Computer Vision
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Lecture - 37
Color Fundamentals and Processing (Part IV)

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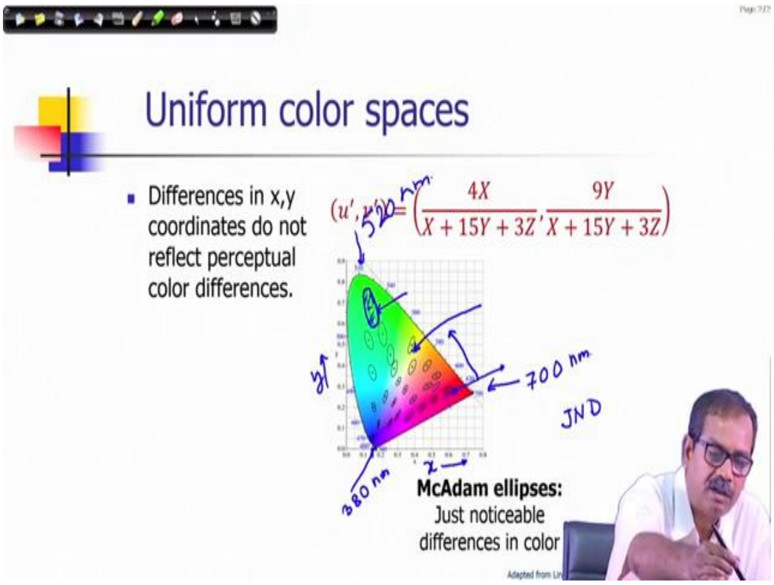

We continue our discussion on Color Fundamentals and Processing of color images. In the last few lectures I have discussed how colors could be represented as a trichromatic vector. And, how the perceptual factors of color in terms of chromatic experience in terms of hue and saturation could be obtained from these calibrated chart as proposed by an international body of colors or in acronym CIE. There is CIE chromaticity chart from where you can represent a color in a x y normalized x y chromatics space.

And as you can see here also in this particular figure that the colours are shown in a semi elliptic region and where the peripheral regions peripheral curve is showing different wavelengths. For example, the wavelengths starting from, see this point is 700 nanometre and this point is 520 nanometre and this point is 380 nanometre. And, across this periphery as you traverse from this point and come to this point, wavelengths are decreasing in this order. And different wavelengths, they correspond to a particular color, a pure color that is sensed by us when that electromagnetic wave of that wavelength is received the energy from those wavelengths.

But, in the chromaticity space any color when they are represented as a superposition of three primary colors particularly when we capture in terms of red green and blue, then we can convert those color points into a two dimensional chromaticity space that we have discussed that is x y chromaticity space. So, for example, this is the x axis of that space, this is x axis of that space and this is y axis and any particular color at this point it has been shown also.

what is the color of that pixel that is how this you know visualization has been created this graphics have been created, where it is also showing the colour. So, you can see there if there are large regions of having almost similar color sensation and the minimum the region where color are almost indistinguishable they can be approximated by ellipses.

As you can see one example of this ellipse is shown here a larger ellipse, here in this region you can see this ellipse I am drawing it just for your convince. So, centring this point all the color covered by this point all the chromatic point they will generate the same sensation. Now, these ellipses are known as McAdam ellipses and these ellipses are also called just noticeable differences in color ellipses or JND ellipses this is a very common acronym what is used.

So, if your points so within these JND ellipses so all the perception of color would be almost similar in our human visual system. Now the problem here in thisx y space is that the size of this ellipse is non-uniform, you can see the size of this ellipse at this location is quite large. Whereas, near to the red region, this size is quite small very small ellipses are shown here, so that is a problem with presentation of color in an x y chromaticity space. So, there is a proposition another proposition for another color space, where you can try, you can make this ellipse.

Size of this ellipse is more or less uniform. it will not be exactly uniform in every place. But we try to minimize the variation of this sizes and this color space is called uniform color space, the uniformity the uniform that adjective comes from the point of view that we are trying to make those sizes uniform by making some transformation on those (x, y) point itself. So, so this is one example of this transformation. you can see that just to make it clear let me rub these points.

So, you can see that the transformation I have displayed here. so this space is called u' v' or UV in short that is a uniform color space. Again it is a chromaticity space, space of representing only the chromatic components and the kind of transformation from the x y z coordinates of the color representation of the color has been shown here.

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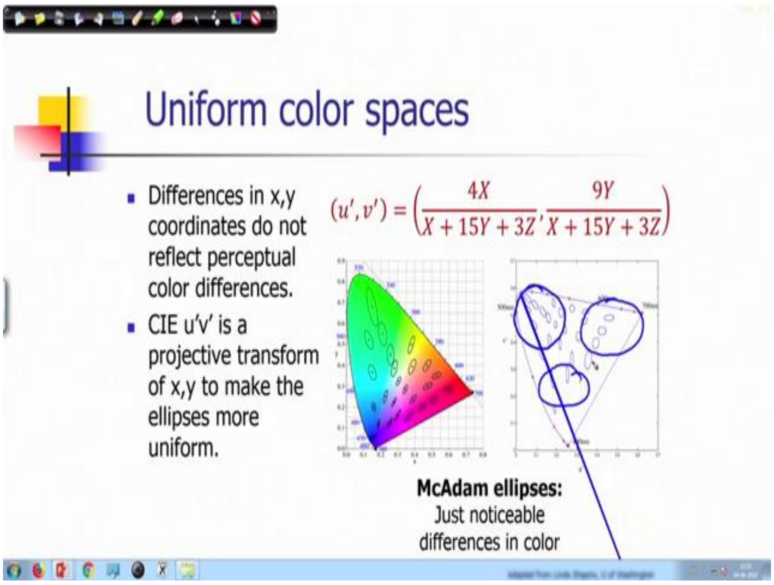

So, the point to note here that it is a projective transformation of (x, y) to make the ellipses more uniform, say you consider the this diagram. Here you can see that the differences of sizes of ellipses in this zone which corresponds to the green zone in this space and in the red zones or in the blue zones, they are reduced grammatically. So, this space is no more suitable when we are trying to compare colors in terms of defining certain distances.

Though it is ellipse it is not circle, circle so Euclidean distance is not very appropriate in that sense in this space. But still you can consider the neighbourhoods are sizes are almost at least sizes are similar. So, they would be more appropriate or they would be more effective for distinguishing colours when they are represented in this space.

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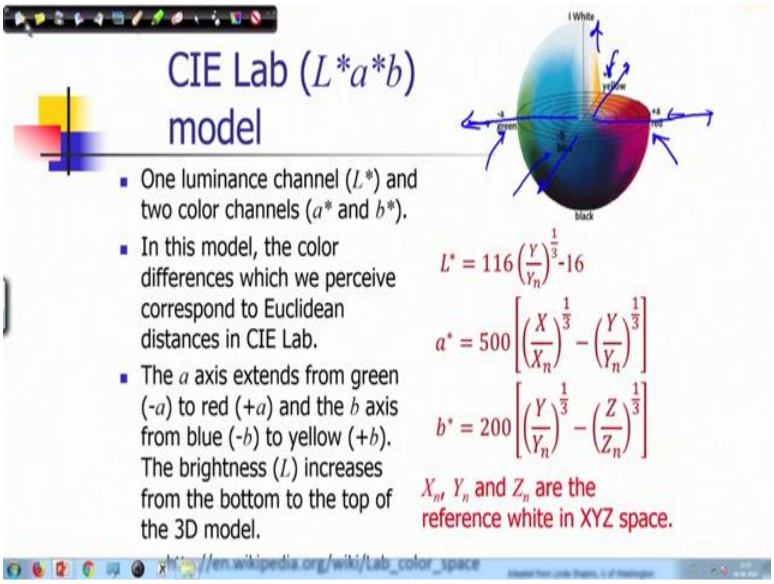

So, let us continue this discussion on color representation. let us see what are the spaces are there. So, one of them with respect to the discrimination of colours there is another very effective space that is proposed also by the international color body CIE and this space is called Lab space or we define this space also $L^*a^*b^*$ space. Here the distances would be more effective Euclidean distance would be more, as the distinguishable the ellipses. If I convert in the "ab" space or that is "ab" chromatic space, so those will be more circular in that shape.

So, in this space we have one luminance channel and the two color channels a and b, I am referring them a and b those sometimes here shown as a^*b^*. As a transformation is also shown here you can see the transformation in this part. So, we have $L^*a^*b^*$ and you can see that is a non-linear transformation which is made using once again they are made using x y z representation of the colour. And note that all this x y z values they are normalized by the respective values of reference white.

So for example, reference white is represented as X_n, Y_n, Z_n, usually the white is that white color and we know that corresponds in the chromaticity chart of x y chromaticity chart the point is nearly $\left(\frac{1}{3}, \frac{1}{3}\right)$ in the x y coordinate. Almost all the components of x y z would be equal, but they may not be exactly equal. so this is a kind of calibration you need to do with respect your system.

So, find out what is the definition of white in your system and it is a kind of white balancing operations in the color representation. So, once you get this values and then you can normalize x y z coordinates, as $\frac{X}{X_n}, \frac{Y}{Y_n}, \frac{Z}{Z_n}$ and then again use this function to derive $L^*a^*b^*$. And so in this model the color differences which we perceive it correspond to Euclidean distances in CIE lab. So, it is very effective and the problem of distinguishing even in the uniform color space that becomes much reduced. I mean we can we can mitigate that problem to a great extent if we use $L^*a^*b^*$ for this purpose.

Just note that the a axis in the case it extends from it is shown in the figure also. So, this is the a axis this is the negative part, this is the negative direction and this is the positive direction. So, $-a$ is green so this is a green portion these are red, similarly for b axis this is a $+b$ and this is actually luminous. So, $+b$ is showing here and this is $-b$, so this is yellow this part this is yellow and this one is blue.

So, blue to yellow and green to red that is a kind of variation of hue in this space along this axis principal axis and along the you know L axis which is shown here as a vertical line it is a intensity what is being varying alone that axis.

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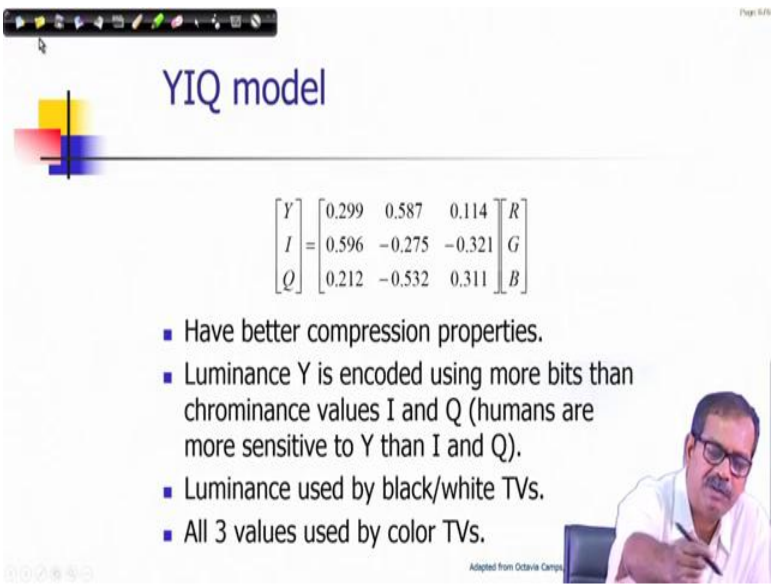

There is another color space which is called YIQ color space and it is respective transformation has been shown here it is a linear transformation, it has the property of better compressibility of information. So, in usually the chromatic component of I and Q they require less bandwidth. So, to represent the color variations. So, if you consider any radio signal color radio signal and if the color is represented into the three forms other than convert them from RGB to this form, then the component of I and Q in that signal will require less bandwidth.

And that is why this particular conversion is used in television signalling color television signalling where this conversion has been made and we can also used in the digital television signals. So, so it is a luminance y is encoded using more bits because it requires more bandwidth. Where as a chrominance values I and Q they require less width. So, the idea is that humans are more sensitive to the intensity y. And in fact if you have black and white television signal, then you know you can just simply use the y and there is a signalling encoding.

So, that even the encoding of I and Q will not affect the receiver of black and white TV. But that is the different point which we are not going to elaborate here. So, the fact is that luminance is used by this black and white TVs and all three values are used by colored TV. So, this YIQ is also a very good model for sending information by factorizing information into these three channels.

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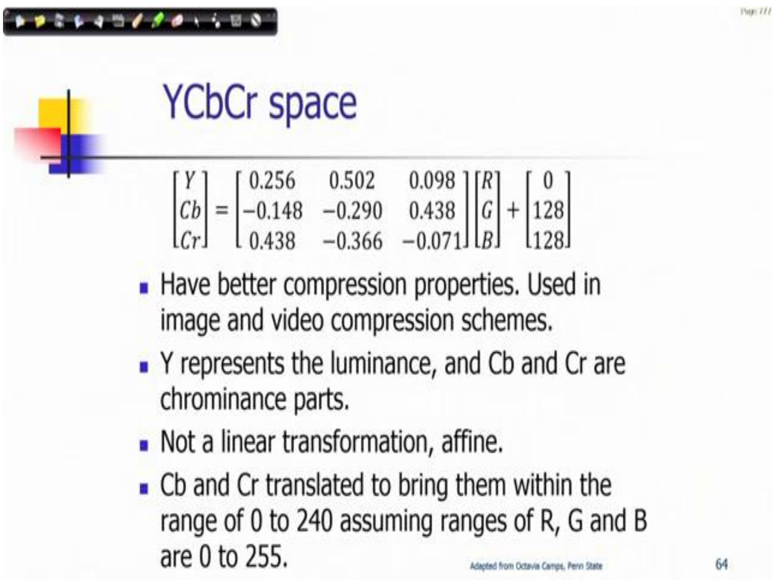

The space YCbCr space we might have already mentioned this space when we discussed about image transformation. Actually this is a space this is the color space used for image compression in JPEG standard and in many other standards subsequent standards also Vario standards. So, you can see the transformation here. there is a linear part of it and then there is an translatory part of it which is which makes this transformation as an affine transformation.

And just to note that it is also having a better compression properties, because of that it is used in different compression schemes and here Y represents the luminance and Cb and Cr they represents chrominance parts. So, Cb is called complementary blue and Cr is called complementary red that is a full term. But it is not a linear transform it is an affine transform because, there is a additive component in the transformation, translatory component or additive component at the end like this particular component which makes this transformation affine.

Otherwise you know if I leave aside this part and consider modified Cb as $Cb-128$ and Cr as $Cr-128$ then you have a linear transformation from RGB to that. So, that is also something used in color representation. So, this translation is done with this motivation that these values without this translation it could it is ranging in a negative zone.

So, for this inconvenience of representation in digital storage and I am making all those values positive. So, that you can represent then you know in unsigned white color representation or pixel representation. Assuming if red green blue the values they varied from 0 to 255 you can see the values of Cv and Cr of the transformation will vary from 0 to 240. So, that is one of the motivations why we make this kind of affine transformation.

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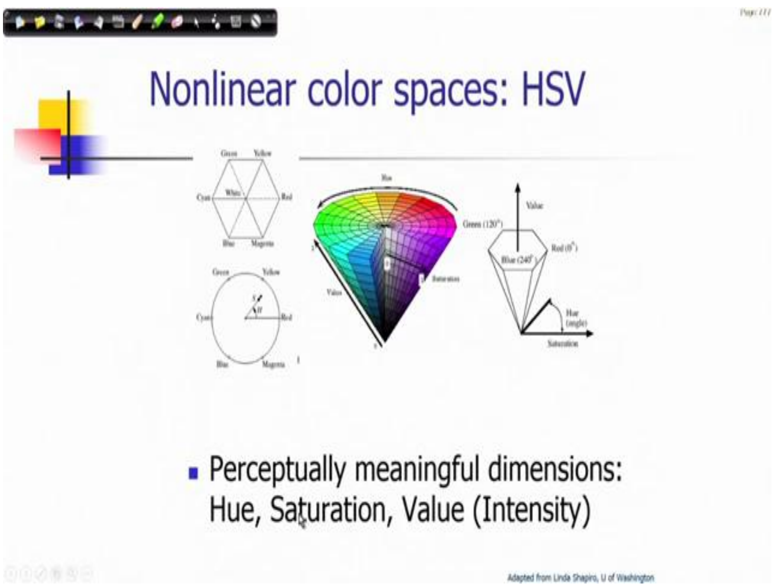

There are other non-linear color spaces where again this hue and saturations they could be factored out from the achromatic information's like intensity. So, this is showing one such example, where you can see it is a conical shaped representation of a space and at the the intensity is varying as we move towards this and as it as move towards the vertical directions.

Whereas spatially in the horizontal directions you have the direction of saturation and the hue is represented by the angle in this. So, such a kind of polar representations what has been shown here. And, depending upon angle you can see .so your reference direction is red and as you increase your angle it is if there is a transition from y green cyan blue magenta to red as you can find out in this circle representation or in this hexagonal representation.

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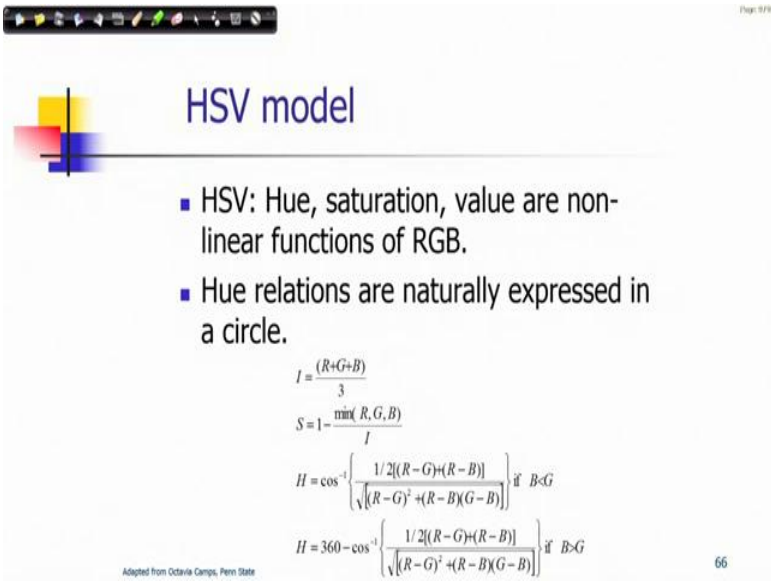

So, we can elaborate this transformation further the mathematical form that we will see. So, the interpretation here is that HSV stands for hue saturation value, value stands for intensity . So, Hue relations are naturally expressed in a circle as I shown as I have shown here and these are the expressions. So, how the intensity which is a value represented here by I which is just a average of red green blue values and then saturation expression is also very simple it is one minus of fraction of intensity and the minimum value.

$$I = \frac{(R+G+B)}{3} \qquad S = 1 - \frac{\min(R,G,B)}{I}$$

So, fraction defined as a as a ratio of minimum of RGB to the intensity value and it is a one minus of that value saturation and where as hue is also expresses angle as has been interpreted in that space.

$$H = \cos^{-1}\left\{\frac{1/2[(R-G)+(R-B)]}{\sqrt{[(R-G)^2+(R-B)(G-B)]}}\right\} if B < G$$

$$H = 360 - \cos^{-1}\left\{\frac{1/2[(R-G)+(R-B)]}{\sqrt{[(R-G)^2+(R-B)(G-B)]}}\right\} if B > G$$

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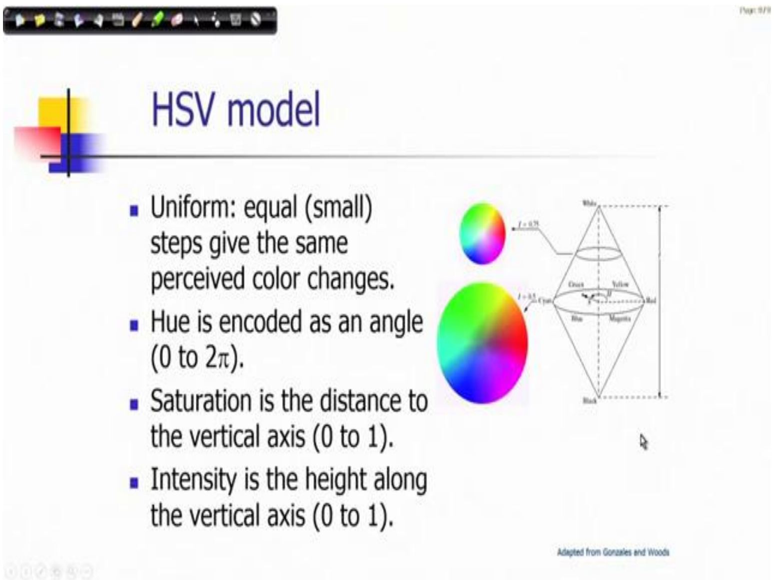

So, the implication is that HSV model it is uniform that is it is equal states it gives a same perceived color changes. So, it has that uniform representations of non distinguishable colours that kind of neighbouring color, non distinguishable color that shape also here it is a quite uniform it is a three dimensional representation. So, it is if I say that is a kind of circular ball around a point, so it has that effect.

But though you should note the the conical regions it is a double conical region what is being represented as it is shown in this part of this diagram and around this point you take small spheres spherical neighbourhood and that would be uniform here. And saturation is the distance to the vertical axis that is 0 to 1 and intensity is a light along the vertex. So, these are all normalized representation. So, ranges of saturation intensity and Hue is an angle, so it is it ranges from 0 to 2π .

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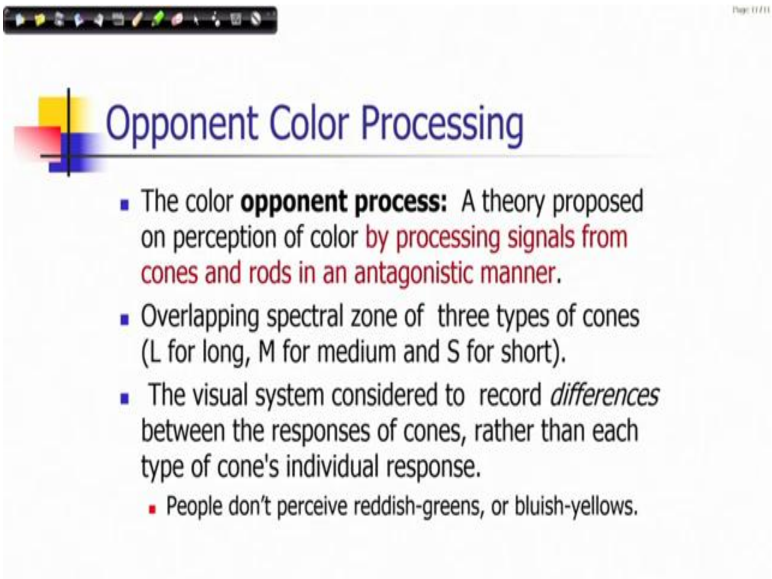

The other interesting color space it has again a theory of opponent color processes opponent processing of colours that is going on in our visual system. it is supported by that theory. this space has been proposed. what it does that you know the theory says that by processing signals from cones and rods in an antagonistic manners.

So, they act in an antagonistic manner. So, rods are kind of inhibiting when cones are very active or rods are active then cones are inhibiting. So, that is an antagonistic way they act. However, so let us consider the representation and in the overlapping spectral zone of three types of cones that we has been considered. We know that three types of cones we discussed that long wavelength zone cones that is if that is a spectral response. If they response move to the longer wavelength that is called L medium wavelengths called M and short wavelengths call S.

So, L M and S types of cones are there in our visual system and it consider the differences between the responses of cones, rather than each type of cones individual responses. So, when we sense a color signal when the received energy in terms of three stimulations of red green blue in three primary forms. It is not red green blue directly being processed for the interpretation of the color, rather the differences of red and green and say blue and also red green part we will see later on what is the model of this difference in the next slides.

So, because a when the fact it is supported by this kind of psycho visual phenomena, that it is hardly there is any perception of reddish green we cannot talk about reddish green or bluish yellows in our color perception. So, from there this opponent color processing theories are developed.

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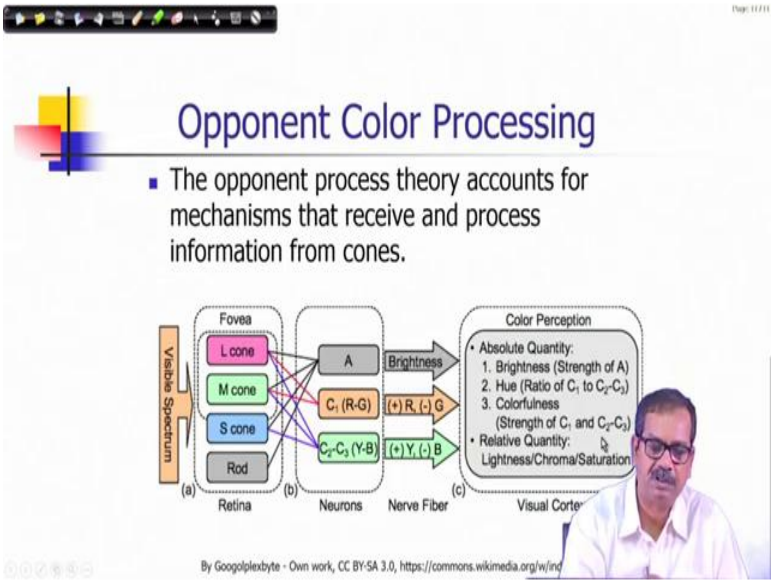

So, you can see that what kind of representation is there. So, this is a L cone and M cone S cone and you see that L and M they are participating in an antagonistic manner with providing you C1 which is $R-G$ that is a component. So, green is opposing the red you know excitations and S cone it is $Y-B$ where y is basically represented by $R+G$.

So, that is what is opposing so and all the three cones and the rod the participate in producing the brightness value. So, you have now this three factors of brightness this is the a chromatic part and $R-G$ and $Y-B$ as the chromatic part. So, this is how this color has been represented and mathematically we can model in this fashion.

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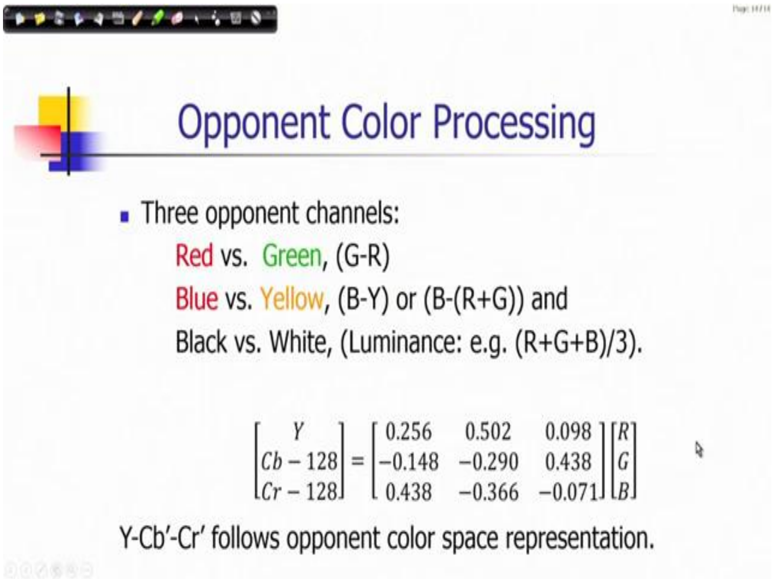

So, we have three opponent channels like red versus green is represented as a $G-R$ and blue versus yellow is represented as $B-Y$, Y is representing yellow or $B-Y$ is represented as a additive composition of red and green or $R+G$ and where is luminance is black versus white $\frac{R+G+B}{3}$ there is a representation. So, this is if you note the that Y Cb Cr conversion where you consider on the linear part, you will find that this is somewhat following this principle because you can see this is red green blue.

So, Y part is representing particularly this luminance which is a weighted average of red green blue. Whereas, the Cb complementary blue part you can see it is representing this component it is blue from the blue you are subtracting addition of red and green. So, that is a complementary blue representation complement representation and Cr this part it is the red. So, red is , you are subtracting major component is green and also some amount of blue is also subtracting in this model.

So, we can see that Y CbCr model in fact that proposition also tends their motivated by this representation of opponent color processing and that is used heavily in various applications. So, this is what is our Cb' prime Cr' is presented to show $Cb-128$ and $Cr-128$ in this slide.

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So, now we will be discussing about another phenomena which is observed when we perceive color. It is the variation of intensities, our environmental illumination and how do you perceive colors. You can see when we take photographs or when we take images in varying illuminations the component red green blue they widely vary.

As you can see the super positions of those primary colors they reproduce you know different kinds of image colors in the images, though they are of the same scene. For example, in this case this image is taken by a flash light and this image image is taken by a tungsten lamp and you can see the differences. The interesting you know property is that as a human being we can adopt this illumination variation.

Even we can understand true red with largely varying illuminations, that means that does not have much effect on our color perception. But when you take the photographs there is a large variation of this red green blue component. So, we will see that how we can add these phenomena while processing and how actually it affects our understanding of color when we do the processing. So, this is the some of that lighting conditions of the scene have a large effect on the colors recorded.

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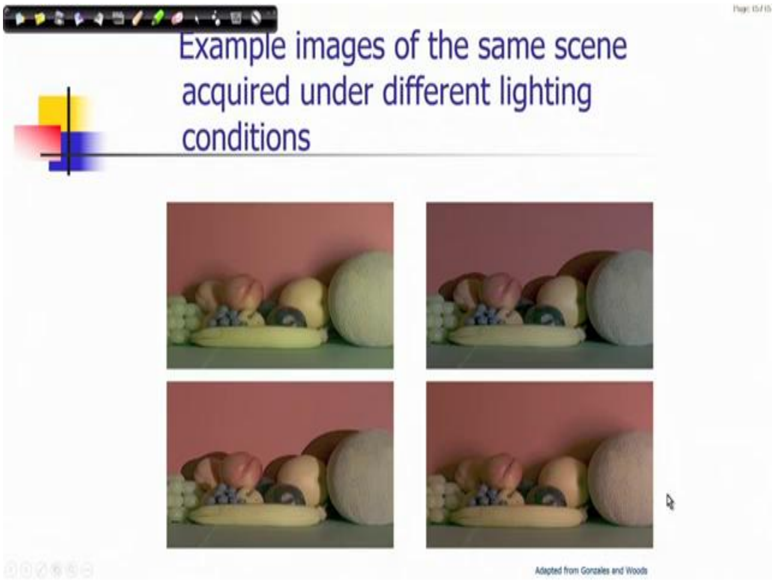

This is another example that same scene has been captured in different illuminations different lighting conditions. But, when you record this intensity values or record the red, green, blue components; there is white variation. But as a human being we do not see much difference we can adopt to these variations.

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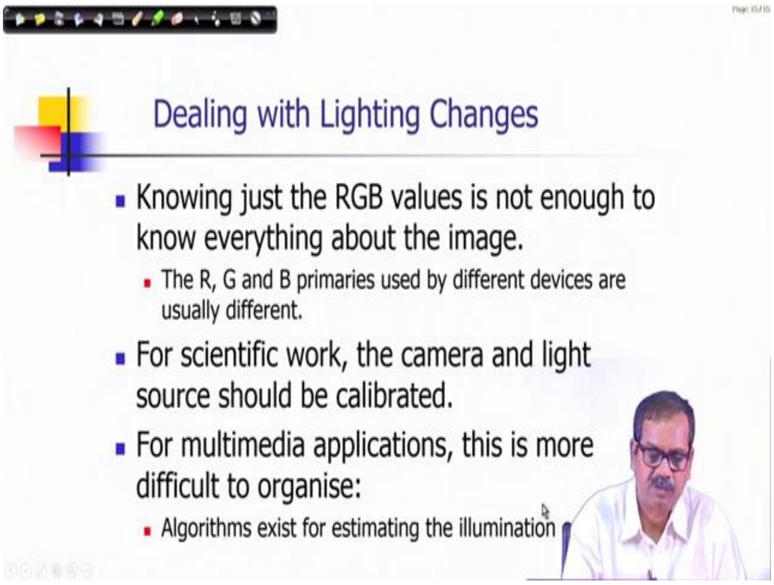

So, so that is what knowing just the RGB value is not enough to know everything about the image. That is a challenge when we interpret a color pixel. And the RGB primary is used by different devices are usually different that is one consideration. So, for scientific work we need to calibrate the camera and light source and for multimedia application this is more difficult to organize this factor has to be addressed there. So, there exist algorithms for estimating the illumination of colour.

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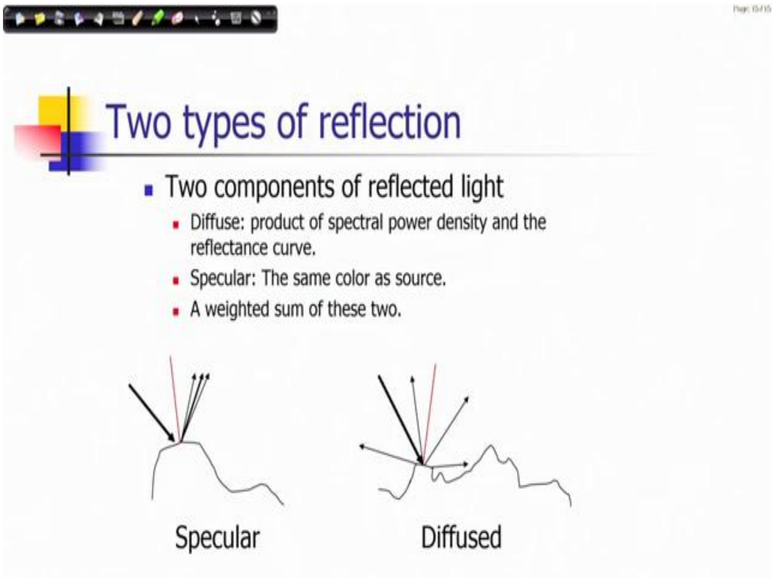

So, this phenomenon is of adaptation of human to perception of color same color or true color under varying illumination is called color constancy. So, when we tried to address this computation, we call that is a computation of color constancy. When we try to achieve this objective. now to understand the once again that you know how the colours are perceived or colours are produced. What are the components are there when we record the corresponding color signal now we have to consider two types of reflection that is occurring on the object surfaces.

So, there are two components of reflected light, one component is a diffuse component and which is the product of spectral power density and reflectance curve as we have discussed and the other component is a specular component and this specular component is just like a reflection by a shining surface. So, you get almost a same color of the illuminant, it is acting those surface points are acting like a mirror point. So, it is actually providing you the color of the illumination or color of the light sources itself.

So, when the same light falls on a surface of diffused surface you get the color of the surface, when the same light falls on a specular surface or get the specular reflection you get the color of illumination, color of the light source. So, there are the two different kinds of color we perceive from the same scene. So, in a diffuse reflection as you can see it has been shown that after reflection when the incident energy it is diffused, means it is reflected in all possible directions and this energy with equal energy in an ideal diffuse surface. And that amount of that energy reflected energy depends upon the angle of incidence in this case cosine of the angle of incidence it means proportional to that.

Whereas specular reflection its like a mirror light reflection. So, the reflected energy goes to a particular direction and if your senses are in those directions it will get those you know reflected energy. It is very narrow directions through with this specular reflection takes place almost following like a Newton law of reflection like a mirror reflections. So, when we perceive when we record color, record the intensity values or received energy at a point a weighted some of this two actually were recording.

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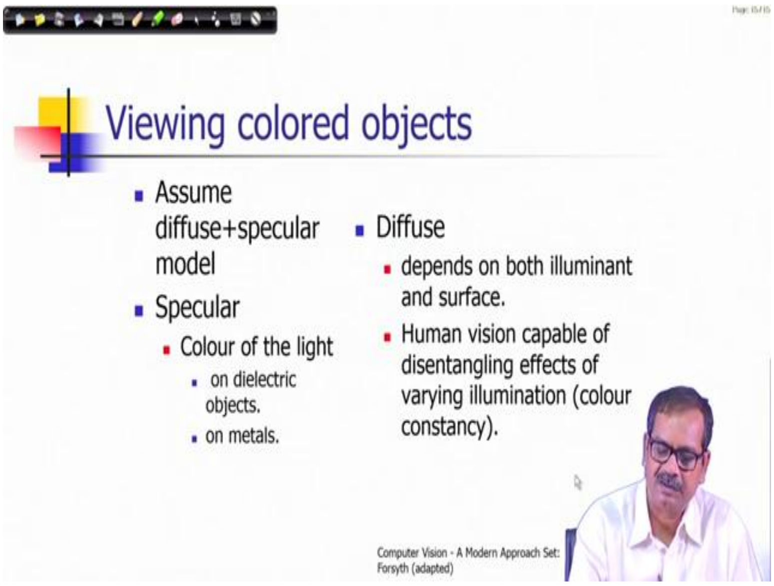

So, let us assume this module diffuse + specular model. So, as I mentioned it is a kind of summarization of the things what I described in the previous slides. So, far it is case specular reflection you perceive color of the light you record color the light on dielectric objects on metals you can get this kind of reflection. Whereas per diffuse reflection it depends on both illuminant and surface. it is the product of the intensity is received from the illuminant and also the reflectance property of the surface, reflection coefficient of the surface.

So, the fact what I stated also that human vision is capable of adjusting the perception of color in varying illumination and this particular phenomena is known as color constancy.

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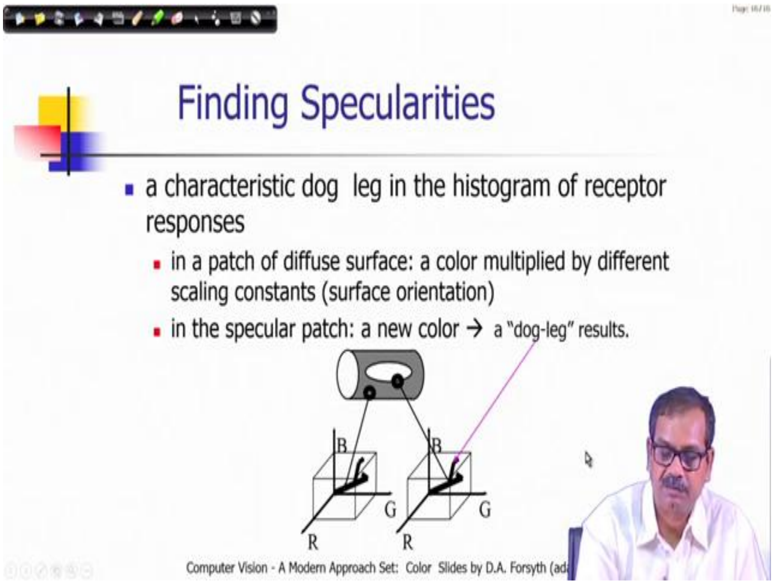

So, we would like to compute or we would like to represent the colors in in terms of illumination in variance representation of color. So, we will have to have this that is what is the color computation of color constancy. Now, we can observe if we plot the points this color points in a RGB space, we can observed a kind of structure a dog legged it is structure as a in the histogram of receptor responses.

So, in RGB space or if I just plot these points in the RGB space we will find out the histogram of receptor or dog legged structure in that plot itself. So, you can see here in this picture we are describing, the presentation of this colours. considered a diffuse surface and so all colours produced by this. diffuse surface. So, this is a diffuse surface all colours they would be more or less of having the similar hue and saturations. So, their color vector would be similar, but only they could be scaled by intensities amount.

So, they will have a in the RGB space, they will have representation of a particular directions, they lie on a linear segment again connecting the origin. But on top of that if there is a shiny surface that is a specular reflection, then this colours will be related to the color of the illuminate. it will give directions along this particular surface and since it is a super position. So, you will get shifted.

So, you will find another directions for some values we will find another points. In the space on top of that and this structure is a kind of dog legged structure. So, we observe this particular structure when you plot this color in a RGB space. So, this is what in a patch of diffused surface, a color multiplied by different scaling constants that we get and the specular patch, a new color and as a result you get this dog legged in this diagram.

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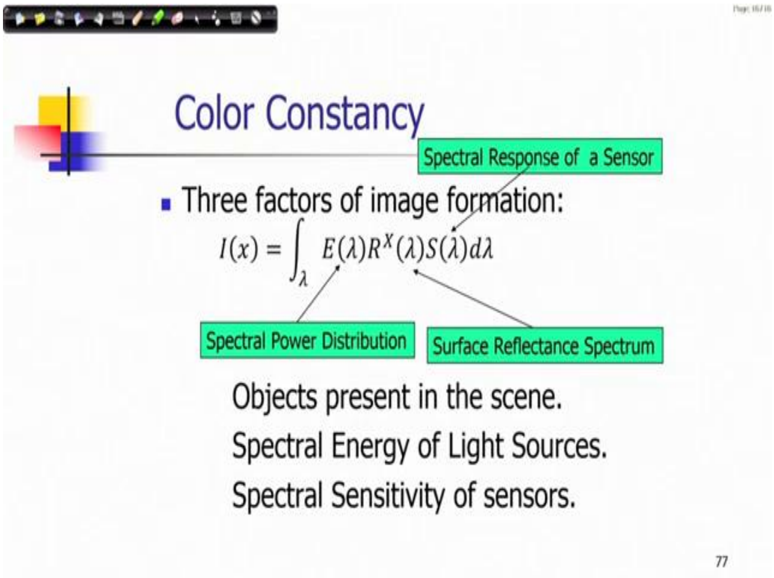

So, now we discuss about computation of color constancy. So, we see that there are three factors of image formations or for producing the sensory information from the surface from the energies of the environment which is reflected from a surface point. So, these factors are: what are the objects present in the scene, then the spectral energy of light source, that is a spectral power distribution and then spectral sensitivity sensitivity of sensors.

So, we can represent this particular thing as you can see that $E(\lambda)$ is representing the distribution spectral power distribution where as $R^X(\lambda)$ is showing you the surface point object point x and that is a surface reflectance spectrum and $S(\lambda)$ is the spectral response of a sensor. So, it is the accumulated response over all the wavelengths over the spectrum that that would be the output from this particular sensor and that is what is expressed as $I(x)$ So, if there are three different sensors are having three different types of spectral responses you will have three such components. $I(x) = \int_{\lambda} E(\lambda) R^X(\lambda) s(\lambda) d\lambda$

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So, that is of the color is represented, it is a same scene captured under different illumination and the problem of color constancy is that : can we transfer colours from one illumination to another.?

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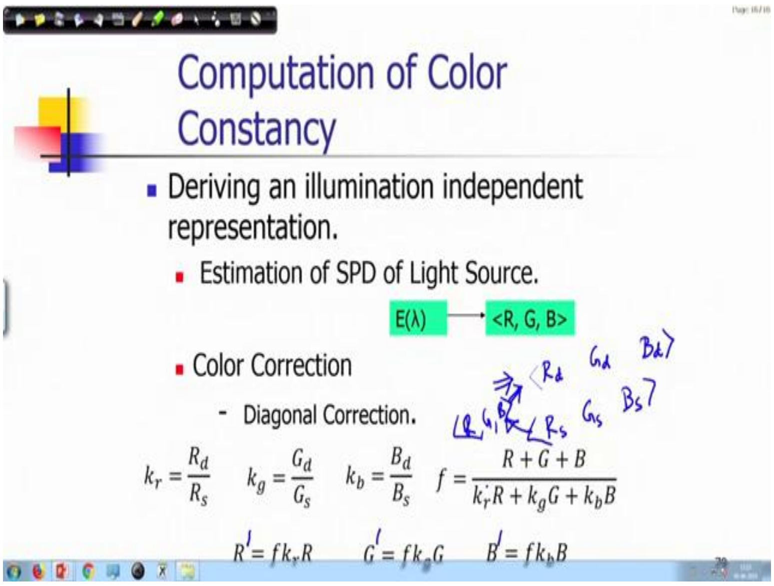

So, this is the problem statement that we need to derive an illumination independent representation of color. And for that what is required? we required to estimate the spectral power density of light source that is the first thing and Then normalize the colors what you get in your as a response of sensors. you should normalize this colours with respect to the spectral power density (SPD) of the light sources.

So, the factor which will be doing that normalization that task is known as color correction and for estimation of spectral power density you need to compute the three vectorial representation of the color of the illuminant. So, there are one method is known as diagonal correction and so this diagonal correction is given in this form. If suppose you have a target color in the color invariant representation, you would like to transfer all the colors as if they are illuminated by this illuminator which has the color equivalent of representation of $R_d G_d B_d$

And, the actual color of the illuminator in the scene or color of the light is given by $R_s G_s B_s$. So, any color what you get say RGB any pixel which is obtained due to illumination how you can transfer you can modify it. So, that same color would be obtained from the illumination of this color vector. So, that is the correction you are going to do.

$$f = \frac{R+G+B}{k_r R + k_g G + k_b B} \quad k_r = \frac{R_d}{R_s} \quad k_g = \frac{G_d}{G_s} \quad k_b = \frac{B_d}{B_s}$$

So, first you find out the proportional factor of these spectral components of or primary components of this color vectors of target illuminator and source illuminator also you compute this factor f it is trying to normalize the intensity values. So, that you can have the same intensity value even after modifying and then your updated color value should be this. So, I should write here updated value.

$$R' = fk_r R \quad G' = fk_g G \quad B' = fk_b B$$

Let me put it R' that is the updated one which is $fk_r R$ then $G' = fk_g G$ and $B' = fk_b B$. So, this is how you can perform this kind of color correction. So, let me take a break here and we will continue this discussion in the next lecture.

Thank you very much for your listening.