Optical Methods for Solid and Fluid Mechanics
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Lecture - 06
Image Processing Preliminaries

So, welcome back everybody to another class on optical methods for solid and fluid mechanics. So, what we are going to look at today is the image processing preliminaries that are required for this particular course, but just to quick recap we were looking into various functions like the autocorrelation function and the covariance function last time.

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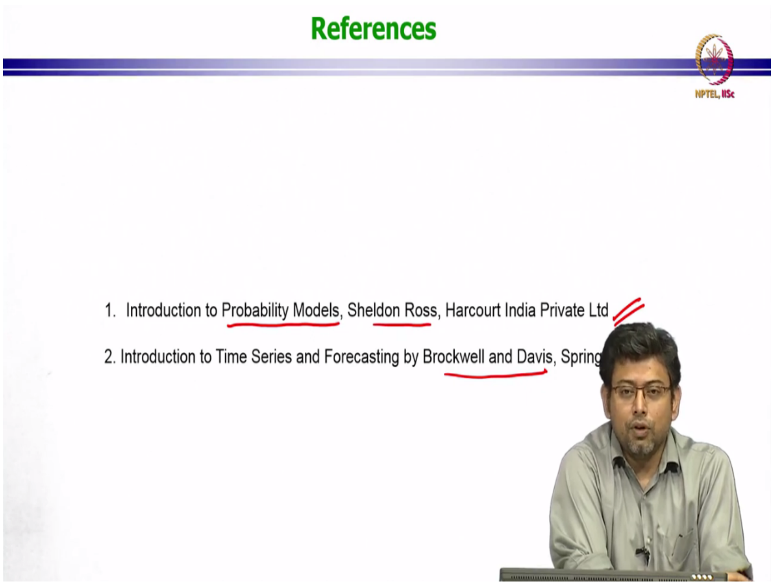

And I wanted to give you these two references if you wanted to look them up. The first book discusses probability models. So, it will deal with things like expectations and the idea of a probability density function or a probability mass function and if you are not familiar with them this is one possible book that you can take a look at. There are many good textbooks this is definitely not the only one, but this is a book that I have and it is proven to be a good material book for me.

Another book could be for the topics of covariance and autocorrelation and how they behave and how to deduce them from let us say time series or series data. This is a very nice book introduction to time series and forecasting by Brockwell and Davis this is Springer-Verlag publication, the previous one is a Harcourt India Private Limited publication, Sheldon Ross was the author for the previous book and these are the two authors for this particular book.

As the name suggests this book also deals with forecasting. So, if you are interested in things like that in an investor understanding trends, for example, in time series data this could prove to be a good book, but for us this we are just looking at preliminaries and this is not a very detailed dive into these mathematical methods. So, we are not going to dive too deep for that. We are just trying to make sure that you have enough introduction to some of the functions that we are going to use in the image processing subsequently.

So, with that I think one of the most important cornerstones of this course will be image processing and we should understand why that is. So, before we go into some image processing preliminaries I wanted to show you some examples that you might come across in your type of work.

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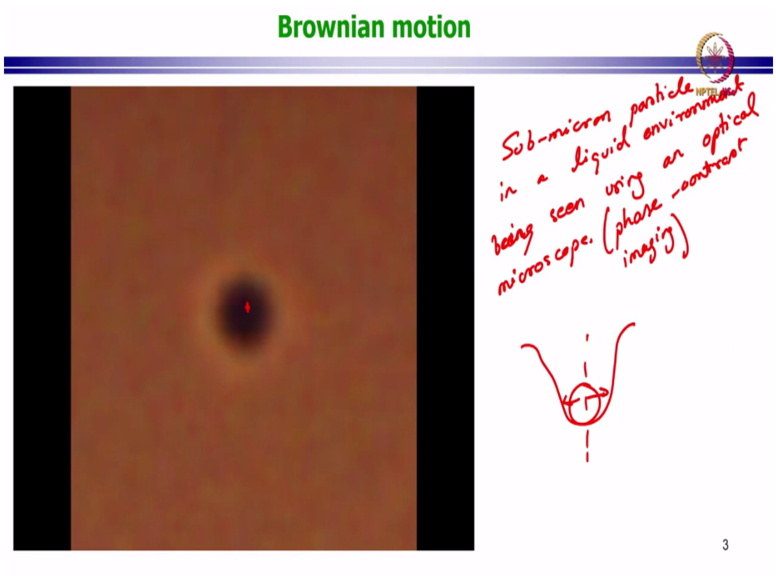

So, for example, this is a video and I will quickly explain what you are going to see here. This is a sub micron particle in a liquid environment being seen being seen using an optical microscope and actually we use phase contrast, optical microscopy for this. So, this is a phase contrast imaging, it is a very particular type of optical imaging and here what the particle is doing is the particle is stuck in an optical trap.

So, it is sort of a particle trap in a well and it is going to exhibit Brownian motion around the center of the well and from here you can actually if you can see this image is very pixelized because the particle is very small and we have to look at the tasks that we had was to look at the center of this particle as it moves. So, I will/shall just play this video we are not going to go through the technique right now.

But I am just trying to give you an idea of the kind of things you might encounter. So, you can see this particle is vibrating, it is a very short video sorry okay so you can see that the particle is vibrating and the center of the particle is moving a few pixels on this side and that is because it is stuck in a potential well, the potential well is actually created by using an optical tweezer.

And I hope maybe perhaps optical tweezer is very interesting technology if you want to look it up there was a couple of nobel prizes for using optical tweezers. Now this particle as it moves the whole idea is to look at the center of the particle and use this. So, the video is basically nothing, but a whole set of images that are put together and you can analyze each image to see where the center of the particle is and you can measure the Brownian motion of the particle.

The measure of the Brownian motion of the particle in this particular case it actually gives you an idea of the strength of the optical or the potential well or the optical tweezer in this case. So, an example of using image processing to quantify certain physical parameters.

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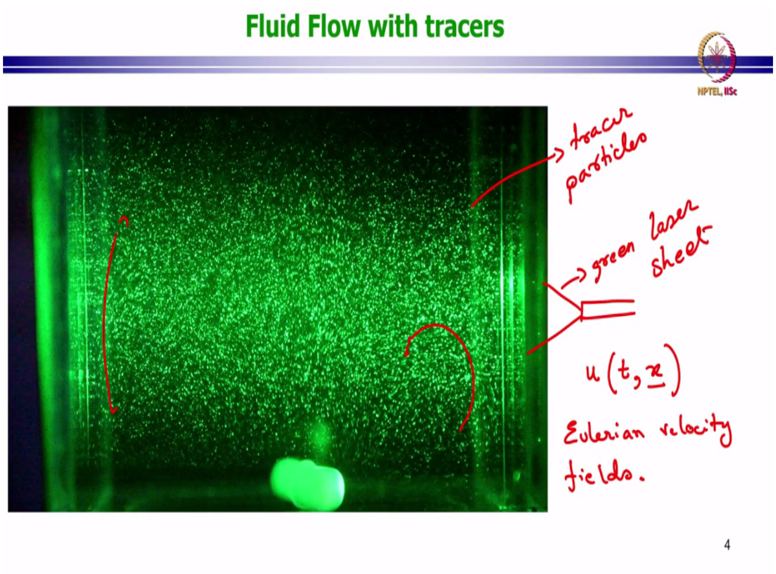

Another example was; so you have seen this video before, but I still wanted to show it again there is a green laser light that is coming from the side, it is coming like this, green laser sheet and these are your tracer particles. The tracer particles are actually not green, but they are reflecting green light so they appear green here and as the fluid moves you can see this fluid behavior, you can see how the fluids are moving and it is possible to get very quantitative Eulerian velocity fields from this kind of data.

So, you can actually get what we had talked about the Eulerian velocity fields by analyzing such videos and we will be in the first part of the course we will be looking at fluid flow. So, we will be really concerned with the Eulerian velocity fields for our case. So, here we are not going to be tracking individual particles, you can see the difference between this example and the previous example.

The previous example you only had one particle that was moving around and the task at hand is to observe how it is moving in the different frames and where it is. So, it is actually locating a single particle whereas where we have to analyze the fluid flow in this particular case we are not going to be analyzing each and every single or motion of each and every single particle. So, here this is a slightly different type of image processing that is required.

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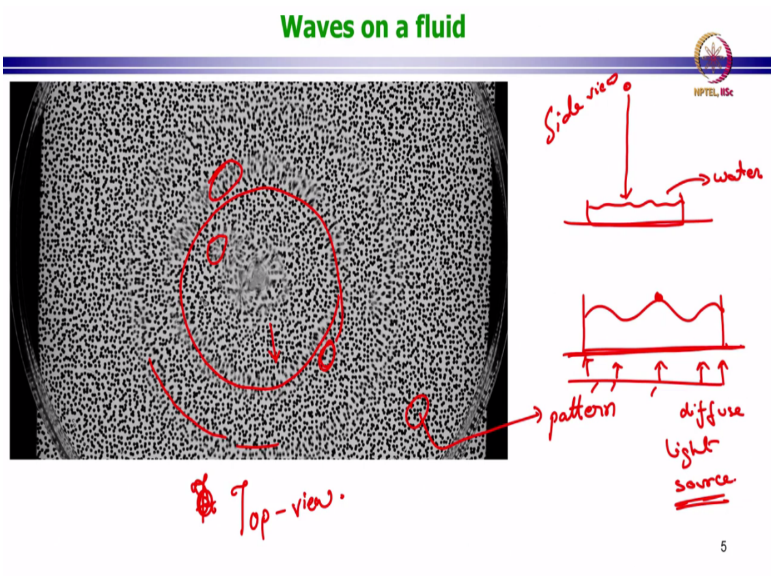

This is another work one of our students in our lab was doing it. I will quickly explain what you are going to see in this particular video. So, what we have is this from the side view if you want to see we have a petri dish; petri dish is full of water and a drop of water is going to come and impact it from the top. Now the water is colorless and transparent totally. So, when the particle hits what it does is it creates these waves when the droplet has hit the fluid surface and these waves are not easily visible because the water is colorless and transparent.

So, what we have done here is we have put a sheet at the bottom which has a certain type of a pattern which is what you are seeing here this is the pattern for example that we are seeing. So, there is a sheet at the bottom on which a particular type of pattern is printed and there is a light source this is a diffused light source at the back. So, we have light coming equally from all sources so diffuse light source.

So, I am going to play this video and so we by the way we are looking from the top. So, this is the side view and this is actually the top view sorry top. So, I hope you could see the wave now the one of the reasons you are able to see the wave is, for example, you see here is the wave right it is very easy to understand where it is intuitively why because all the particles here they are appearing distorted.

Here there is no distortion in this region. So, I pause the video here for a very specific reason is that because okay let me play it again and try to pause it again. I am being a bit slow. So, you can see that there is a wave front right here because there is a lot of distortion that is happening in this region. So, you can see that these particles are distorted whereas here where the wave has already passed here there is no more distortion.

So, you can observe the wave front and you can see there is a wave here. Now this distortion is smaller than the distortion let us say in this region or elsewhere. So, it also tells you where the wave is amplitude is higher or lower from this. So, this requires a slightly different type of image processing in order to; if you were trying to locate the wave front as a function of time you could do this with this kind of a image sequence also.

So, what I basically did is I showed you three different examples, all of which concern fluid mechanical phenomena. The first one concerned Brownian motion where this is a single particle which is moving and exhibiting Brownian motion. The second one this is bulk flow in a fluid and the third one which involves a wave on a fluid body. So, all these require image processing in order for us to understand or quantify these things.

So, unless we understand more about images I will switch over now to my notes. So, unless we understand the intricacies of image processing it is going to be difficult for us to appreciate how to do these, how to apply these image processing tools. So, a necessary precursor to quantifying the fluid mechanical of phenomena is to understand image processing basics.

So, again as I said this class is not going to go into a whole lot of detail about each and every aspect of this the preliminaries that are required, but we want to give you enough insight so that you are not left hanging up out there.

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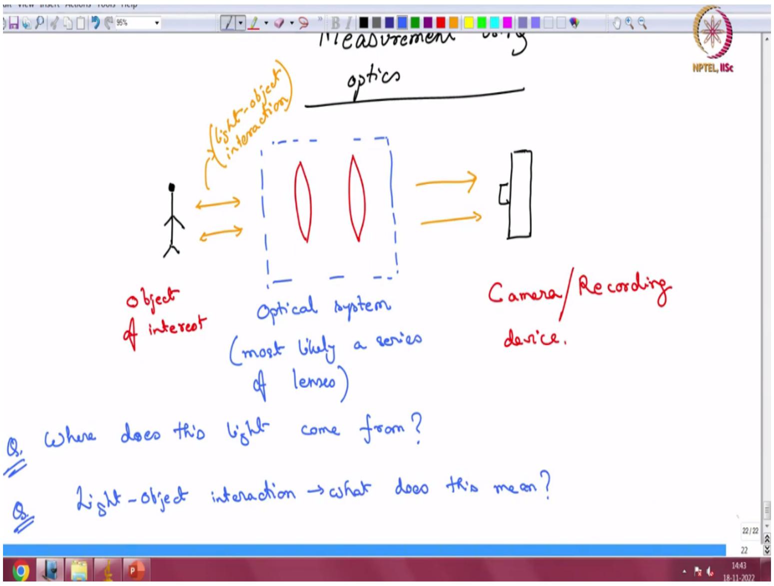

Now overall our idea here is we are going to be doing some kind of a measurement; measurement using optics, this is our basic idea. Now in order to do that what we have is let us say we have a object of interest. So, I am just going to draw a person here stick diagram and let us say this is object of interest is by fluid in this case and you are trying to observe that. Now the way you are going to observe is going to be; there is going to be a camera somewhere.

So, you will put a camera and is not going to be great diagram I am just drawing some so this is your object of interest, this is my camera or recording device. So, some kind of a recording device has to be there. The most common recording device for us will be the camera so that is/has why I am just going to write camera slash recording device. Now how are you going to; how is this slide going to come.

So, some light is from these; from the object of interest is going to come and hit your camera and get recorded there, but in between it is probably going to pass some lenses or some kind of an optical trend which may be a lens system or something. So, let us we will say that there is; it could be a simple lens it could be a compound lens, it could be something else. So, you will have an optical system most likely a series of lenses that will be there.

And then you are going to have some kind of a light that is going to be interacting and with the object of interest going to pass through my optical system and finally reach my camera. So, this is; this indicates light object interaction. A good question here to ask would be where does this light come from? So, this is a question I am not going to answer this question right now.

I am going to first talk about the imaging portion and then I will come back to where this light comes from? There can be many different ways in which this can happen and each imaging process or system can have its own way in which this light comes and this light object interaction what does this mean? So, these are good questions we are going to leave that for right now.

We are just going to assume that some of this happens and then light comes and gets recorded on my camera or the recording device. So, we are just going to assume that and essentially the result is that you have these photons that are there. So, these photons are going to come and hit your camera.

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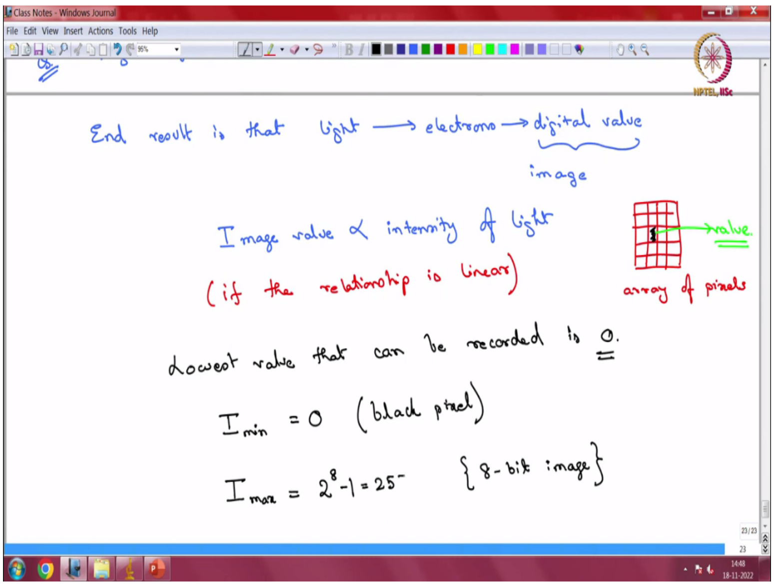

And end result of all this is that the light end result for us is that this the photons or light gets converted to electrons in my recording device or the camera and this electrons finally are stored as some integer or digital value in the recording device itself. So, what happens is now my electrons are going to be converted and remember this is what is going to comprise my image, this set of digital values this is my image.

So, what we do is your image value the data that you are recording is basically proportional to the intensity of light. It may not always be proportional and we will see that image processing can may render this to be a non-linear function, but usually it is a monotonic function. So, your higher image value represents a higher amount of light, it may not always be proportional, but for simple systems.

So, I will just have the caveat if the relationship is linear then the proportionality holds which means that the image value it should be equal to the proportional to the intensity of light received at that. Now my camera or my recording device again a recording device I am just going to mean camera in all our cases because that is what we are going to use, but I say recording device helps to for a slightly more general purpose.

So, we have a array of pixels on my camera. So, my camera is essentially nothing, but an array of pixels where my electrons my light comes and hits and this gets converted into electrons and some value is recorded here. So, this is some value, some value gets recorded here. Now assuming this monotonic nature of image value; a value of 0 basically means that there is no photons that have been recorded.

So, the lowest value that can be recorded is zero. So, my I minimum is equal to zero and this is usually interpreted to mean a black pixel. So, the click pixel; so your computer will display if the value is 0 or below a certain threshold it will display a black pixel, but the question is what is the maximum value that can be stored. Now this depends upon actually the way the image is stored.

So, if we assume; so now you have to decide how many bits are being spared for storing each. So, every data here in this pixel needs a bit to be stored. So, if this were a 8-bit image which means eight bits were available to it to store the value then the maximum value that can be stored is actually 2 to the power - 1 which is actually 255. So, this is the highest value that can be stored for 8 bit.

But if it is not a 8 bit if it is a 16 bit then obviously this number changes and this becomes 2 to the power 16 – 1. Now many of the images that we are going to deal with 8 bits are more going to be more than sufficient. So, from here onwards we are just going to assume that all the images are 8-bit. So, for our purposes they are you can always go for higher bits 16 bit also 32-bit also.

The amount of extra information that comes out versus the data storage requirement they do not plan out that well 8 bits are usually more than sufficient for us. Now what happens if your; so some high current okay.

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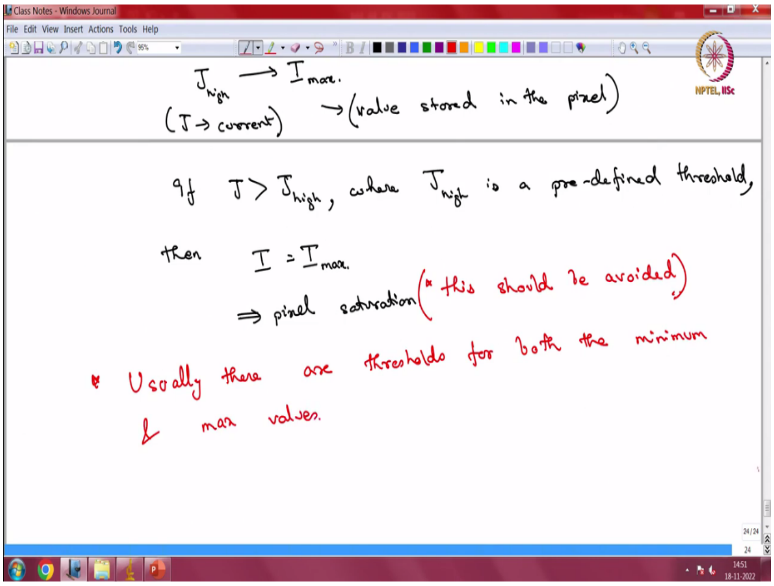

So, let us say some high current becomes I max in your camera. So, this is your current maybe I should use different notations here wait a second. So, okay I will just use J for current. So, this is J is my current or my amount of charge that is created because of the photon sitting and this I is the value stored in the pixel. Now if my J is the current, if the number of photons that hit are more than some J high. This is let us say a threshold that you have defined.

So, where J high is a predefined threshold then my I that is stored is equal to I max because your bit cannot hold more than that. So, this effect is also often called pixel saturation and for our case we will try to avoid this; should be avoided and also one more thing to note is usually there are thresholds for both the minimum and maximum value and max values by which what we mean is that there will be some sort of a current value below which if the current is below the certain threshold then you will store the value 0 there.

So, the value 0 does not mean 0 current in that cell so it just means that you have defined a threshold or the number of photons falling on it is small enough to not register a high enough current you end up getting a zero value on the pixel and similarly for the max. So, now that we understand what so okay one more quick thing before I move on to images used in scientific cameras.

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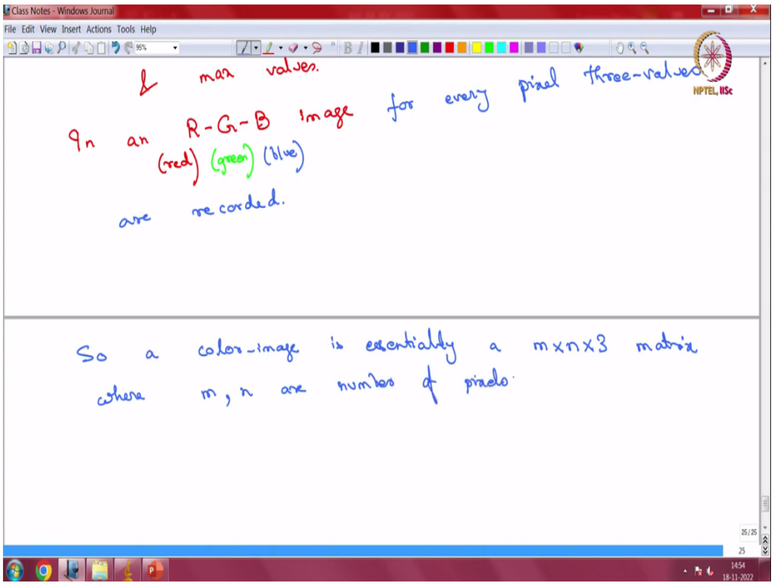

In an RGB image where the words R stands for red, G stands for green and B stands for blue. For every pixel three values are recorded. So, if you have an RGB camera or a color camera and if it is a color camera if it is storing images in an RGB format you have to figure out how your chip is storing the image. It could be some other form also CMYK etcetera other formats also exist.

But for the our case we will just assume that color photographs imply an RGB image. If that is the case then for every pixel you actually note three values okay and the first value will correspond to R, the second value will correspond to G and the third value will correspond to blue. So, basically in a color image; so a color image is essentially m cross n cross 3 matrix where m, n are number of pixels in the two directions.

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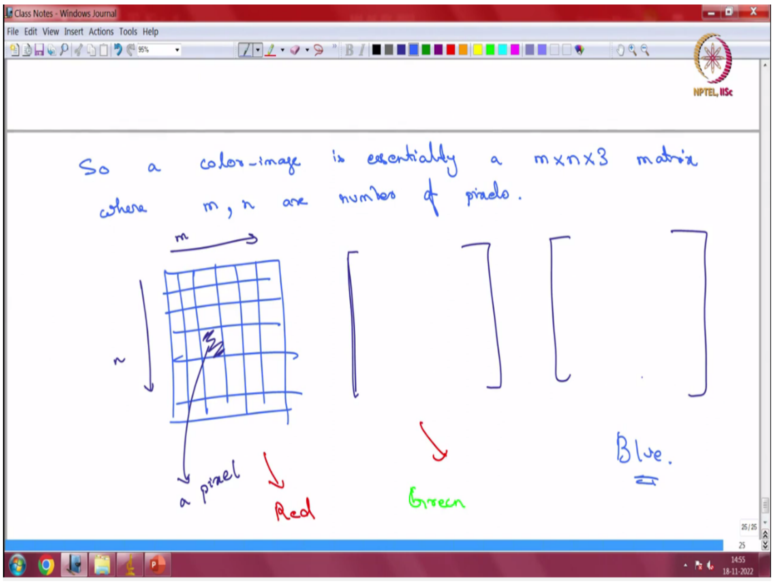

So, if your chip is such; so let us say this is your chip and it is made out of these things called pixels where these boxes are basically pixels. So, this is a pixel and this is let us say this is m this is n. So, then you have every image is m cross n, but if it is a color image then you have three such matrices. Now the first corresponding to R so this is color R and this will be your green and this will be your blue.

But this gives you a very good idea of what image usually comprises of. So, we have been discussing images this overview should I am just going to add a page here just a second mouse is frozen for some reason.

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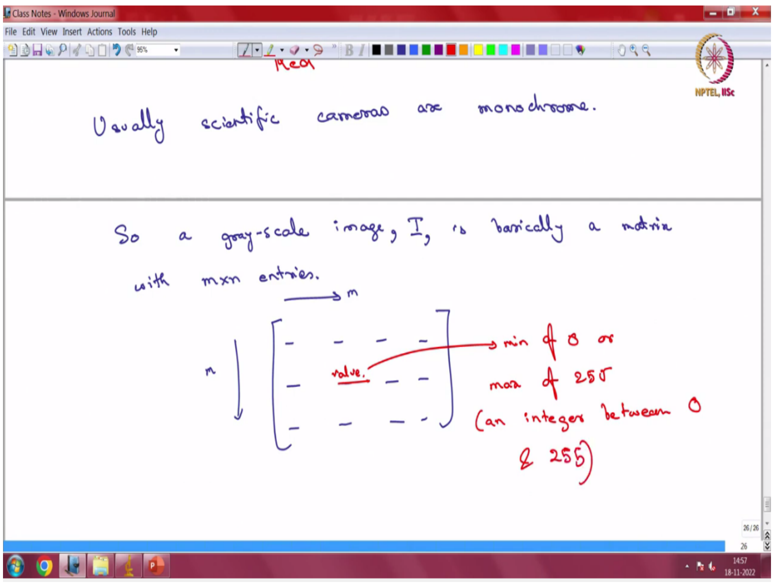

So, usually scientific cameras are monochrome not always, but often and why they are monochrome we will discuss when we are discussing the impact of light and the lenses and everything usually, but again there is no hard and fast rule there it all basically depends upon the system. Many a times there is no need for three matrices a grayscale image is good enough.

So, if you have a grayscale image what you have. So, to summarize a grayscale image let us call it I is basically a matrix with m into n entries, So, you basically have a matrix you have m columns, n rows and you will have for every place you will have some value that is being stored. So, some value that is going on so here some value that is being recorded, Now this value is what we just discussed that.

So, this value is a minimum of 0 or maximum of 255 or basically any integer between 0 and 255, so an integer between 0 and 255. So, it can take on both values 0 and 255, but it is usually some number in between and this is what a grayscale image which is a and 8 bit image will comprise of. So, let us do one thing here I am going to show you; so now what I am going to do is I am going to; so when you have a image that is being displayed on your computer.

Usually you will see an image rendering which is your computer's rendering on that, but in reality as you now know it is just composed of some integers stored in a matrix format. So, as a scientist you would want to be able to access those numbers and that is/has the key if you want if you want to start playing around with images you want to be able to access this matrix and you want to start playing around with this matrix.

And for you to be able to do that you have to know how to access or how to understand what values are being stored. Now what I am going to do here is I am going to show you using a free software called image J. **(Video Starts Here: 30:02)**. Now this software is freely available for download for various operating systems. So, what I urge you to do is just go ahead and try to get this software. So, if I go here and I say about image J.

It tells you that this is image j 1. 53 t and these are the contributors and it is available at this location and images J is in the public domain. So, in order to understand or follow through this next tutorial what I will ask you or urge you to do is to go ahead and download image J for yourself irrespective of what operating system you have you should be able to find a release version that is appropriate for you.

And then I will try to show you how this works. So, what I am going to do is I am going to use that image that we had we have seen before. This image you remember I was telling about the Orion Nebula which I imaged this is my photograph that I have taken with one astro club member here and I am going to show you how image J works. **(Video Ends Here: 31:34)**

So, what I have done is I have opened this image in this particular software and I am going to show you a few things how it works in this particular context. So, before that we will end this lecture here and in the next class I will show you some image processing basics. So, in the meantime I urge you to go ahead and get this software for yourself if you want to look around with me. I will stop here today. Thank you.