HW3

Name: Xujia Qin

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1. Consider the situation where you want to put a camera in a car, looking towards the front of the car. A car is roughly 2.5m wide. You have a camera with a 1cm wide sensor with 2000 horizontal pixels.

A. If you want the car to be at least 50 pixels wide at 100m, what does your focal length need to be? Give the answer in mm. Be sure to identify which equation is relevant to the question before starting.

   car width / distance = image width on the sensor / focal length

   pixel pitch = (10mm / 2000 pixels) = 0.005mm / pixel

   image width on sensor = 50 pixels * pixel pitch = 0.25mm

   2.5m / 100m = 0.25mm / focal length

   Focal length = 10mm

B. How many pixels would a car be in the image at 12.5m with the same focal length?

   car width / distance = image width on the sensor / focal length

   2.5m / 12.5m = pixel pitch * pixels / 10mm

   Suppose pixel pitch remains the same,

   Then pixels = 2 / (0.005mm / pixel) = 400 pixels.

C. Given a 10mm lens, do you need to make any adjustments for the scene to be in focus from 20-100m? (Clarification: you might need to make an adjustment if the change is bigger than 1 in 100.) Identify which equation is relevant to the problem before answering.

   According to the thin lens law:

   1/f = 1/d(in) + 1/d(out)

basically, we want to check when the d(out) changes from 20-100m, if the change of d(in) will be within 1%?

When d(out) = 100m, 1/d(in) = 1/f - 1/d(out) = 1 / 10 – 1 / 100000 = 10.001mm;

When d(out) = 20m, 1/d(in) = 1/f - 1/d(out) = 1 / 10 – 1 / 200000 = 10.005mm;

Changes in d(in) = 10.005mm – 10.001mm = 0.004mm

Percentage change = 0.004mm / 10.001mm = 0.04% < 1%

Therefore, no adjustments are needed to keep the scene in focus from 20–100 m.

2. Do an internet search to find information about the response distributions for human rods and cones.

A. What percentage of our cones are sensitive to long wavelength (red), medium wavelength (green), and short wavelength (blue)?

   The human eye has a higher proportion of green-sensitive cones (around 32%) compared to red-sensitive cones (64%) and blue-sensitive cones (2-4%).

B. When you look at the response curves for the red, green, and blue cones, how would you describe the differences between the three?

   The response curves for red, green, and blue cones vary in their peak sensitivities (red ~575 nm, green ~535 nm, blue ~445 nm) and the extent of their spectral overlap. Green cones are highly sensitive and play a key role in brightness perception, whereas blue cones, with their narrower range and lower sensitivity, are specialized for detecting short-wavelength light, whereas red cones are for detecting long-wavelength light.

C. Given the information above, explain why the Bayer pattern on camera sensors has two green sensors for every one blue or red sensor.

   Because the human eye is more sensitive to green light, which contributes most to brightness. This design ensures sharper, more natural-looking images that align with human vision.

   Source: http://hyperphysics.phy-astr.gsu.edu/hbase/vision/rodcone.html

3. Do some research on Bayer Patterns / Bayer Filter (the wikipedia site is pretty good).

   A. What are some issues that might arise because of the interpolation of colors to get RGB values at each pixel?

      Interpolation can cause issues like incorrect colors patterns, or blurry details, especially in areas with a lot of contrast or texture, because it averages neighboring pixel values, reducing the effective resolution of the image.

      It can also add noise or make colors look off because it guesses the missing color values based on nearby pixels.

   B. What is the benefit of saving RAW images and doing interpolation off the camera?

      Saving RAW images preserves the unprocessed sensor data by storing the direct output from the sensor without interpolation, compression, or in-camera adjustments, allowing for greater accuracy in post-processing.

   C. Why might you want to use Cyan-Magenta-Yellow (CMY) instead of RGB filters? How would you get RGB values?

      CMY filters are used because they block complementary colors (e.g., cyan blocks red) and allow better corresponding light sensitivity and color reproduction.

      To get RGB values from CMY, it uses the formula $R=1-C$, $G=1-M$, $B=1-Y$, scaling if needed for a 0–255 range.

4. Color Spaces

   A. When would it be important to use the CIE-Luv color space?

      For the cases where small color differences need to align with human perception, particularly for reflected light, where perceptual uniformity is crucial.

   B. For the YUV color space, the U channel is often called Blue - Yellow, and the V channel is often called Red - Cyan. Given the RGB to YUV conversion matrix, explain why U and V have those labels (you can find the matrix on Wikipedia or in my lecture notes).

      According to the equation from wiki:

PAL signals in Y′UV are computed from R'G'B' (only SECAM IV used linear RGB[9]) as follows:

$$Y' = W_R R' + W_G G' + W_B B' = 0.299R' + 0.587G' + 0.114B',$$
$$U = U_{\max}\frac{B' - Y'}{1 - W_B} \approx 0.492(B' - Y'),$$
$$V = V_{\max}\frac{R' - Y'}{1 - W_R} \approx 0.877(R' - Y').$$

The resulting ranges of Y′, U, and V respectively are [0, 1], [$-U_{max}$, U_{max}], and [$-V_{max}$, V_{max}].

Inverting the above transformation converts Y′UV to RGB:

$$R' = Y' + V\frac{1 - W_R}{V_{\max}} = Y' + \frac{V}{0.877} = Y' + 1.14V,$$
$$G' = Y' - U\frac{W_B(1 - W_B)}{U_{\max}W_G} - V\frac{W_R(1 - W_R)}{V_{\max}W_G}$$
$$= Y' - \frac{0.232U}{0.587} - \frac{0.341V}{0.587} = Y' - 0.395U - 0.581V,$$
$$B' = Y' + U\frac{1 - W_B}{U_{\max}} = Y' + \frac{U}{0.492} = Y' + 2.033U.$$

UV is chromaticity space, where U is represented as coefficient * (b – y), and v as coefficient * (r – y).

Why we need b – y && r – y? Since Y is a weighted sum of the RGB components (y = 0.299*r + 0.587 * g + 0.114 * b), when we subtract it from the R, we're isolating the amount of red in the color relative to the brightness, similarly for r – y.

C. Is there any connection between the UV definitions and the human visual system?

Yes

Y = 0.299*R + 0.587 * G + 0.114 * B which is the conversion to RGB:

UV reflects the human eye's sensitivity to colors. Green has the highest coefficient (0.587), meaning we are most sensitive to green, while blue has the lowest (0.114), meaning we are least sensitive to blue.