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Thesis Document/ Progress Report

LED module for Maka Niu

After meeting, I have identified three separate components of the project.

1. Geometry of the Light
2. Requirements of Light
3. Circuit Design

**Geometry of Light**

The desired geometry will heavily depend on the use interviews and input. In order to account for that I created a script in MATLAB to visualize different combinations of variables in order to see what the light covers.

The variables in the geometry are the following

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Considerations into the geometry include the ideal range of photography and the width of the lights from the camera. These both will depend on the use cases. The following figures display different combinations. The light projection of the LED is based on the Full Width Half. Minimum (FWHM) value. The beam of light is not as definitive as pictured. The distance between the lower and upper FWHM intersection points and the camera are calculated by



**In these figures, the blue outlines are the edge of the FWHM beam. The camera view is shown in-between the red lines.**

Without more user input there is no way to choose the optimal lighting situation. Additionally, different usages may contradict each other in terms of optimal lighting geometry. These must be taken into account when deciding the geometry.

**Requirements of Light**

In order to determine which LEDs to use and design the module the light necessary must be calculated. The light required will depend on many available such as time of day, depth, and distance. To accommodate these changes another MATLAB Script was written to determine the minimum light for various distance.

The minimum light required for a camera is dependent on make and model. To begin we look at the responsivity of the cameras sensor module. Transforming that information into a light requirement per pixel allows for the calculation of light needed at the object of interest to begin.

Factors that affect the light requirement that will be variable

•Distance of the Object ( (assuming it is directly in front of camera)

•Distance of the lights from camera ( *x* )

•Light attenuation Coefficient ( *Kd* )

•Emissivity of the Object ( )

•The Led Projection angle ( )

Factors that affect the light requirement that are constant

•Active Pixel Count (3280 x 2464)

•Camera Lens Angle (62.2 degrees) ()

•Absolute Sensitivity Threshold (\*NEED THIS\*)

•Shutter Speed

•Pixel Size

Starting with the absolute sensitivity threshold we can calculate the total lumens needed for any given factor by the following steps. I created a MATLAB script that follows these calculation and results in the lumens required for the light.

1. \*Translate the Absolute Sensitivity Threshold into a useable Unit\* Preferably into the Lumens needed per pixel using the Shutter Speed, Pixel Size, and Absolute Sensitivity Threshold.
2. Using the Lumens needed for pixel account for the attenuation of light from the object to the lens. Where is the attenuation coefficient and the is the distance to the object from the light
3. Accounting for the emissivity of object, calculate the lumens needed per pixel.
4. Calculate the Lux at the object using the projection of a single pixel at the distance to the object. Assuming that the pixels cover a square distance, calculating the distance of the arc at the objects’ distance and dividing it by active pixels in that direction gives us the projected area.
5. With the lux at object needed known, we can back track using the surface area of the cone of light provided by the LED. To calculate we must know the distance from the light to the object.
6. To calculate the surface area of the light provided by the LED at the distance we must calculate the Solid angle.

Using a unit sphere so R = 1, the solid angle equation reduces to

1. To calculate the total lumens at the given distance we can use the Surface area of the light (the spherical cap) at the distance and the needed lux.
2. Accounting for the light attenuation from the LED to the object we are left with the total lumens needed from the light.

This calculation should give us an idea of the lowest number of lumens needed to be produced by the LED given the situation.

Some Key Assumptions made

•Light is evenly distributed within the FWHM

•Attenuation equation works for Lumens

•Pixels cover equal area

•Only use the active pixels

•The object is directly in front of camera

To begin the calculations to determine lumens the amount of light per pixel is necessary. There are many ways or estimating/ determining this number, the below steps show the method in which I estimated it. The data sheet is not complete, so researching similar cameras I was able to come up with an estimate for many necessary components. A detailed study was conducted with the use of the IMX249 sensor (<https://www.flir.com/discover/iis/machine-vision/how-to-evaluate-camera-sensitivity/>) The IMX249 has some key differences from the Raspberry Pi Camera’s IMX219, but it provides useful details. They differ on pixel size, shutter speed, and total active pixels, but use the same CMOS board and should have similar sensitivity.

The IMX249 absolute sensitivity threshold, meaning the signal is equal to the noise of the sensor is at a light density of 1[ . Additionally, the saturation light density for the IMX249 is 1200 [ . The IMX249 has a pixel area size 30 times of that of the IMX219. This results in the IM219 absolute sensitivity threshold to be approximately 30 [.

The energy of the photons were estimated using blue light, the most prominent light in the water. Where is the wavelength of blue light, h is planks constant, and c is the speed of light.

Using the steps listed above to reach the absolute minimum threshold, 39 lumen are required at an object distance of 2 meters with a light FWHM angle of 30. This only reaches the lowest boundary of visibility. For a quality photo I estimate we will want 1/3 of the saturation lighting which puts are light density at approximately 1200 [. Using the MATLAB script based off the methodology above this lighting density requires 1550 lumens between the two LED modules.

<https://www.flir.com/discover/iis/machine-vision/how-to-evaluate-camera-sensitivity/>

-all the absolute sensitivity stuff

<https://aggressivegarden.com/ppfd/>

<https://www.lumigrow.com/learning-center/blogs/par-ppf-ppfd-dli-ppe/>

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imx 219

<https://photo.stackexchange.com/questions/21776/what-is-the-lowest-level-of-luminous-flux-a-camera-can-detect>

<https://photography.tutsplus.com/articles/a-guide-to-using-consumer-led-bulbs-for-photography-and-video--cms-22708>

<https://www.dormgrow.com/par/>

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<https://support.pixelink.com/support/solutions/articles/3000034837-how-to-interpret-digital-camera-parameters>

<https://www.nde-ed.org/EducationResources/CommunityCollege/Radiography/Physics/attenuationCoef.htm>

<https://www.esf.edu/efb/schulz/Limnology/Light.html>

<https://www.lumenera.com/blog/understanding-camera-sensitivity-a-look-at-the-numbers>

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<https://www.ledsupply.com/leds/cree-xlamp-xm-l2-leds?gclid=CjwKCAjw9vn4BRBaEiwAh0muDIgXzSZ8uIiwv8MGID8M_GXzRxrjX149hkezV1Zndyf2tEIbTEkI-RoCdfIQAvD_BwE>