C is without scattering, C dashed is contrast with scattering. Clearly, if you have scattering, contrast in an image reduces right.

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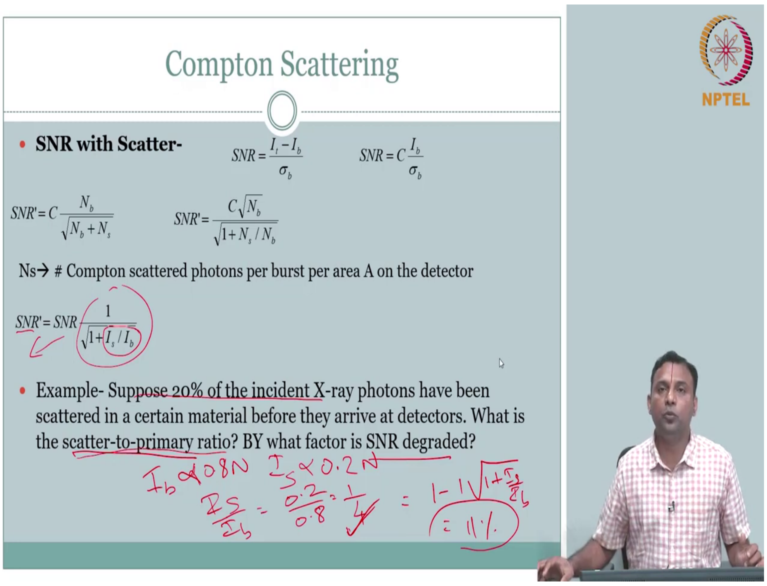

So, likewise, what happens to our signal to noise ratio? Of course, we talked about signal to noise ratio also going down, but what we will do is show it right. How do we show? Same thing; SNR with scatter is I t minus I b by sigma b, the same definition be the s started for SNR right; your target minus background intensity is divided by the variance. So, this is my signal.

So, quickly, we can write this. What do we need? We need to introduce scatter. So, if you introduce the scatter, so we can start to write SNR in terms of local contrast. Remember, this we did a few slides back. So, C I b by sigma b, but my new signal to noise ratio after my

Compton scattering in effects are included will be C sigma b right. So, you have your N b by N b plus N s.

So, you have your new signal to noise ratio in terms of local contrast right N b by square root of N b plus N s. Of course, this is not in a convenient form, this is the is capturing, but it is not in a convenient form. What do I mean by convenient form? I need it in terms of some ratio, so we can quickly look at the relationship between SNR dashed and SNR right. We have we kind of said that the Compton scattering reduces the SNR.

So, this is a new SNR with Compton scattering included. So, we need to see this SNR dashed in terms of SNR right. So, N s is the number of scattered photons per burst area A on the detector ok. So, this is the number of Compton scattered photons. So, your SNR dashed is this guy, I just manipulated right.

So, divided by square root of N b numerator and denominator and then, you can take this guy in ok. So, why is this convenient form? Well, I have SNR dash C, I have something as N s by N b ok. So, SNR dashed is in terms of SNR by 1 plus I s by I b. So, I can just manipulate. So, the idea was I want to write my SNR dash in terms of SNR. SNR dash is equal to SNR times 1 by 1 plus I s by I b. What is this I s by I b? We already talked about scattered to primary ratio right.

So, SNR dashed is essentially you can look at it from here, SNR what would be without Compton scattering; due to your Compton scattering 1 by 1 plus, so this this guy goes greater than right the denominator 1 plus; so, this guy goes greater than 1 and so, 1 by square root of this guy which is greater than 1. So, some factor less than 1. So, your SNR into a factor less than 1 is going to give your SNR dashed; that means, SNR dashed is reduced ok.

So, this is a important aspect right, contrast we are not going to talk about resolution, we talked about signal to noise ratio, we talked about Compton scattering included as well. So, we will just do one example here. Suppose, 20 percent of incident X-ray photons have scattered in a certain material right, before they arrive at the detector, what is the scattered to primary ratio?

So, this is you have your I s by I b what is that because once you get that by what factor is SNR degraded right. So, this is straightforward right. You can calculate this. What is given; what is given? So, what you are once you get this, this is not a big issue. What is given? You are given 20 percent of the incident X-ray photon have been scattered. So, what is my right what do I need? I need I s by I b; I s by I b.

So, what is I s? What is I b right? I can give I b is about 90 percent of the sorry 80 percent of the N. This is proportional right because you have given 20 percent is scattered. So, your I s is going to be proportional; intensity, number of photons, they are proportional right. So, I s is going to be 0.2 times the number of photons you are dealing with. Clear?

So, once I have this, I can get my I s by I b. What is that? 0.2 by 0.8 ok; by 0.8 which is about 1 by 4 right. So, I have scatter to primary ratio. What is asked, by what factor SNR degraded? So, look at the; so, SNR dashed by SNR right. So, you have to calculate this guy for which you have your I s by I b computed already right. So, you are going to have loss ok. So, you are going to have 1 minus right 1 square root of 1 plus this point 1 by 4 right I s by I b. So, this turns out to be about 11 percent ok.

So, how much is the by what factor is this degraded? So, if this is 11 percent loss. So, it is reducing the SNR by 11 percent because of Compton scattering ok. So, this is a very important aspect because image quality, now what we did is we are able to see most of it is related to the number of photons and the inherent contrast right and then, we talked about detector efficiency.

So, even after you have a particular detector, if you can manipulate N, you can manipulate your signal to noise ratio. So, whichever form we saw with scattering, without scattering, noise by itself this N number of photons place a important part ok. So, much for noise and scattering, which is to do with your image quality.

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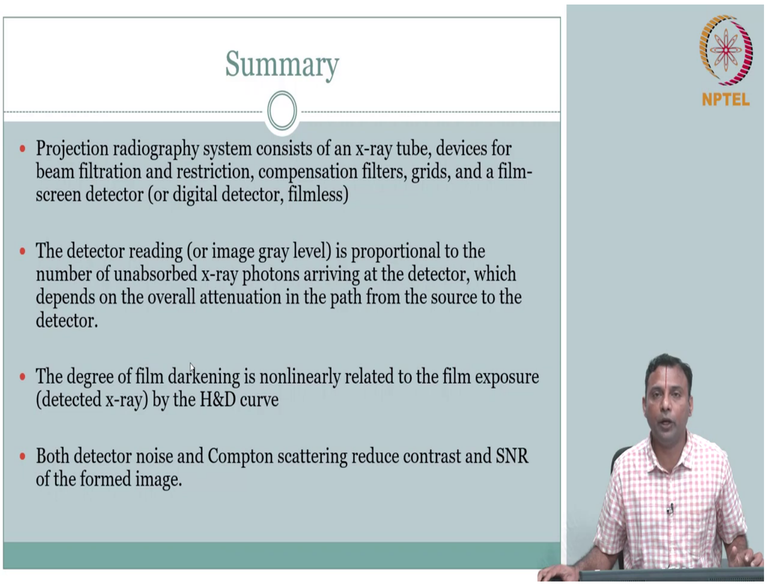

So, now, we will just summarize what we have covered so far in this projection radiography. In projection radiography, we talked about the system right consisting of your X-ray tube and then, all the other parts; filtration, field of your restriction, compensation filters, grids right, including film detector, in fact the intensifying screen, we talked about all that.

And then, we talked about after it hits the detector that input X-ray exposure converted to light photon, how does that expose the film and then, the development of the film and what you talked about right. So, detector reading is proportional to the number of unabsorbed X-ray photons right, which depends on the overall attenuation path of the source.

So, in some sense, here you have to think about why the in a typical X-ray, bone comes out to be white right; if you have a fracture, the fracture is coming out to be dark. Why is bone white? Because there is more attenuation so, the film is not exposed, is exposed by less number of photons because the bones absorb the X-ray photons. So, if a detector is behind the path that has bone that would receive less number of X-ray photons and therefore, less darkening of your X-ray film ok.

So, degree of this darkening is related by the S curve or the H and D curve that we talked about and then finally, we talked about the noise; both due to detector noise and the inherent physics which is your Compton scattering ok. So, that concludes the aspects that we wanted to cover with respect to projection radiography. So, from subsequent lectures, we will talk about the next modality which is going to be your X-ray CT.

Thank you.