Optical Engineering
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Lecture - 24
Interesting Geometric phenomena and applications

So, we have actually come to the end of the geometric optics part of this course and this is the last lecture that we will do on the geometric optics part. As I wanted to end with a discussion on some phenomena that you can see and some applications that can be explained using just geometric optics and not wave optics ok.

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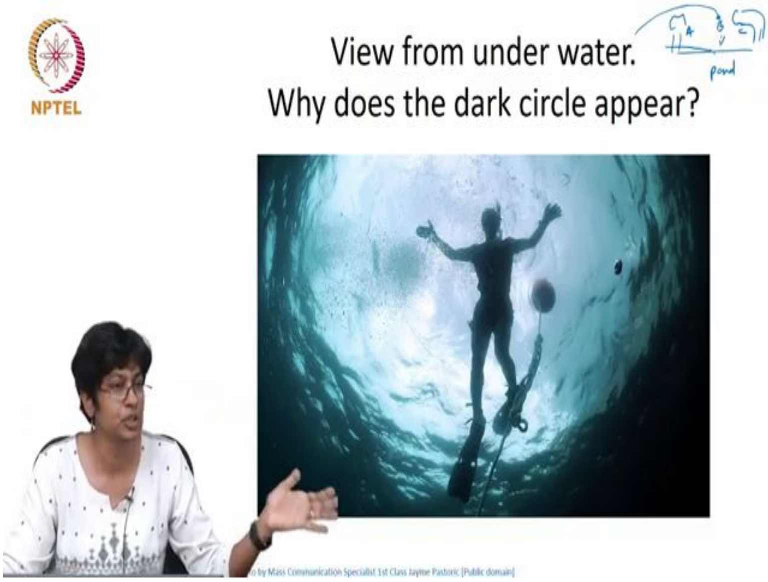

This is a photograph that has been taken from underneath the water. So, there you have, you have a diver, swimming on you know closer to the surface of the water and there is someone below this person, who has looked up outward and taken the photograph.

Now, what you should notice is; this is not a feature that has been added, this naturally arises. When you look at a photo that has been taken from inside the water looking out, you will always see this dark circular round. Now, knowing what you now know, can you try to figure out where that dark circle arises? Why does that dark circle arise? This is a completely geometric optics phenomena.

So, if you are trying to tackle this, if you are trying to figure out how to solve this, a good place to start is to draw. Try to draw a schematic of this. So, what do you know for sure about the system I am giving you, well there is water and there is air. So, you can start by drawing a sideward look, where you have air and you have water. Can you give me one key word you think might explain?

Student: Total (Refer Time: 02:01).

Total internal reflection ok. Now, it is not exactly total internal reflection that is happening here, because the light source is outside and there is no light source in the water. You are capturing this image from light that is coming from the air, from the rarer medium to the denser medium, but it is big the same reasoning the same reason you have total internal reflection is why this happens.

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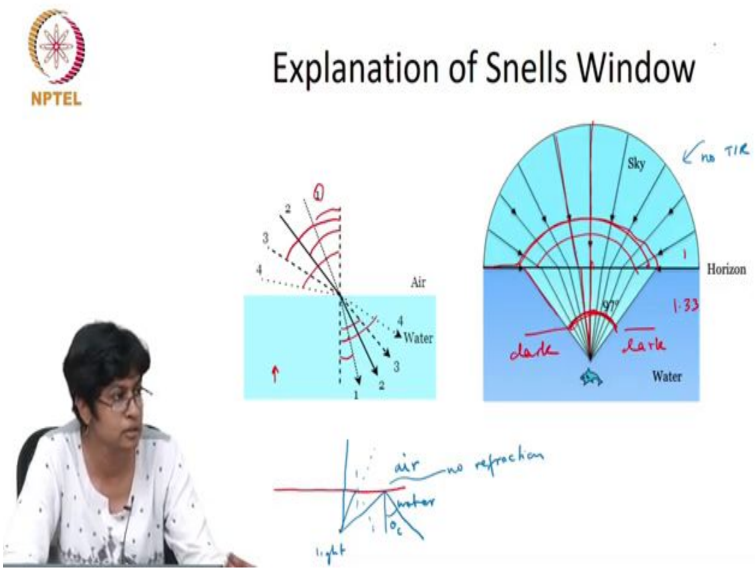

So, let us look at this in a little more detail. So, anytime you are given geometric optics phenomena or events to explain, start with the ray drawing right and usually the ray drawings are just going to follow Snell's law and trigonometry right. So, start with the ray drawing;

however, hard it may seem to start with the ray drawing ok. So, in the case that in the previous photograph, someone is taking a photo looking up right.

So, there in the water there in the denser medium and they are looking up. Now, let us just look at how light enters the water. The light source in this case is definitely outside right, how does light enter the water? If you take this ray; ray number 1 right, when it enters the medium since water is a denser medium it is going to bend towards the normal.

So, it has a smaller angle over here, but as you go on increasing the angle of the incident rays. So, this goes on increasing while in every case the ray of course, bends towards the normal. If you have a larger angle here, you also have a corresponding larger angle over here right and at some angle the ray is; so, what is of interest to us is why do we have that dark circle ok.

So, just this is just to remind you of Snell's law. As you have a certain angle over here you are going to have a smaller angle over here right ok. Now, what happens in this air water case? These are all the rays coming in from the sky. So, I have rays that come in from the entire 180 degrees. The normal incident ray carries on no deviation, this ray deviates slightly, this ray deviates and comes in at this angle.

Now, I cannot have an angle greater than 90 degrees. So, I am capturing all of the light, I am not losing any of the image, but the entire image that was or the entire object if you will that was spread across 180 degrees in air is now bending, all the rays from that 180^{θ} cone in air is now being bent as it enters the water and it only if I assume this as refractive index 1 and this is 1.33, I have a 97^{θ} cone over here right.

So, very-very careful with what you see. It is not that the dark circle does not mean that you have cut off anything in your image, it is not that light is blocked. All you are saying is, because of Snell's law.

The light that comes in at 90 degrees, it gets bent and comes into the water at a smaller angle. So, this entire range is compressed into a smaller cone of light, but of course, inside the water you can see the full 180 degrees, but you will only see the image in this region and so, therefore, these regions will appear dark. You can think of it like this, if the light source were here, say the light source.

So, this is water, this is air. If the light source were in the water of course, the normal ray would continue through, but the ray incident at some angle would get reflected and there would be some angle at, but there would be some reflection, there would be some transmission, but at some angle you would have all of the light reflected. Let us say this is theta c and there would be no refraction right. We know light rays travel reversibly.

So, although in this case the light source is outside, exactly the same phenomena is happening, because the light is coming from the rarer medium, all of it refracts, it the rays here, there is no total internal reflection here, because that is the rarer medium. Total internal reflection happens only if the light is within the denser medium, this is a rarer medium.

So, there is no total internal reflection. Everything transmits, everything refracts through them that interface the air water interface, but it bends and it bends and thereby, the cone which was could have been 180 in air is has a smaller value in water and the result is that whenever you take a photograph in water looking out, you are always going to have this dark ring ok.

Now, this particular photograph does not really have a lot of detail. All your scenes are actually just the diver who is in the water, but I could have had a scene. So, I have a pond and then I could have had trees over here maybe, something leaning over like this right. I should be seeing all of that in the photograph, we are not saying that let us say something was hanging over here, you would see this. So, let us say I have different images, different objects.

The object B would probably appear clearer than A, because A is coming in from that glancing angle. So, the amount of light coming in, remember Snell's law does not tell you anything about the magnitude of the light coming. It just tells you the angle, if light is coming in at a certain angle, this is the angle with which it will refract. Does not say that 100 percent of the light reflects ninety percent Snell's law does not tell you that you have to go back to Maxwell's equations to get that.

We know that the amount of light that refracts or reflects changes with the angle of incidence. When do you have the best reflection? The closer you go to the glancing angle right. You can take even your notebook, hold it up a glancing incidence and it is almost like a mirror very reflective. It is very reflective, when you are looking at very large angles of incidence. If more light is being reflected, it means less light is being refracted.

So, the amount of light coming in from this, this magnitude is much less than the amount of light coming in, like this ok. So, if you had a lot of objects outside, around this water body, the objects that were in the center would probably be much clearer than the ones at the side, because the amount of light you are getting would be much larger from those objects, but having said that people often get confused and think this black ring means we have cut out.

You have not cut out, you have the full 180^{θ} view. It is just that it is been compressed into a smaller cone right. You can think of it is some kind of distortion right, because what should have been in this smudge area has now been squeezed into smaller area ok. This is called unsurprisingly Snell's window, because you can explain it completely by Snell's law.

If you go look it up you get some really beautiful photographs that have been taken. It is again we are not, then you are not doing anything special to get these photographs. It comes automatically, because of the way light refracts ok.

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So, that is just some phenomenon, but geometric optics. Why do we spend five weeks, six weeks studying geometric optics and in fact, you could do an entire course on geometric optics.

We use geometric optics, because many real everyday systems, applications are based completely on geometric optics and one very important one to do with security is the fingerprint sensor ok. So, this is an image of my finger. Now, it is very easy for me to take this photograph. In fact, today I just pulled up my phone and I took a photograph, but it is not easy to see the fingerprint at all, right. And if I want to use this or use the fingerprint to and store it somewhere and then have it stored against maybe the entry of a doorway so that we can check the fingerprint and then open the door based on that or some you know for your Aadhaar cards you have to do that.

How do you get the fingerprint? Now, why is the fingerprint not real easy to see? Why is the pattern of those whirls and curls not easy to see and to answer that one really has to look at what do we mean by imaging ok. I keep asking you this question at different points in the course to focus on some particular aspect of image ok. So, in this case I am asking it, because I have this image, but I want to have images like this ok.

So, in effect I am asking you, what is the difference between the photograph of my finger and these images down here? What is the big difference between them right and the answer to that is contrast and a large or a very important aspect of any imaging is that your image must finally, have very clear contrasts.

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Now, this is a picture of India gate taken and so I chose Delhi, because if you want to have poor contrast, you have so much pollution over there. It is easy to get images with poor contrast.

So, here I am telling you there is India gate over there, but you can almost not see the visibility is very poor, the result of that is there is no contrast between the region around the structure and the structure itself and the effect of that is you do not see the structures ok. And you if your goal was to take a picture of the structure you have not achieved it here, because there is not enough contrast in this image for you to make up the difference. Imaging this successfully, a good image allows you to see something, because you see the difference between different points on different places of that image.

So, everything looks the same, even if there is information there you are not able to ascertain that information ok. That is why imaging things like cells is so hard, because there are slight refractive index differences there. There is a difference, it is not that your imaging surface or an object, where there is no difference. You are not taking a homogeneous uniform object and imaging it.

You are taking an object which has a lot of variation and that variation can convey a lot of information to you. So, if you are looking at cells, you might be looking, you could be able to make a diagnosis out of that by saying this cell has this problem and therefore, it means this person has this disease or this medicine is working or it is not working.

So, there is a wealth of information there, but because that information lies in very slightly varying refractive index, you are not able to see that difference and if you cannot see the difference as far as we are concerned that information is not there ok. So, a good imaging system needs somehow to extract that information. So, the same photograph taken on a clear day and you can see now there is a big difference in contrast. So, it is obvious that you can see the structure in the lower picture, because of the contrast the difference between it and the air around it.

So, in the fingerprint sensor, we are not able to see the print, sorry in the photograph of the fingerprint, you are not able to see the print, because the contrast between the ridges and the depressions of your finger that difference is too small for you to make out ok. So, it looks like an almost continuous surface. You can make out this faint structure there, but not clear enough for you to get these nice, clear patterns as shown down here ok.

So, if you want to make a fingerprint sensor, you want to somehow enhance those differences, that would be the goal of a fingerprint sensor ok. How many of you did an Aadhaar card registration? So, what did you have to do for the Aadhaar card registration? One of the biometrics was you have to have your fingerprint taken, how did you do that?

Student: (Refer Time: 16:50).

So, you had some glass surface you had to press with your hand. How many of you have to do it multiple times, because it did not work the first time right. What did they ask you to do between that they ask you to do something?

Student: (Refer Time: 17:06) hand sanitizer.

They made you clean your hands ok. So, sometimes there is grease over there right and that is one of the reasons. So, even though we are going to learn about that system that helps enhance the contrast, that system also cannot work if there is the natural whatever oil, natural oils are there, but that lies between the ridges and that works to lower the contrast.

So, the hand sanitizer helps to remove that and allows the machine to enhance the contrast ok. They might have also asked you to press quite firmly right. All of these are ways to help the tool enhance the contrast ok.

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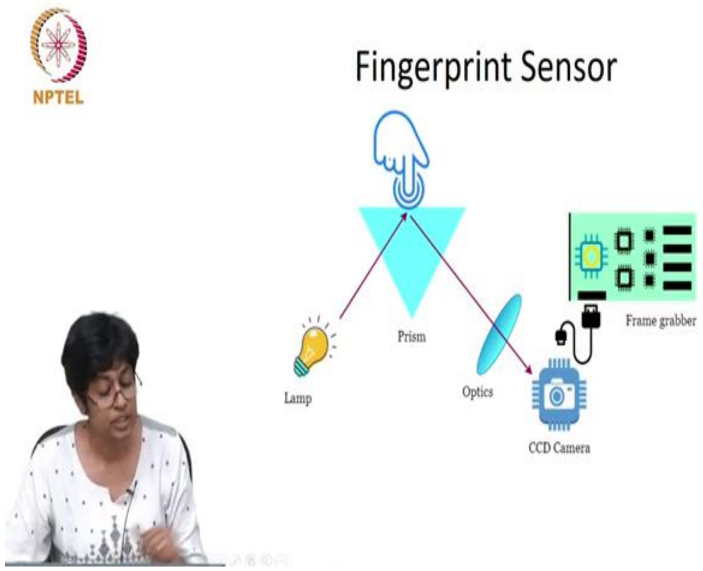

Now, this is roughly, it is a very simple system. This is roughly how it is working. So, you have a light source, it is not a bulb like this, but it is a light source and you are going to press your finger. So, this is the surface use.

So, this surface, I am going to ask you soon why you have a prism like this, but you would have just seen the upper surface of the prism. You press your finger down upon or your fingers down upon it and then the light that is reflecting off, this is being collected by a lens and being collected by a camera and giving you that image ok. So, this is the basic anatomy of most fingerprint senses.

Now, how exactly is this working? If you remember the image of India gate, you were some who has taken the photograph standing in front of the structure and whatever ambient light is there is using that ambient light, it is reflecting off the structure and being collected by the camera and it is forming the image.

So, the reflected light is being used to form the image. So, it looks like at first glance that all I am doing here is creating a system that will reflect light of the image of the finger. So, why should that make any difference? I should again just get the image that I had got of my entire finger without the fingerprint being. How is this enhancing contrast? Ok. That is the question that you have to ask.

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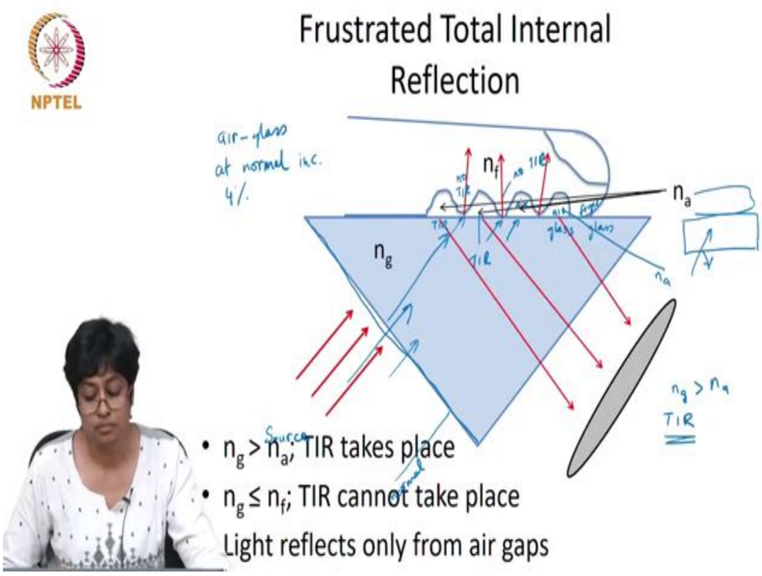

So, if you look at it in a little more detail. Now, forgive this finger, it is not a diseased finger. It is my attempt to show you a finger with the detailed fingerprint, so that we can next understand how geometric optics is working over here.

We use the prism, because we want to send light from the source on to the finger, where the region, where we want to image the print. Now, why do I want the light to be incident on the surface of the prism like this? Why could not I have us, this is a finger and this is my block of glass block.

Student: Is now will be a glass will be clear?

Yes. So, here I want light to go through this, but I want if, if I send light through this structure, there is always going to be reflection here, there is always reflection. The amount of reflection over here is minimum, because the incidence is normal right. So, if I, in a normal air glass interface, at normal incidence, if you have not done anything to the glass, if you have not treated it in any way at normal incidence, you have 4 percent reflection. And the amount of light that is reflected goes on increasing as the angle of incidence goes on increasing.

So, here, because the surface of the prism I mean, because you are using a prism the normal, is this is the normal. So, here I am sending in light along the normal which means I have the minimum reflection of 4 percent. So, I am losing the minimum amount of light by having that incoming surface along the same direction as the light ok. So, that is why we use a prism.

Now, its incident on the finger and it is reflecting, but it is not reflecting the same way from the regions where the ridge touches the finger, touches the glass plate and regions where there is an air gap. So, you can think of this as an air gap and that is how you want this to be an air gap not an oil gap, which they are sometimes they ask you to wash your hands to remove those natural oils ok.

So, let me get rid of it. So, what is happening is; I can consider the refractive index of these regions to be air, the refractive index of the prism itself is glass. We are now sending in light. So, this is the reason why we press the finger against a glass object, because we are now setting up the condition where total internal reflection could happen right. Total internal reflection cannot happen, the incident medium is a rarer medium.

So, I have now set up. So, using $n_g > n_a$ oh, I have already written that here, I am allowing total internal reflection to up, but this total internal reflection occurs everywhere. I have regions, where I have the glass and I have air and then I have regions where there is glass and there is the finger.

So, in some places the refractive index of the first medium is larger than the second medium and in other places, the refractive index of the first medium is not larger than that of the second medium or the difference is much smaller. Now, how did I start this whole discussion? I said, somehow, we need to enhance contrast and the previous sentence should make it clear how we are enhancing contrast.

In some places, the conditions are perfect for total internal reflection to happen and in other places they are not. So, yes we are using reflected light, but we are using totally internal reflected light and in some regions total internal reflection is not allowed to happen and that is why it is called frustrated total internal reflection and it is that difference which is enhancing contrast.

So, I would have total internal reflection happen in this region and it will not happen here. I will have total internal reflection happen here and it will not happen here and so on and therefore, the reflected light it is strongly reflected in some places, it is not reflected in other places and what dictates where it is reflected and where it is not it is the structure of the fingerprint and that is exactly what you are trying to image right.

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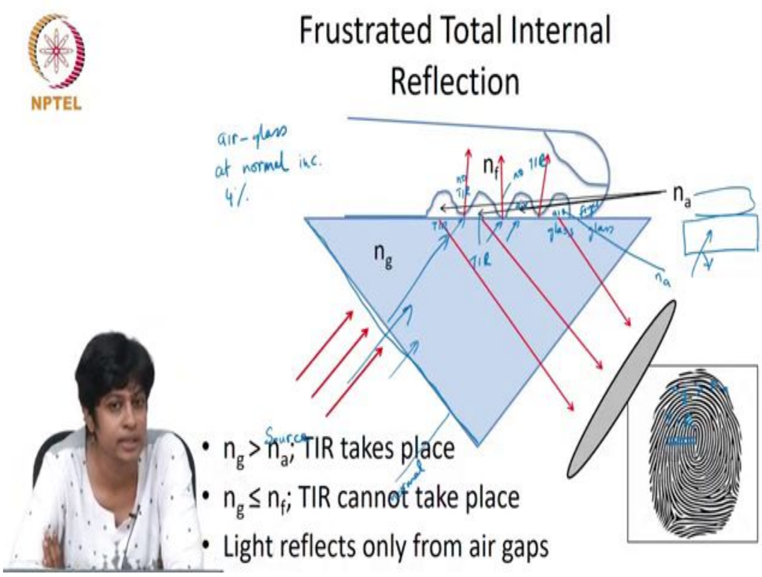

So, you are going to then get an image where yes you get reflected light, but you get reflected light from some regions of the print not from other regions of the print and that is where the contrast comes with it ok. Very-very simple idea, but that is good, because you want the fingerprint sensor to be extremely simple, it you should be able to make it fairly small, it should be lightweight, you should be able to very simply capture those fingerprints ok.

So, we can do a demo of this and that is what I want to do now right. So, I am not sure if you have noticed this, but any time you are holding a fingerprint sensor in your hand, every time you hold a glass and it works better with cold water.

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So, all I am doing is so you might have noticed this effect anytime you have a glass of a liquid and a colder liquid helps.

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I am not going to do the next example, I am just going to give it to you, for you to figure out, but in most cars you have so, you always have the driver has a rear-view mirror, the mirror that is within the car and this allows the driver to see the traffic behind. So, you can adjust this mirror and it is called a day night mirror, because during a night you the car behind you of course, will have the headlamps on. So, if the mirror setting is the same as it were during the daytime the bright headlamps of the car reflect directly into the driver's eyes and of course, that is not good.

So, the mirror has two different settings, you use one setting true so that it works during the daytime and gives you a good image of the car behind that the cars be or traffic behind and then you change the setting you still want to see the traffic behind, but you do not want to see the headlamps of the traffic behind and sudden you change, you flip the angle of that rearview mirror. So, that it is different for the day setting compared to the night setting and it allows you to see the traffic behind in both cases, but it ensures that you do not get the headlamps during the night time.

So, I will just draw these images like this here and now I want you to go and figure out. So, that is an exercise I leave to you to figure out how it works ok. So, his question is how do we see the fingerprint say so, how do we see that? The water and the glass is acting exactly like the glass prism right. So, you have the glass and the water, that is acting like the glass prism of this design.

So, I have pressing my finger against it that is how you look from here, because there is light coming in its hitting the region, the surface of the glass where your finger is, does not help if you look like this right, because I am here I am not getting the effect of the light hitting that particular region and seeing the total internal reflection right. So, when I look from here, the light entering the water surface is not the best and I do not have normal incidents.

So, there I am losing some light there, but that is in matter. Light reaches the finger, reflects off the finger and comes to my eye, but total internal reflection is occurring there and it is only occurring in regions where there is a water glass air gap and where the finger the ridge touches the glass, then I have a water glass finger. So, the refractive index difference there is not the same as water glass air.

So, the reflection that is coming back is different from different regions of the fingerprint and that is why the contrast is enhanced, but yes you should think about it in more detail exactly how this works, but this is the basic principle ok.