**Digital Image Processing**
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**Module 09 Lecture Number 44**
**Estimation of Degradation Model and Restoration Techniques - 1**

Hello, welcome to the video lecture series on digital image processing. In the last class we have started discussion on image restoration. We have said that there are certain cases where image restoration is necessary. In the sense that in many cases while capturing the image or while acquiring the image some distortions appear in the image. For example if you want to capture a moving object with a camera, in that case because of the movement of the camera it is possible that the image that is captured will be blurred, which is known as motion blurring.

There are many other situation say for example the camera is not properly focused then also the image that you get is a distorted image. So in such situation what we have to go for is restoration of the image or recovery of the original image from the distorted image.

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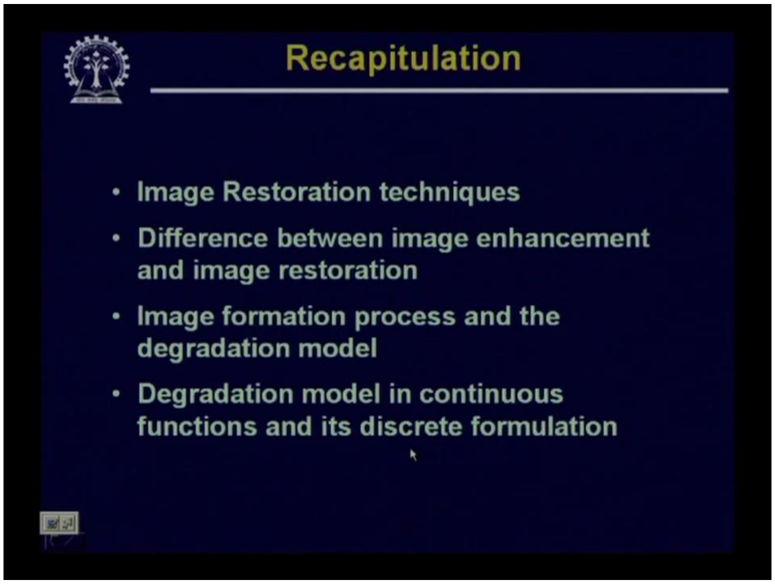


Now regarding this in the last class, we have talked about what is image restoration technique. In previous classes we have talked about image filtering. That is if the image is contaminated with noise. Then we have talked about various types of filters both in special domain as well as in frequency domain to remove that noise. And we just mentioned in our last class that this kind of noise removal is also a short of restoration. Because they are also, we are trying to recover the original image from a noisy image. But conventionally this kind of simple filtering is not known as restoration.

But by restoration what I, what we mean is that if we know a degradation model by which the image has been degraded and on that degradation model and on that degradation image some noise has been added. So recovery or restoration of the original image from a degraded image using the (())(2:31) knowledge of the degradation function of the model using which the image has been degraded. So that kind of recovery is normally known as restoration process.

So this is the basic difference between restoration and image filtering or image enhancement. Then we have seen an image formation process, where the degradation is involved and we have talked about that degradation model in continuous function as well as its discrete formulation.

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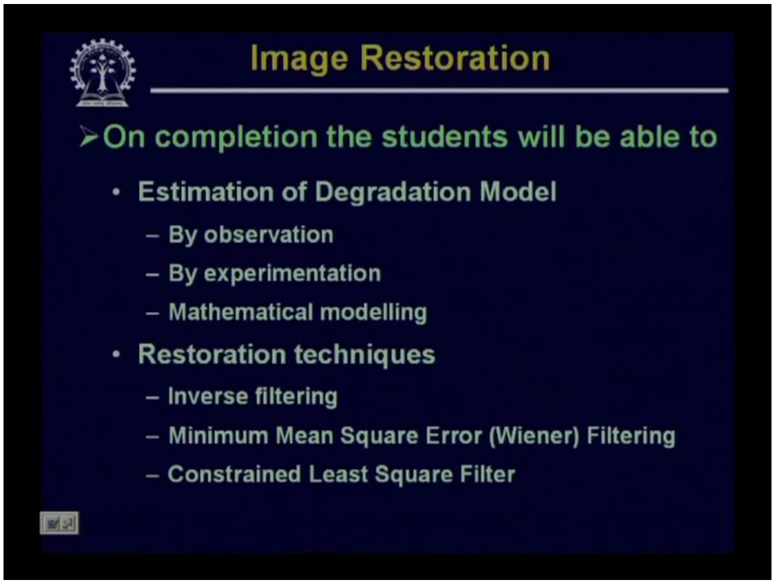


So in today's lecture we will talk about the estimation of degradation model and we will see that there are basically three different techniques for estimation of the degradation model. One is simply by observation that is by looking at the degraded image we can estimate that what is degradation function which is involved that has degraded the original image. The second approach is by mean through experimentation. So there you can estimate the degradation model by using some experimental setup. And the third approach is by using mathematical modeling techniques.

Now once you know the degradation model, I mean whichever way we estimate the degradation model whether it is by observation or by estimation or by using the mathematical models. Once we know the degradation model then we can go for restoration of the original image from those degraded images. So will talk about various such degradation techniques. The first one that will see is what is called inverse filtering. The second one will be called minimum mean square error or wiener flirting and the third approach is called constrained least square filtering approach.

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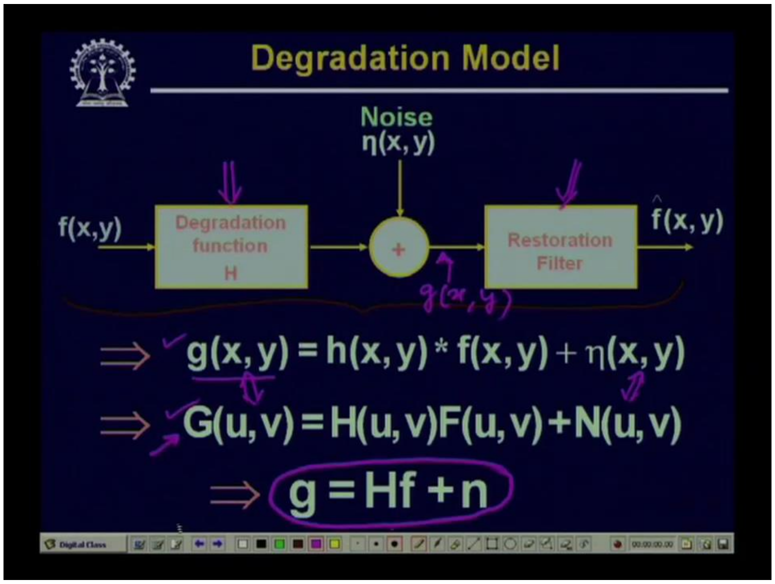


Now in our last class we have seen a diagram like this. So in this diagram you see that we have a shown the degradation function. So here we have an input image f (x,y) which is degraded by a degradation function H, as has been shown in this diagram. So H is the degradation function. So once I degraded, once we get the degraded image at the output of this degradation function H then a noise eta (x,y), a random noise eta (x,y) is added to that degraded image and finally here we get what is degraded image we call as g of x and y.

So this degraded image g (x,y) which is normally available to us. And from this g (x,y) by using the knowledge of this degradation function H we have to restore the original image. And for that what you have to make use of is a kind of restoration filters. And depending upon what kind of restoration filter we use. We have different types of restoration techniques.

Now in our last class based on this model we have said that the degradation mathematical expression of this degraded operation, degraded operation can be written in one of these three forms. The first one is given by g (x,y) which is equal to h (x,y) convolution with f (x,y) last eta (x,y) which is the random noise. So here f (x,y) that is that original image and the degradation function h (x,y). They are specified in the special domain.

So in special domain the original image is f (x,y) is convolved with the degradation function h (x,y) and then random noise eta (x,y) is added to that to give you the observed image which in this case we are calling as g (x, y). So this is the operation that has to be done in the special domain. And we have seen earlier that a convolution operation in special domain is equivalent to performing multiplication of their corresponding Fourier transformation.

So if for special domain image f (x, y) the Fourier transformation is capital F (u, v) and for the degradation function h (x, y) its Fourier transformation is capital H (u, v) then if i multiply this capital H (u, v) and capital F (u, v) in the frequency domain and then take the inverse transform of it to obtain the corresponding function in the special domain then I will get the same result. That is convolution in the special domain is equivalent is to performing multiplication in the frequency domain.

And by applying that convolution theorem this second mathematical expression of this a degradation model which is given by G (u, v) is equal to H (u, v) into F (u, v) plus N (u, v). Where this N (u, v) is nothing but Fourier transform of the random noise eta (x, y) and G (u, v) is the Fourier transform of the degraded image that is the g (x, y). So i can, we can either we can perform this operation in the frequency domain using the frequency coefficients or we can also perform the same operation in the directly in the special domain.

And in the last class we have derived another mathematical expression for the same degradation operation but there the mathematical expression was given in the form of a matrix. And that matrix equation as has been shown here is given by g is equal to H into f + n where this g is column matrix or column vector of dimension m into n where the image is of dimension m by n. F is also column vector of the same dimension of the m into n.

This degradation matrix H this is of dimension of m into n by m into n. So there will be m into n number of rows and m into n number of columns. So you find that the dimension of this degrade degradation matrix H is quit high if our input image is if of dimension capital M into capital N. And similarly this n is a noise term and these all these three terms together that gives you the degradation expression in case with, in the form of matrix equation.

Now this particular expression that is matrix expression direct solution using this matrix expression is not an easy task so we will talk about this matrix expression the restoration using this matrix expression a bit later. But for the time being we will talk about some other simple expressions which are direct fall out of the mathematical expression which is given in the frequency domain. Now here you note one point that whether we are doing the operation in the frequency domain or we are doing the operation in the special domain, all we make use of this matrix equation for restoration operation.

In all of these cases a knowledge of the degradation function is essential. Where that is what is our restoration problem that is we try to restore or recover the original image using (())(10:55) knowledge of the degradation function. So accordingly as we have said earlier that estimation of the degradation function which degrades which has degraded the image is very very essential.

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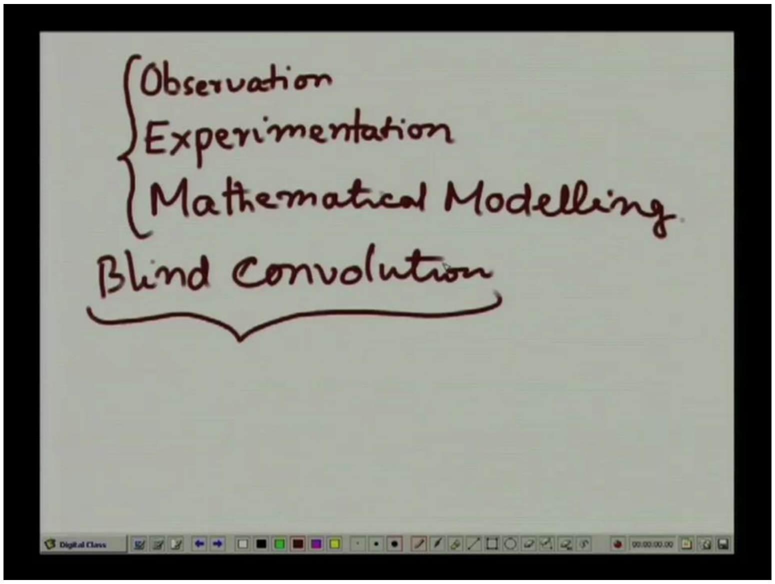

And we have three different approaches using which we can estimate the degradation functions and those approaches we have said that there are three basic approaches; the first approach is by observation. That is we observe a given image, a given degraded image and by observing the given degraded image, we can estimate, we can have a estimation of what is the degradation function.

The second approach is by experimentation. That mean, we will have a experimental set up using which we an estimate what is the degradation function. That is degraded the image. And the third approach is by mathematical model. So we can estimate the degradation function using one of these three approaches and whichever degradation function of the degradation model we get using that we try to restore our original image from the observed degraded, degraded image.

And the method of restoring the original image from the degraded image using the degradation function obtained by one of these three methods is what is called a blind convolution. That is it is called a blind convolution operation is that using one of these estimation techniques the degradation model of the degradation function that you get is just an approximation. It is not the actual degradation that has taken place to get the degraded image. So because it is not the actual degradation function, it is just an approximation the method of getting the inverse process that is restored image using one of this degradation functions is known as blind convolution operation.

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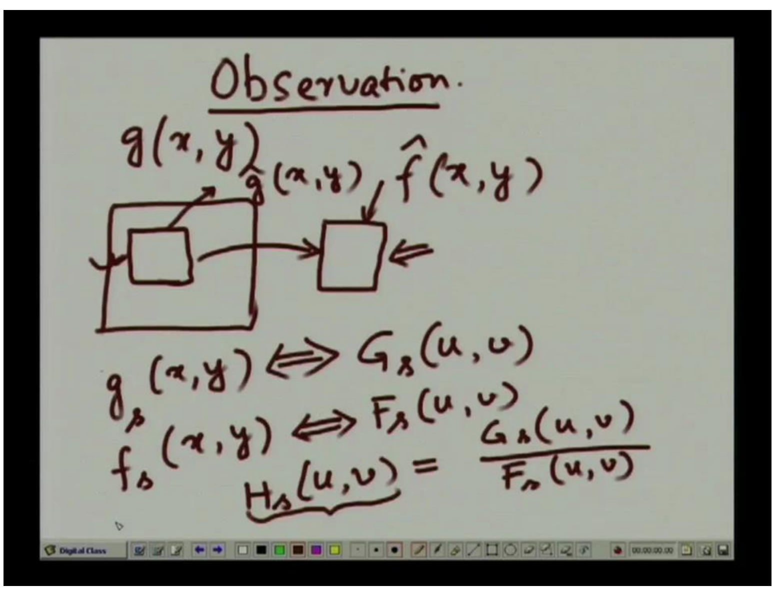

So will talk about this degradation functions one by one. The first one that will talk about is estimation of the degradation function by observation. So when we try to estimate a degradation function by observation. When no (())(14:07) knowledge of the degradation function is given, so what we have is the degraded image g (x, y) and by looking at this degraded image g (x,y) we have to estimate what is the degradation function in both.

Now for doing this what you do is you look at a degraded image then try to identify a region which is having some similar structure. So if we have a complete degraded image. In this complete degraded image you identify a small region, the region which contains some simple structure. Say for example it may be an object boundary where a part of the object as well as the a part of the background Spirent.

Now after you identify such a region having simple structure then what we do is? We try to estimate an originally image which should have been degraded to give you this degraded image. And this original image should be of same size as the image that has been chosen from the sub image which has been chosen from the degraded image, their structure should be same and the gray level regions in this estimated image should be obtained by observing the gray level in different regions of the image of the sub image of the degraded image that has been chosen.

And once I get this, this is my approximate reconstructed image say f hat (x, y), and this is my degraded image, let me call it is g hat (x, y). And once i get this then i take the Fourier transform of this g hat (x, y) or because it is sub image instead of it calling it as g hat let me a call it as g s, G s (x, y), I take the Fourier transform of to get capital G s (u, v).

Similarly the image that has deconstructed that have formed by observation what should be the actual image. I call it f s (x, y) and from this if i take the Fourier transform, I get the Fourier coefficient written by f s (u, v). Now our purpose is that we can have an estimation of the decode degradation function which is given by h s (u, v), that should be estimated as g s (u, v) upon f s (u, v).

So while doing this the find that we have got this particular expression. What we have done is, we have neglected the noise term. Now, in order for this to be logical a logical one this approach to the logical one. When I chose a sub image in the original image of which the reconstructed image should have been this. This sub image should be in a region where the image contained is very strong. To minimize the effect of the noise in this particular estimation of f s (u, v), h s (u,v).

Now this h s (u, v) has been approximated over a small sub region of the degraded image and then we have formed an approximation of that degraded image, that what should have been the original image. So naturally this h s (u, v) is of at smaller size. But for the restoration purpose we need h (u, v) to be of size m by n if my original image is of size M by N. So the next operation will be that you extend this h s (u, v) to h (u, v) to in encompass all the pixels all the frequency component of that particular image.

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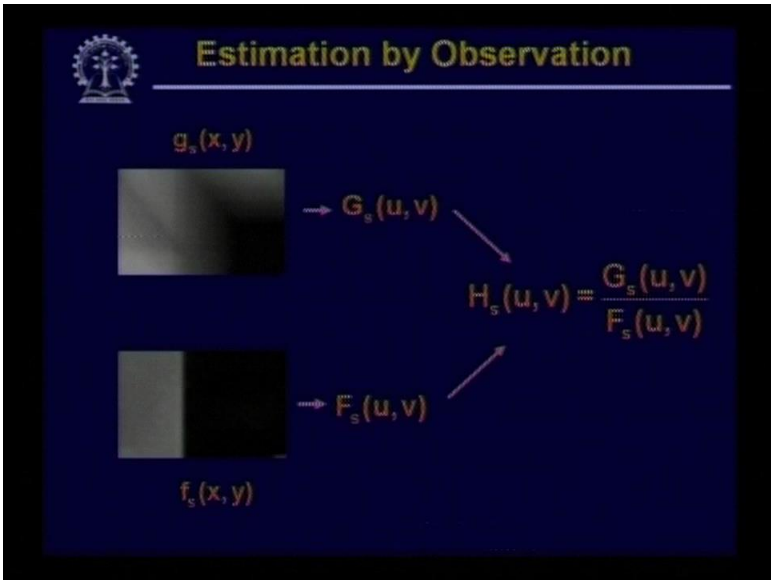


Now, let just look at an example. Say here we have showed a degraded image, so this is degraded image, which has been cut out from a bigger degraded image. So this degraded image has been cut out from a bigger degraded image. And by observation we form a original image like this, so in far that if this is the degraded image then the original image should have been something like this, and while construction of this approximate original image you find that in this region the intensity value is maintained to be similar to the intensity value in this region.

Similarly in this region the intensity value is maintained to be similar to the intensity value of this. So this is my F s (x, y) and this one is my S (x, y). So from this by taking Fourier transform we will compute f s, F s (u, v), and from here by using the Fourier transformation we will compute G s (u, v). So by combining these two from these two now I can have an estimation of the degradation function which is given by h s (u, v), which is equal to G s (u, v) upon F s (u, v). So this is the method that we can use for estimation by observation.

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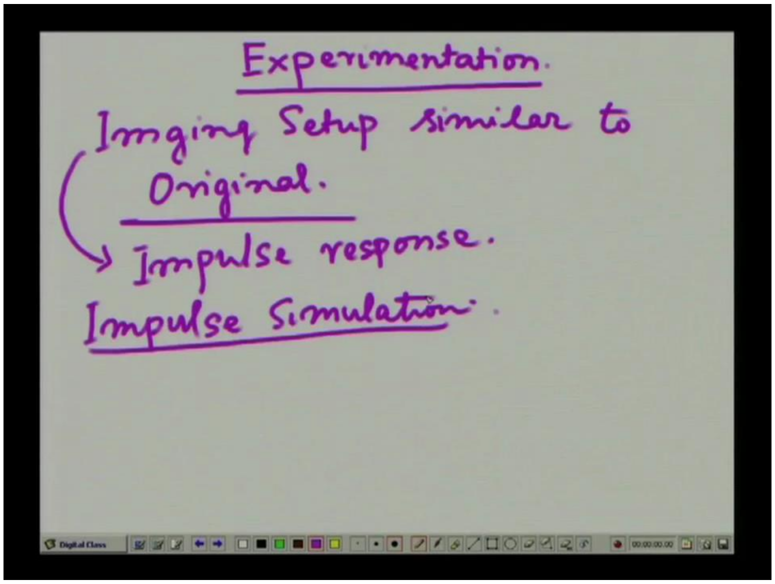


The next technique, the other technique for estimation for the degradation function is by experimentation. So what we do in case of this experimentation. Here we try to get an imaging set up which is similar to the imaging set up using which the degraded image has been obtained. So first we have to get an imaging set up similar to the original imaging set up, and the assumption is that using this using imaging setup which is similar to the original imaging setup, if I can estimate what is the degradation function of this imaging set up which has been acquired which is similar to the original then the same degradation function also apply to the original one.

So here our purpose will be to find out the point spread function or the impulse response of this imaging set up. So our idea will be to obtain the impulse response of this imaging set up. And we have said earlier during our earlier discussion that it is the impulse response which fully characterizes any particular system. So once the impulse response is known, the response of the system to any arbitrary input can be computed from the impulse response. So our idea here that we want to obtained the impulse response of this imaging set up and we assume that of this imaging set up is similar to the original that the same impulse response is also valid for the original imagining set up.

So here the first operation that we have to do is, we have to simulate an impulse, so first requirement is impulse simulation. Now how do you simulate an impulse? An impulse can be simulated by a very bright spot of light. And because of our imaging set up is camera so will have a bright spot as small as possible of light falling on the camera. And this bright spot if it is very small then it is equivalent to an impulse and using this bright spot of light as an input whatever image that you get that is the repose to that bright spot of light which in our case is an impulse.

So the image gives you the impulse response to an impulse which is imparted in form of bright spot of light. And the intensity of light that you generate that tells what is the strength of that particular impulse. So, by this simulated impulse and from the image that you get, I get impulse response and this impulse response is the one which uniquely characterizes our imaging set up, and in this case we assume that this impulse test response will also be valid for the original imaging set up.

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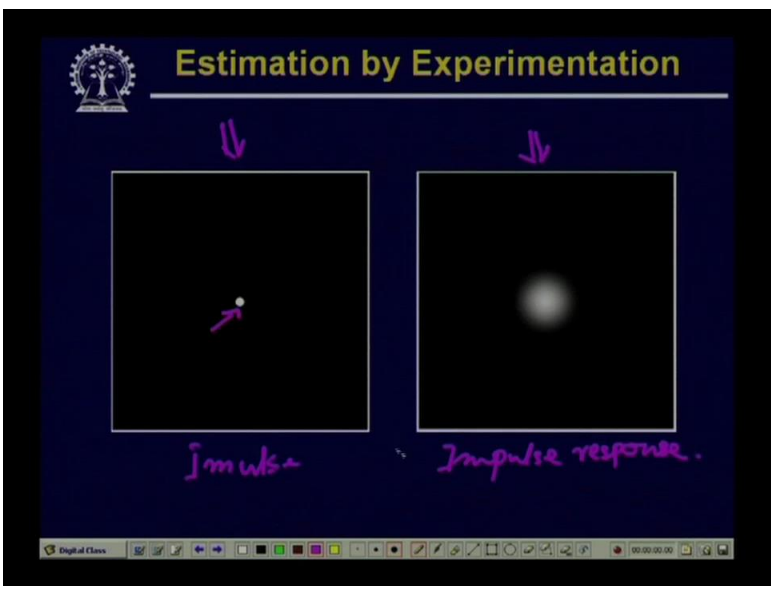


So now let us see that how this impulse response will look like. So that is what has been shown in this particular slide. The left most image is the simulated impulse. Here you find at the center we have a bright spot of light. Of course this spot is shown in a magnified form. In reality this spot will be even smaller than this. And on the right hand side the image that you have got this is the image which is captured by the camera when this impulse falls on this camera lens.

So this is my impulse simulated impulse, and this is what is my impulse response. So once I have the impulse and this impulse response then from this I can find the out what is the degradation function of this imaging system. Now, we know the from our earlier discussion that for a very very narrow impulse the Fourier transformation of an impulse is a constant.

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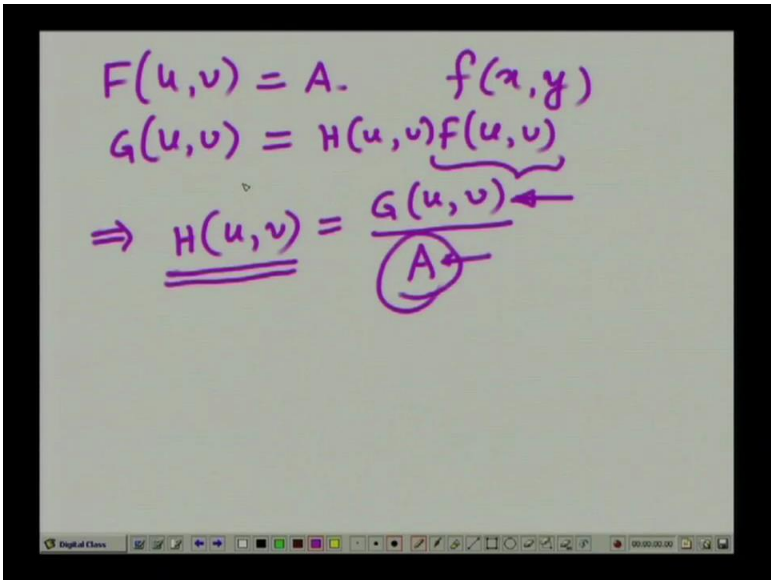


That means F (u, v) where f (x, y) is the input image in this particular image it is the impulse in that case Fourier transform of a f (x, y). Which is f (u, v) this will be a constant say constant A. And our relation is that the observed image G (u, v) which will be same as H (u, v) times F (u, v). Now, because this f (u, v) is now the impulse response in frequency domain, so from here I straight way get H (u, v) that is the degradation function which is same as G (u, v) upon that same constant A.

So in this case this G (u, v) is the Fourier transform of the observed image and here this Fourier transform is nothing but the Fourier transform of the image that we have got which is response to the simulated impulse that has fallen on the camera. A is the Fourier transform of the impulse falling on the lens and the ration of these two that is G (u, v) by this constant A That gives us what is the deformation or what is the degradation model of this particular imaging set up.

So here you find that we have got the degradation function through an experiment or experimental set up is we have an imaging set up. And we have a light source which can simulate an impulse. Using that impulse we got an image which is a impulse response imaging system. We assume that the Fourier transform of the impulse that is two is A constant A as has been shown here. We obtained the Fourier transform of the response which is G (u, v).

And now this G (u, v) divided by A should be equal to the degradation function H (u, v) which is the degradation function of this particular imaging set up. So I get the degradation function. And the same degradation function we assume that it is also valid for the actual imaging system. Now, in this point regarding this one point should be kept in mind tShat the intensity of light which is the simulated should be very very high so that the effect of noise is deduced.

If the intensity of light is not very high if the light is very feeble in that case it is that noise component which will be very very dominant and using that whatever estimation of this H (u, v) we get that estimation will not be correct estimation. Or in any case we will not get a correct estimation, but it will be very far from the reality.

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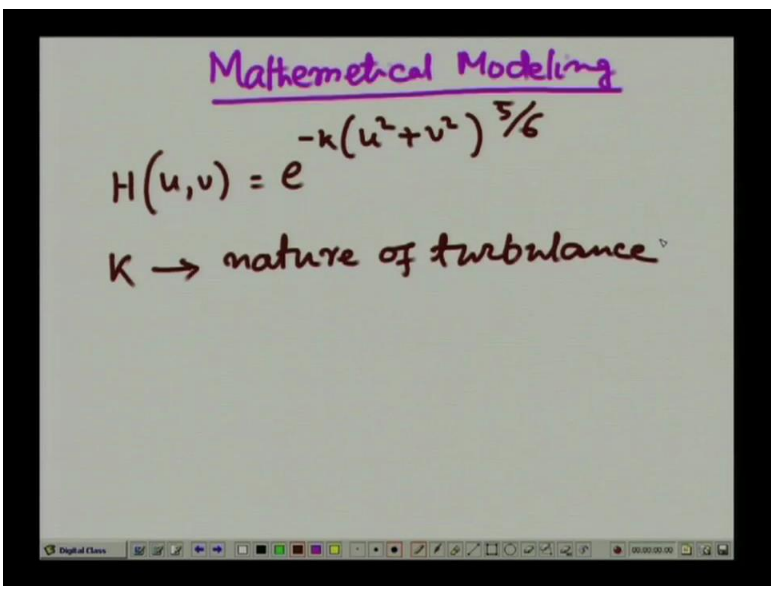


Now the third approach of this estimation technique as we said that is estimation by mathematical modeling. Now this mathematical modeling approach for estimation of the degradation function has been used from many many years. There are some strong reasons for using this mathematical approach. The first one is, it provides an insight into the degradation process. Once I have a mathematical model for the degradation I can have an insight into the degradation process. The second reason is such a mathematical model can model even the atmospheric disturbance which leads to degradation of the image.

Now, one such mathematical model which is used to model the degradation and this also can model the atmospheric turbulence which leads to the degradation of, degradation of the image is given by this expression. H (u, v) is equal to e to the power – K into u square plus v square to the power five by six. So this is one of the mathematical model of degradation which is capable of modeling the turbulence the atmospheric turbulence that also leads to degradation in the observed image.

And here this particular constant K this gives you what is the nature of the turbulence? So if the value of is large that means the turbulence is very strong or if the value, if the value K is very low, it says that the turbulence is not that strong. It's a mild turbulence, so by varying the value of K we can have the intensity of the turbulence that is to be model.

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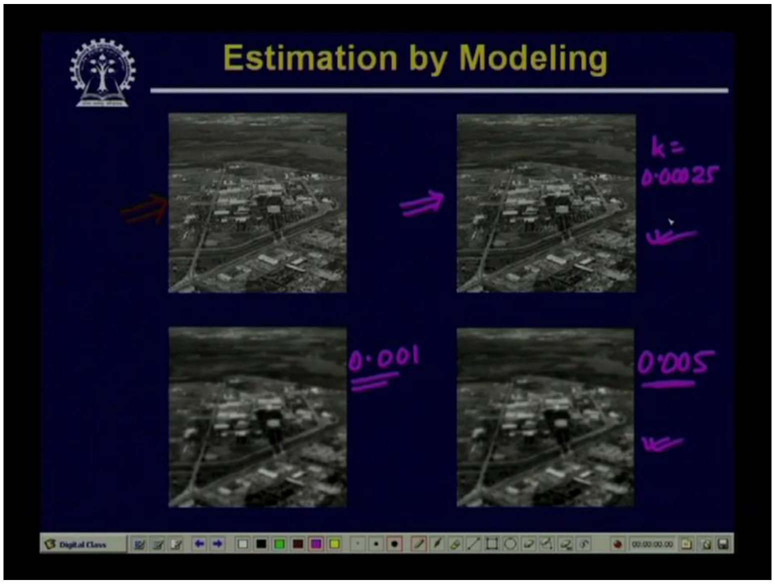


Now using this we can have a number of degraded images as has been shown in this particular slide. So here you find that on top left we have this original image, this shows an original image. This is a degraded image where the value of K, was something like 0.00025. This is the value of K in this particular case. Here the value of K was something like 0.005 and in this case the value of K was something like 0.001, sorry here it was 0.001 and in this case it was 0.005.

So the first image this particular image here the turbulence is very poor so this has been degraded using the same model as we, as we have just said which models mild turbulence. Here the turbulence is medium and here the turbulence is strong. And if you closely look at these images you will find that all these three are degraded to some extent. In this particular case the degradation is maximum, here the degradation is minimum. So this is the one which gives you modeling of degradation which occurs because of turbulence. Thank you.