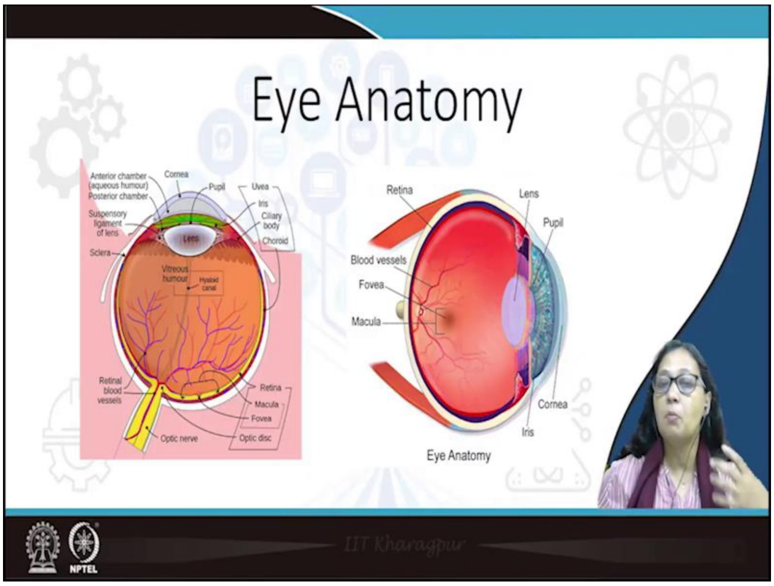
Cognition and its Computation

Prof. Rajlakshmi Guha
Prof. Sharba Bandyopadhyay
Biotechnology and Bioengineering
Indian Institute of Technology, Kharagpur

Lecture - 07
Eye Tracking and Cognition

Hello and welcome today to our talk on Eye Movements and Cognition. So, in the last class we spoke about neuropsychological measurements primarily cognitive measurements and how it is related to understanding cognition. In today's class we are going to talk with a special focus on eye movement research, how it has developed over the years and why is it important, why it has emerged as an important source of understanding cognition.

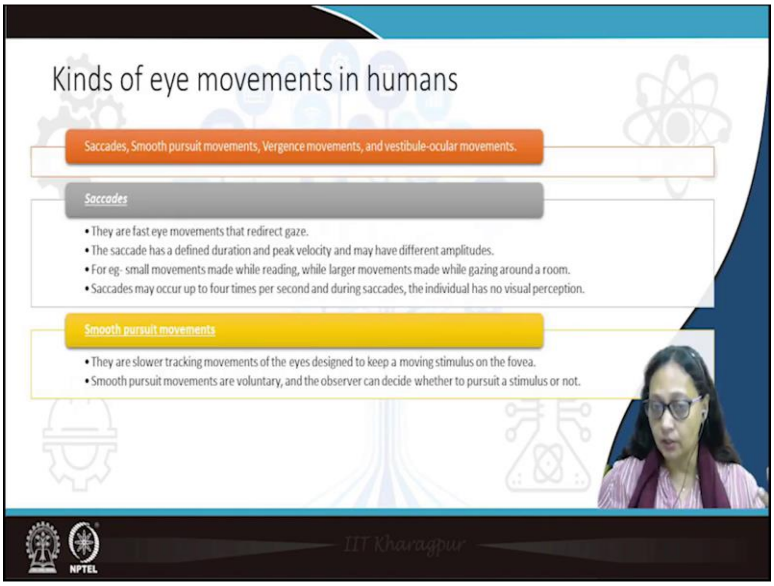
(Refer Slide Time: 01:03)



So, we are going to we know already that much of our actions are guided by our senses. Especially by what we see, especially when we are talking about a visual sense. And to get the best image what do we do the eyes move towards to get the image focused on the fovea to have where we have the highest resolution. The eyes are attached to the sockets by muscles which also helps in its movements and after the planning of intent.

So, first before we actually look into something the intent is planned visual movements then involve stimulus processing and transformation into commands for activation of the relevant muscles. So, this is our basic idea about visual processing. I am not going into the anatomy of physical anatomy or visual processing, but we are going to look at how these eye movements occurred and how are they measured.

(Refer Slide Time: 02:01)



So, each eye movement represents the basis of outcome of two basic decisions. What are they? Where to look and when to look. So, this decision of where to look requires the interaction of visual processing and cognition and the decision of when to look requires gaze control. So, this temporal alignment is very important when we are talking about case control. Humans and higher primates have 4 kinds of eye movements. Saccades, smooth pursuit movements, vergence movements and vestibule ocular movements.

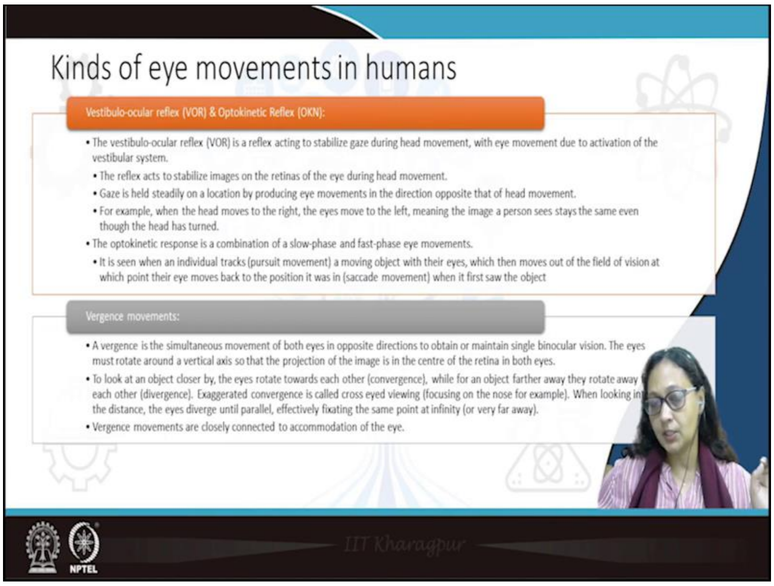
We are going to discuss all these 4. While viewing a visual stimulus humans have a saccades and fix it. So, saccades that is the movement and then fixate strategy and this is what we use when we are trying to view the world and with information is gathered during the stabilized fixations.

So, when the saccades happen actually our eyes are blinded we are not seeing any information, but the information is processed only or visualized only when the eyes are fixated. And saccades are used to shift the gaze directions as rapidly as possible. Now, specific neurons in the frontal eye field respond to visual stimuli while other neurons are responsible for saccadic movements.

So, what are saccades? Specifically, saccades are fast eye movements that redirect case. Now there are there is something called micro saccades as well, we are not going to discuss all that in this lecture this is just a brief overview. So, coming back to saccades, the saccades has a defined duration and a peak velocity and may have different amplitudes.

So, for example, in small movements like reading they there may be small smaller amplitudes, while larger movements may maybe while we are gazing around to see the world in a room or say you know even if you are in a mall. So, saccades may occur up to four times per second and during saccades the individual as I mentioned has no visual perception. So, between the saccades what happens between saccades. So, there is movement and then there is a fixation. Again, there is a saccades and there is a fixation.

(Refer Slide Time: 04:51)



So, between saccades gaze is held constant by slow stabilizing movements and this happens because of two reflexes. So, what are the reflexes? The vestibule ocular reflex and the optokinetic reflex or many times its known as VOR and OKN in the vestibulo ocular reflex and the optokinetic reflex. So, our ability to reliably perceive the environment while moving depends on these two reflexes. Why? Because they act to stabilize the gaze.

The vestibular and the visual sensory information are used by the CNS that is the central nervous system for producing eye movements. And this these a reflexes are used to provide are and these eye movements are used to are provided provides the two reflexes to maintain stable gaze.

So, when at the onset of a target say, for us a saccades it takes around 200 milliseconds for the eye movements to begin and during this delay the position of the target with respect to the fovea is computed by the brain. So, that is how far the eye has to move to get the image to the fovea.

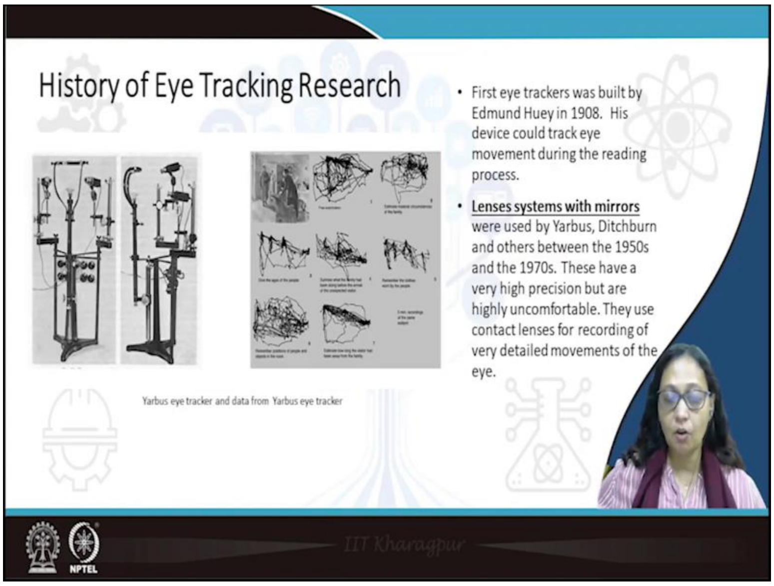
So, the small eye movements. So, that is this is computed by the brain. And this the difference between the initial and the intended position or the motor error is converted into a motor command and that activates the extraocular muscle muscles to move the eyes the correct distance. So, a little bit of movement to fix it in the appropriate direction.

So, what does that mean? To get the image on the fovea centralis. The next one is smooth pursuit movements and smooth pursuit movements are slower tracking movements of the eyes designed to keep a moving stimulus on the fovea. Smooth pursuit movements are voluntary and the observer can decide whether to pursuit a stimulus or not. So, these are conscious movements when you are instructed to follow a dot say or you are trying to read, ok.

So, when a target moves towards or away from the movement, it is tracked by vergence movements. This is the fourth kind of eye movements that we have and this these vergence movements what are they? So, the eyes converge or diverge in to get a better image on the fovea. Now, this vergence movements is in contrast to all other eye movements which are conjugate that is the eyes move in the same direction.

So, in the case of a saccade or you know the reflexes both the eyes move in the same direction, except in vergence movements. And vergence movements align the fovea of each eye with targets located at different distances. So, the movement of both the eyes are aligned, but are on opposite directions it is not conjugate. Again, the objective is simple to get the best image and to get the best image the objective of the eye is to make the image fall on the fovea centralis of the retina.

(Refer Slide Time: 08:45)



So, now this is the basic physiology of eye movements how it happens and I spoke simply about the eye movements. Now let us look at the history of eye tracking research. So, research in eye tracking evolved long before the development of computers and one of the first eye trackers was built by Edmund Huey in 1908.

His device could track eye movements during reading. And with technological advancements objective eye trackers developed in the late 19th and early 20th centuries. And these have helped us to answer several queries in the study of cognition and visual experience. From around 1950 individuals have developed a number of different techniques for eye tracking, for measuring eye movements and the most common of which are the lenses systems with mirrors.

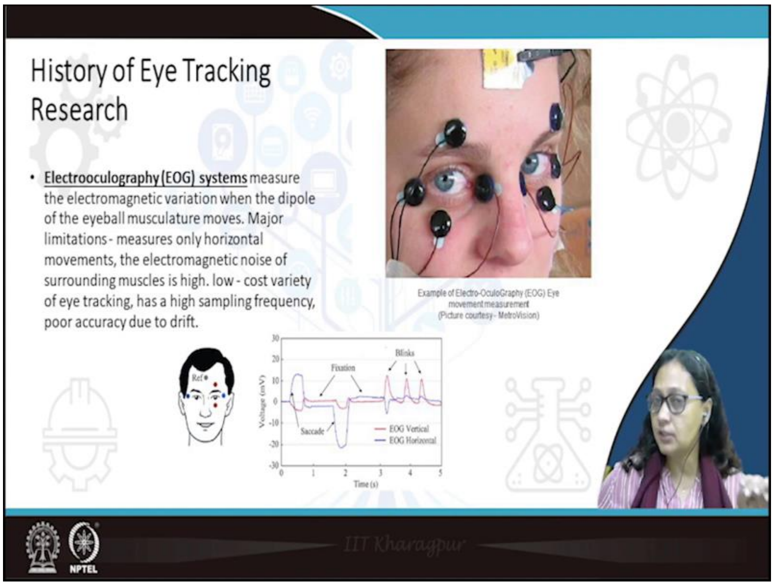
Now, this system was used by were primarily used by Yarbus, Ditchburn and others between the 1950s and 1970s.

(Refer Slide Time: 10:06)

And the lenses systems have a very high precision, but are extremely uncomfortable. What they use is they introduce contact lenses for recording very detailed eye movements and one of these being the electromagnetic coil systems. Now this these electromagnetic coils they are actually silicon contact lenses placed in the anaesthetized eye.

And this is as you can well understand because it is well you know anaesthetized or rather I should say well fixed within the eye it has a very high precise the you know precision. And, but the it is very uncomfortable and that is why it despite its accuracy, this method lost popularity.

(Refer Slide Time: 10:56)

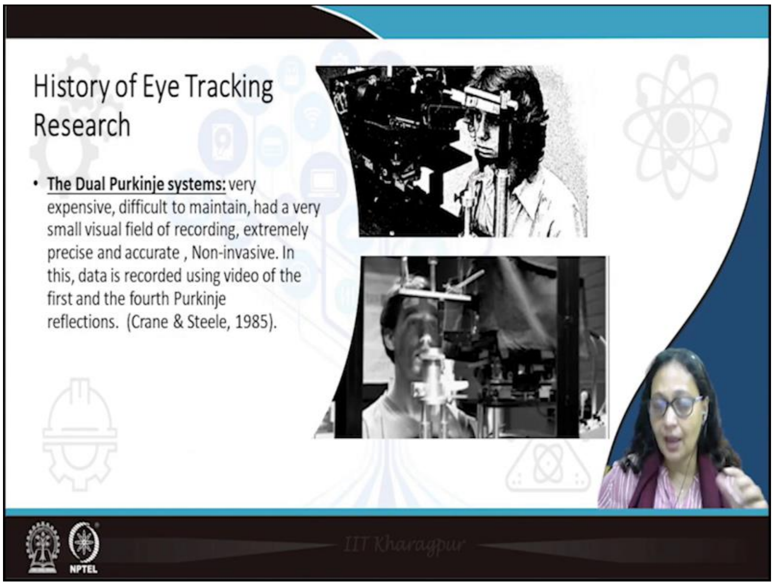


The next method that has been used is the electrooculography or electrooculogram as you often see. These the EOG systems they measure the electromagnetic variation when the dipole of the eyeball musculature moves.

But one of the major limitations of this system is that, EOG is EOG measures only the horizontal movements and the electromagnetic noise of surrounding muscles is high. So, you cannot capture all kinds of eye movements with the EOG.

This method of the EOG systems is still existing and it is a low cost variety of eye tracking. Having good sampling frequency or a high sampling frequency although, accuracy is pure poor due to the drift. Also, the noise but you will come across many EEG systems having EOG sensors especially if you are looking at the 256 channel EEG systems. They have sensors here you know as part of the EEG system that actually capture EOG that work as EOG sensors. So, it is still in use.

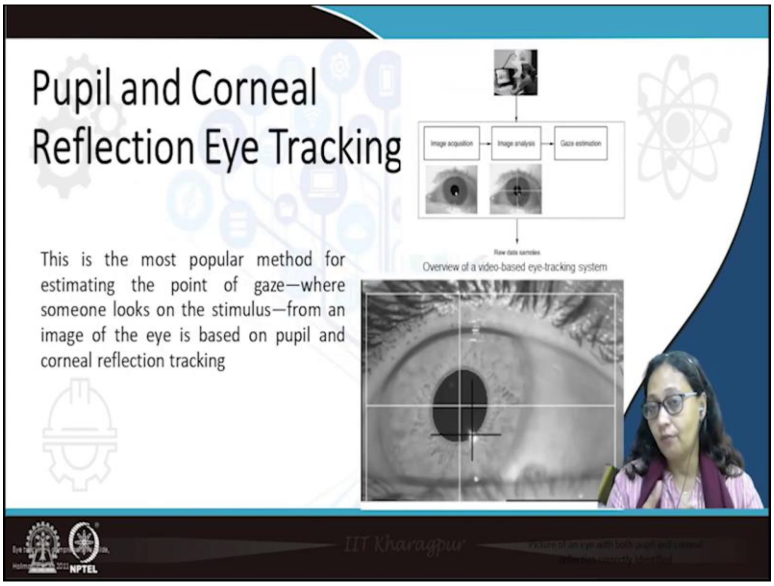
(Refer Slide Time: 12:25)



The third kind of eye tracking systems that were in use are the dual Purkinje systems. This was again a very very expensive method, difficult to maintain and had very small visual field of recording.

But again, the advantage being that it is extremely precise and accurate without having to place something directly on to the participant side. So, this is a noninvasive technique and non noninvasive techniques and noncontact techniques are always better appreciated for experimental reasons in experiments.

(Refer Slide Time: 13:16)



Simply because that does not act as add as an added you know an additional variable extraneous variable to the experiment. So, how do these Purkinje systems work? So, the Purkinje image, ok many of you are familiar with it. It talks about the reflection when there is a light ray that is put on the participants on the subject side. The reflection is are there are four reflections four image reflections. Two from the cornea and two from the lenses.

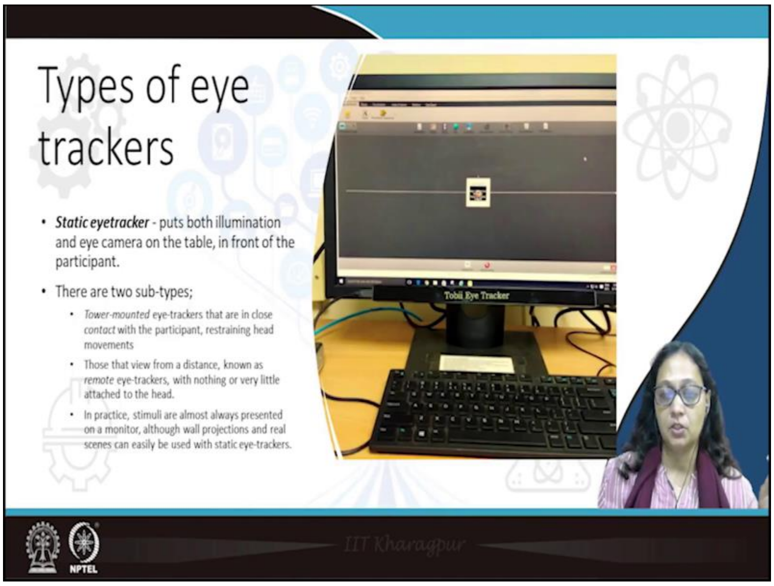
So, in the Purkinje image systems, the dual Purkinje systems the data is recorded using video for the first and the fourth Purkinje reflections. So, this was a very very effective technique and in fact, but very expensive now. In fact, the pupil and corneal reflected eye tracking the next one that we are going to talk of has emerged from this technique.

And this is the most common type of on the popular type of eye tracking methods that are use today. And what do we actually look at in pupil and corneal reflection. Where someone is looks at a stimulus and from the image the eye is based from an image of the eye, it is we can see the pupil and corneal reflections and these two reflections are tracked.

So, in like in the dual Purkinje systems we would track the first and the fourth reflection on the eye. So, that is the first corneal reflection and the last lenses reflection. And here the image is from the corneal reflection and the pupillary reflection again.

Now, what is done here, but before I get to what is done it is. So, as I already mentioned that this is one of the most popular eye tracking methods used today and most of the available eye trackers today use this method. So, we could also use only pupil eye tracking or, but the corneal reflection in this case for such eye trackers offers an additional reference point in the eye image.

(Refer Slide Time: 16:14)

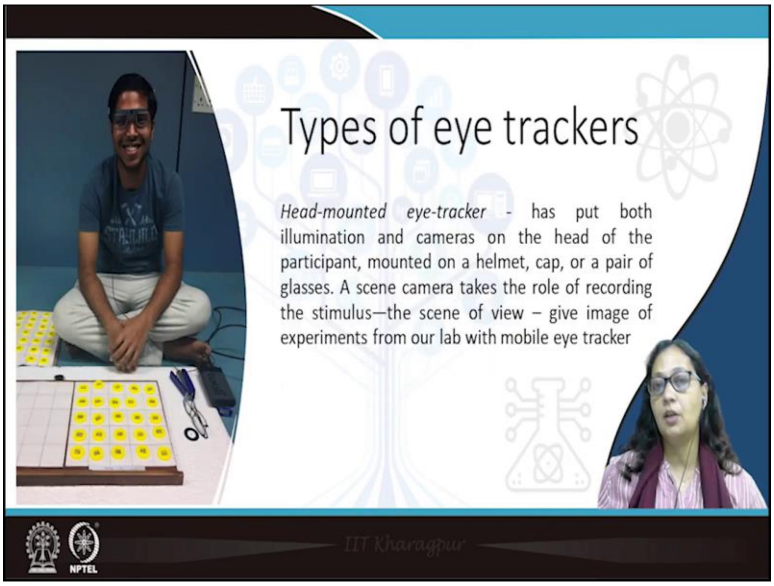


That may be that is needed to compensate for the small head movements. So, this advantage has made the video based pupil and corneal reflection tracking the most dominated method since the 1980s. And so, what exactly happens in a video based eye tracker?.

It can be static eye tracker it can be a mobile light tracker, ok. So, the common setup is generally a static eye tracker which puts both the illumination and eye camera on the table. So, either it is on the table sometimes like the eye tracker that we use we have a bar kind of a thing that is fixed on the monitor, ok.

And as I said that it could be, you know again there are two subtypes of static eye trackers. They are tower mounted eye trackers that are in close contact with the participant. So, it restrains head movements. So, it speaks like this where the head rests on where the chin there is a chin rest where you actually put your head and the head is fixated in one point.

(Refer Slide Time: 17:40)

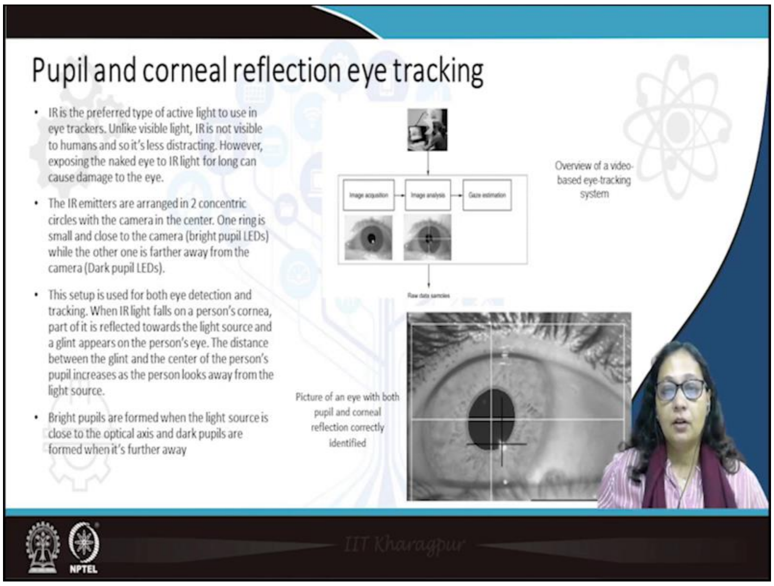


Obviously, that is to take care of the head movements and the other is as I mentioned noncontact or remote eye trackers where you know like the one that we use in our lab. Where the it is like a small bar which is fixed onto the machine, ok. Another common setup is the head eye tracker where you know you it is like.

So, one is a tower minded a tower mounted eye tracker the other is a head mounted eye tracker. So, you have the eye tracker put on you. So, it could be. So, mostly these are like helmets these are a cap or a pair of glasses, this is a mobile light tracker. The advantage of this eye tracker is you can move from one place to another and a again the way you move your head, the way you are capturing the scene in a natural real time you know situation.

Along with it the senses that are positioned within the glasses we also use this kind of a night tracker the sensors are placed here. So, a they capture the your pupil and pupillary and corneal reflections. Now, most for experimentation in cognition most of the times these static eye trackers are used.

(Refer Slide Time: 19:23)



But when we are trying to use it for understanding consumer behavior, especially in a mall where to set up your goods in a mall? Ok. How when the person enters the mall how does a person look at it what draws the attention first? So, such kind of experiments the mobile eye tracker or as I said here the head mounted eye tracker is more effective.

So, now talking about the pupil and corneal reflection eye tracking in a little detail. So, what exactly happens? So, as I mentioned this is the most common type of eye tracking that is eye tracker that is used in research now the eye tracker. So, if I just talk about our system most of the it is a static eye tracker. So, in that bar static eye tracker there are there is a source emitting infrared rays and a camera to capture the image of these reflections.

Why is infrared use? Though we know that infrared rays may be harmful for the eyes if it is beyond a certain wavelength, but the advantage of infrared rays is it is not visible to the human eye. So, unlike other visible light it is not as distracting because the individual it is not affecting the vision, ok. Now the infrared emitters are arranged in two concentric circles with a camera in the center as I mentioned and one ring of the infrared you can is small emitter and close to the camera.

So, this is for bright pupil LEDs as you can see from the image while the other one is further away from the camera, that is for dark pupil LEDs, ok. This setup is used for both eye detection and tracking. When IR light falls on a person’s cornea part of it is reflected towards the light source and a glint appears on the persons eye.

So, that is the white glint that you see. The distance between the glint and the center of the person’s pupil increases as the person looks away from the light source. Now this distance is calculated. So, bright pupils are formed when the light source is close to the optical axis and dark pupils are formed when it is further away. A difference image between the dark pupil, dark and bright pupil images is used to track the eyes.

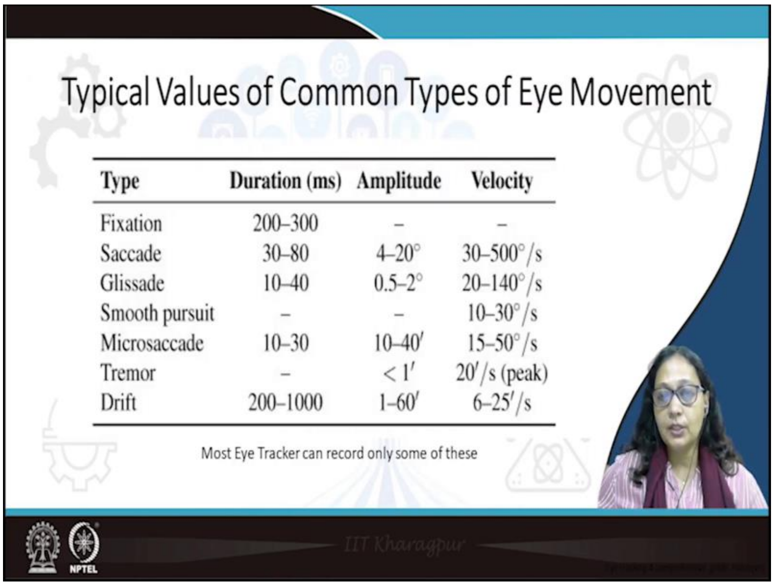
So, again some of these measurements are inbuilt within the system within the software itself and some we need to calculate ourselves to write down a code for calculating certain kind of eye parameters that. So, what happens is after the image is the differences in the image is used to track the eyes the 2 rings are turned on and off within milliseconds. So, this I am talking about the infrared rings.

So, the light emits and it stops. So, in milliseconds of each other and producing both bright and dark pupil and the camera captures the eye image. This difference image is then formed by subtracting the image from the dark pupil and from the image from bright pupil. As I said the difference is calculated and the user the provides the system with models of the eye and these calibrations. So, one of the way the eye tracker calibrates is for the eye movements is initially when you switch the eye tracker on.

It asks you to look at the 4 edges with the head static to move the eye and rather in simple terms to look at the image on the 4 sides of the screen. So, there is a ball like a yellow dot moving in different parts of the screen and without moving the head one has to move the eye.

So, this is the way the eye tracker which has some inbuilt codes tries to calibrate its system as per the error between the 2 the constant error for this individual, ok. So, between the 2 images of the bright pupil and the dark pupil.

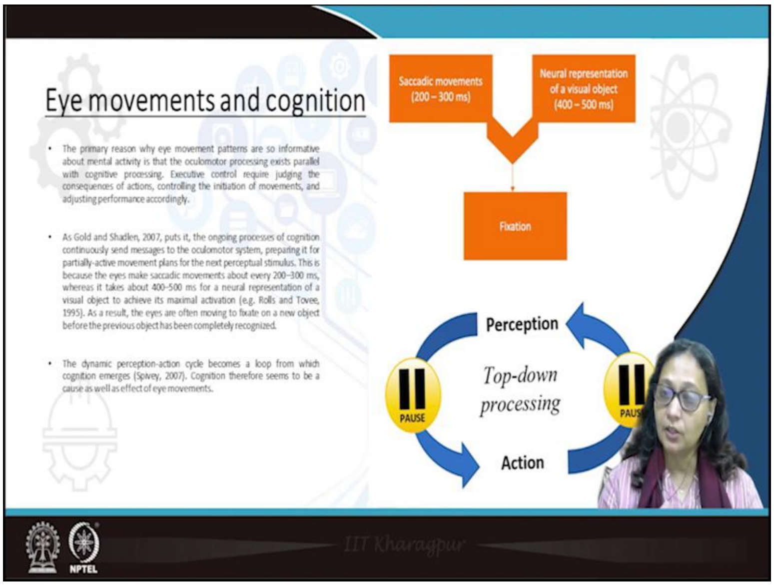
(Refer Slide Time: 24:47)



And. So, this the advantage of this eye tracker is it works the static eye tracker is as I was mentioning that this is used more in experimental conditions. So, for in a controlled environment where the head movement is low. The advantage is that it generally the, this kind of eye trackers are more accurate to identify the larger the various parameters various eye parameters. So, when I talk about various eye parameters what am I talking about.

So, some of these again are calibrated within the some of these are inbuilt into the system. So, you get fixations you get. So, for fixations you get number of fixations, fixation duration, you get the number of saccades, saccadic duration saccadic velocity, saccadic amplitude, ok and you can also get the area of interest how the eyes moved towards a certain area. So, these all of this. So, if you are looking at an image.

(Refer Slide Time: 26:07)



If you want your ex subject participant to look at an image and you want to see which area actually draws maximum interest to draws more attention. Then you simply need to follow the eye movements and this we can calculate the AY area of interest and as per time frame. So, along with the video the eye movements are. So, this the is captured, ok. So, even.

So, for a tenure of say if you are doing it for the experiment runs for 10 minutes 15 minutes whatever. So, it is captured as a video and. So, the eye movements and certain parameters as I said these are the common parameters that are in use. That these are you know calculated from within the codes that are available within most of these eye trackers and for some of it we have to write down the codes.

So, now why are where are eye trackers used. So, eye trackers have been used very frequently. In fact, for the first eye trackers were used for reading studies. So, similarly many of these eye trackers still today are used to understand how people are looking at reading material. So, it is used for dyslexia studies, attention deficit hyperactivity disorder, for autism what draws the attention where do children with autism look you know if it is an emotional image.

So, it has been seen that you know autistic children generally prefer to look at non human images, more than human images and non emotional images. Now, so these can be easily calculated. Now along with this eye tracking is now used for understanding working memory. So, and attention studies. So, mostly with attention studies and beyond that in problem solving studies. So, why in problem solving research because for the eye movements is a pathway to the cognition. How?

Because when the primary reason why eye movements eye movement patterns are informative about mental activity is that the oculometric processing exists parallel with cognitive processing. Why am I saying that. So, the executive control you know that is controlled by the frontal lobes requires judging the consequences of actions, that is planning the action, controlling the initiation of movements and adjusting the performance.

Now, when I say performance, I am here I am talking about the eye movements where to look and when to look. And as Gold and Shadlen in 2007 pointed out the ongoing processes of cognition continuously send messages to the oculometric system. So, that is we actually plan our actions before looking at something. So, the planning part is done by the front loop.

So, the premotor area then it goes to the motor area and this is all from the decision and planning that is happening in the prefrontal cortex. So, the oculometric messages that are you know sent to the oculomatricies, oculomotor system prepares the eyes for partial active movement plans towards the next perceptual stimulus.

So, whether I am going to look at it whether I am not going to look at it whether I will follow this line this is the end of the line. So, I should move down, ok to the next line how should I go this planning is done before. And this is because the eyes make saccadic movements about every 200 to 300 milliseconds whereas; it takes around 400 to 500 milliseconds or a neural representation of a visual object to achieve its maximal activation.

And therefore, the eyes are often moving to fix it on a new object before the previous object has been completely recognized. So, a partial recognition by the time a partial recognition happens through a fixation the next saccade continues. So, you know. So, that when that saccade is happening there is no vision, ok.

But the planning sequence has struck it. So, the computation within the brain has been done as to what I need to do then comes the fixation. So, the dynamic perception action cycle becomes a loop and from here we have an understanding of the stimulus in simple terms we have cognition and this is what PV says in 2007.

So, cognition therefore, seems to be a cause as well as an effect of eye movements. So, with this background theoretical background in place eye trackers are gaining a lot of popularity in cognition research. You will see when we talk of cognition research, we will talk of multiple other systems that I used.

So, for how to understand cognitive processing from single neurons, Professor Bandyopadhyay will be talking about it. What I tried to do in these 2 lectures is give you a summary of what is done to understand human cognition from a social perspective. And how you know how the cognitive tests have helped and how eye tracking as a system is gradually developing as an inroad to cognition. So, I guess that is about it.

Thank you.