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Measurements

Report

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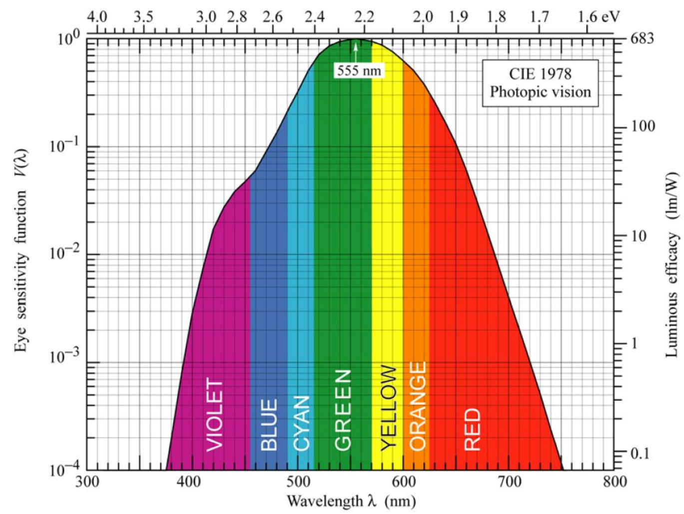
1.Introduction

1.1 Human Eye Sensitivity and Photometric Quantities

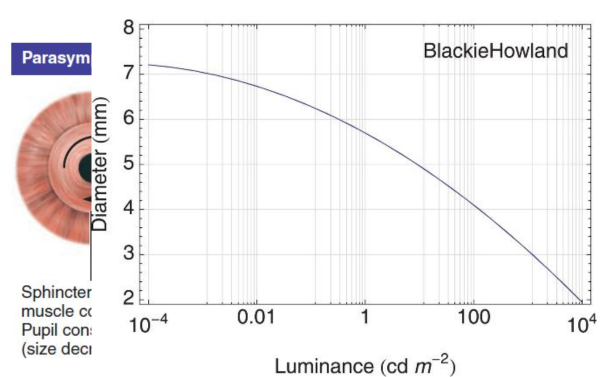
The inside of the eyeball is clad by the retina, which is the light-sensitive part of the eye. There are three different vision regimes for the eye. ***Photopic vision*** relates to human vision at high ambient light levels (e.g. during daylight conditions) when vision is mediated by the cones. ***Scotopic vision*** relates to human vision at low ambient light levels (e.g. at night) when vision is mediated by rods. Rods have a much higher sensitivity than the cones. However, the sense of color is essentially lost in the scotopic vision regime. At low light levels such as in a moonless night, objects lose their colors and only appear to have different gray levels. ***Mesopic vision*** relates to light levels between the photopic and scotopic vision regime.



The ***luminous flux***, which is a photometric quantity, represents the light power of a source as perceived by the human eye. The ***illuminance*** is the luminous flux incident per unit area. The illuminance measured in ***lux*** (lux = lm/m2). Illuminance is *subjective*, in the sense that lux values are adjusted according to the spectral sensitivity of the human eye. In other words, when calculating illuminance, 1 W/m^2 of red light doesn't equal 1 W/m^2 of green light, because the human eye is more sensitive to green. Thus, illuminance is designed to convey information about *how well a human being could see* under certain lighting conditions.

1.2 The Iris

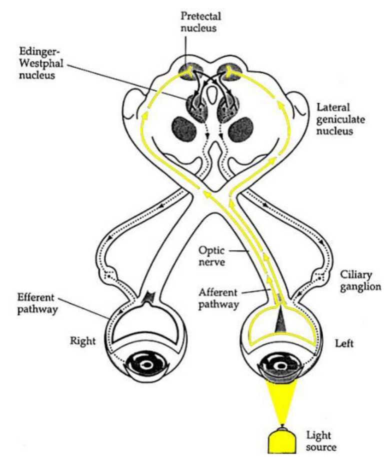
The iris, the colored part of the eye, is the most anterior portion of the vascular layer. Shaped like a flattened doughnut, it lies between the cornea and the lens and is continuous with the ciliary body posteriorly. Its round central opening, the pupil, allows light to enter the eye. The iris is made up of two smooth muscle layers with bunches of sticky elastic fibers that congeal into a random pattern before birth. Its muscle fibers allow it to act as a reflexively activated diaphragm to vary pupil size.



In close vision and bright light, the sphincter pupillae (circular muscles) contracts and the pupil constricts. In distant vision and dim light, the dilator pupillae (radial muscles) contracts and the pupil dilates, allowing more light to enter. Sympathetic fibers control pupillary dilation, and parasympathetic fibers control constriction. The pupillary light reflex (PLR) or photopupillary reflex is a reflex that controls the diameter of the pupil, in response to the intensity (luminance) of light that falls on the retinal ganglion cells of the retina in the back of the eye, thereby assisting in adaptation to various levels of lightness/darkness.

Pupillary reflex should have been named iris reflex, because iris is the actual muscular structure that responds to light and pupil is merely the passive opening formed by the active iris. Pupillary reflex is synonymous with pupillary response, which may be pupillary constriction or dilation.

The pupillary light reflex two main parts: **an afferent limb and an efferent limb**. **Afferent Pathway of Pupillary Light Reflex** (solid yellow in pic):



- Light enters the **pupil** and stimulates the **retina**.
- Retinal ganglion cells transmit the light signal to the **optic nerve**
- The optic nerve enters the **optic chiasm** where the nasal retinal fibers cross to contralateral **optic tract**. while the temporal retinal fibers stay in the ipsilateral optic tract
- Fibers from the optic tracts project and synapse in the **pretectal nuclei** in the dorsal midbrain in the collicular region
- The pretectal nuclei project fibers to the ipsilateral **Edinger-Westphal nuclei** and also to the contralateral Edinger-Westphal nucleus via the posterior commissure.

Efferent Pathway of Pupillary Light Reflex (black dotted above):

- The Edinger-Westphal nucleus projects pre-ganglionic parasympathetic fibers, which exit the midbrain and travel along the **oculomotor nerve** (CN III) and then synapse on post-ganglionic parasympathetic fibers in the **ciliary ganglion**
- Ciliary ganglion post-ganglionic parasympathetic fibers (short ciliary nerves) innervate the sphincter muscle of the pupils resulting in pupillary constriction.

The below picture from Wikipidea gives a mathematical model that represents the pupil.

Mathematical model [edit]

Pupillary light reflex is modeled as a physiologically-based non-linear delay differential equation that describes the changes in the pupil diameter as a function of the environment lighting:[13]

$$M(D) = \tanh^{-1}\left(\frac{D - 4.9}{3}\right)$$

$$\frac{\mathrm{d}M}{\mathrm{d}D}\frac{\mathrm{d}D}{\mathrm{d}t} + 2.3026\tanh^{-1}\left(\frac{D-4.9}{3}\right) = 5.2 - 0.45\ln\left(\frac{\Phi[t-\tau]}{4.8118\times 10^{-10}}\right)$$

where D is the pupil diameter measured in millimeters and $\Phi(t - \tau)$ is the luminous intensity reaching the retina in a time t, which can be described as $\Phi = IA$: luminance reaching the eye in lumens/mm^2 times the pupil area in mm^2. τ is the pupillary latency, a time delay between the instant in which the light pulse reaches the retina and the beginning of iridal reaction due nerve transmission, neuro-muscular excitation and activation delays. $\mathrm{d}M$, $\mathrm{d}D$ and $\mathrm{d}t$ are the derivatives for the M function, pupil diameter D and time t.

Since the pupil constriction velocity is approximately 3 times faster than (re)dilation velocity,[14] different step sizes in the numerical solver simulation must be used:

$$\mathrm{d}t_c = \frac{T_c - T_p}{S}$$

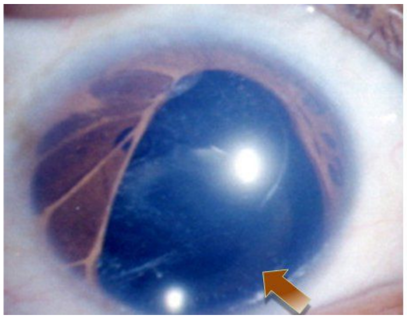
$$\mathrm{d}t_d = \frac{T_c - T_p}{3S}$$

where $\mathrm{d}t_c$ and $\mathrm{d}t_d$ are respectively the $\mathrm{d}t$ for constriction and dilation measured in milliseconds, T_c and T_p are respectively the current and previous simulation times (times since the simulation started) measured in milliseconds, S is a constant that affects the constriction/dilation velocity and varies among individuals. The higher the S value, the smaller the time step used in the simulation and, consequently, the smaller the pupil constriction/dilation velocity.

In order to improve the realism of the resulting simulations, the hippus effect can be approximated by adding small random variations to the environment light (in the range 0.05–0.3 Hz).[15]

1.3 Iris Abnormalities

Abnormalities of the iris can result from trauma, infection, neoplasm, or genetic reasons. Iris changes can reflect systemic as well as strictly ocular disease. Aniridia is the total or partial absence of the iris resulting in a large and/or distorted pupil (arrow). This means that your eye isn't able to adjust to differing levels of light. This image shows the absence of the inferior half and most of the anterior leaf of the upper half of the iris.



2. Task Idea

Our task idea is a model of an artificial iris for those with abnormalities in the iris that makes it unable to adjust to different light levels. In the model we represent the retina with the light sensor that measures intensity of light in lux and according to the values controls the dilation and constriction of the pupil. We are working on two levels of light intensity: dark and light. For each stage the pupil's diameter changes. We used an MPU6050 sensor to measure the angle of change in pupil diameter so as to control the degree of constriction and dilation.

Currently in the United States, there are no Food and Drug Administration (FDA)-approved artificial iris devices. However, one of these devices is part of a clinical trial in several locations around the country.

Currently, there are four manufacturers of artificial iris devices globally: Morcher (Stuttgart, Germany), Ophtec (Groningen, Netherlands), HumanOptics (Erlangen, Germany), and Reper (Nizhny Novgorod, Russia). The HumanOptics device is currently undergoing FDA trial.

3. Light Sensors

3.1 LDR Calibration

We calibrated the LDR sensor to get an equation that relates illuminance to resistance of LDR. We used the lux meter on a mobile phone to get the actual values of illuminance. We took 10 values of illuminance and LDR resistance by changing the intensity of light falling on both the sensor and lux meter. $Lux = 2.53 \cdot 10^{7} \cdot R^{-1.5839}$

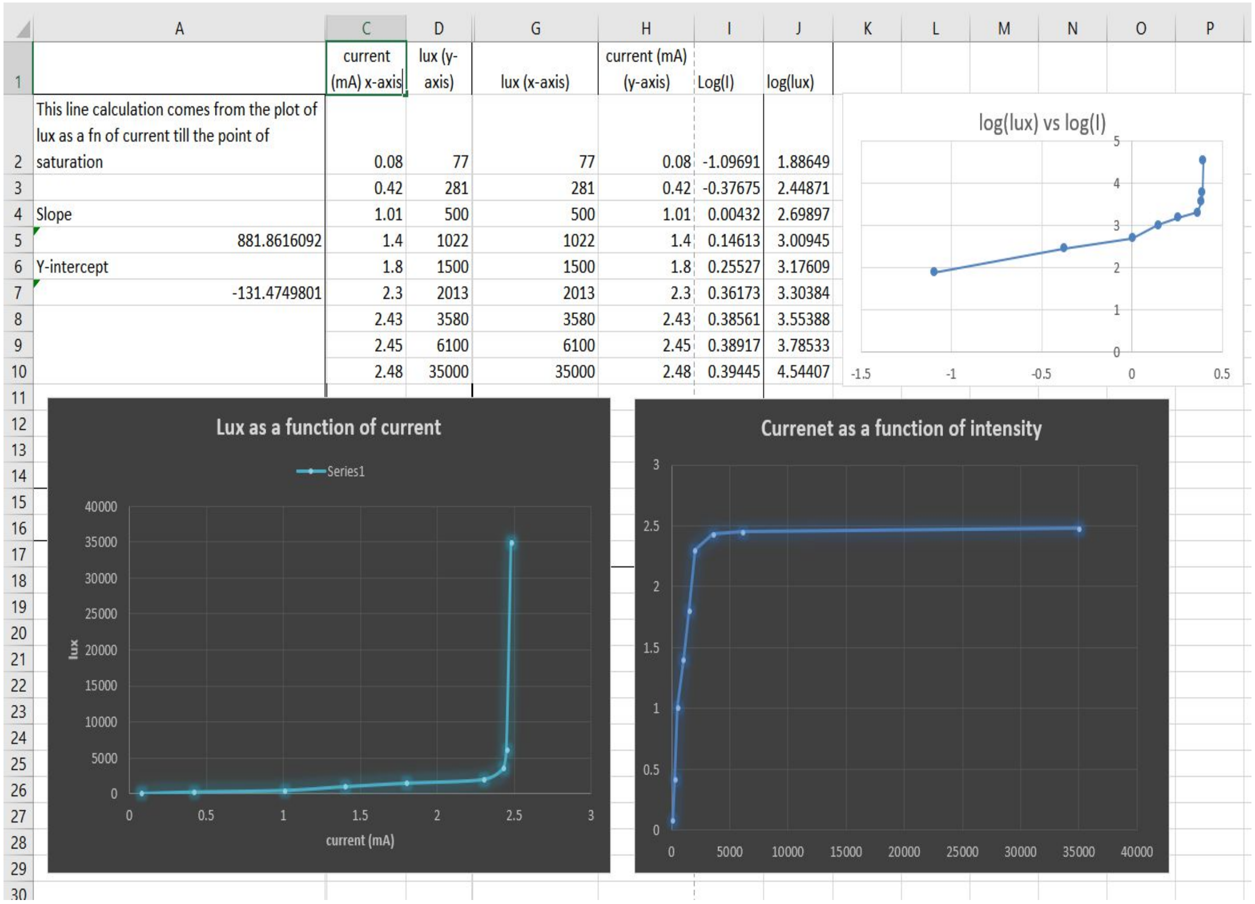
	LDR Resistance (Ω)	Illuminance (lux)	log(R)	log(lux)	(approximation formula is = A*R^B)	A	B
This line calculation comes from the plot of log(lux) as a fn of log(R)	815	650	2.911157609	2.812913357	619.7872023	25311597.33	-1.58393
	333	2200	2.522444234	3.342422681	2558.222568		
Slope	711	754	2.851869601	2.877371346	769.3975572		
-1.583932431	146	7860	2.164352856	3.895422546	9443.454069		
y-intercept	235	3670	2.371067862	3.564666064	4443.326938		
7.403319553	633	1088	2.80140371	3.036628895	924.8799487		
These coefficient calculations come from	1069	546	3.028977705	2.737192643	403.2956453		
solving the above line calcuation (log(lux) =	1580	261	3.198657087	2.416640507	217.2015184		
m*log(R) + b) for lux. Giving: lux = A*R^B	2004	170	3.301897717	2.230448921	149.0516111		
A = 10^(y-intercept)	25500	2	4.40654018	0.301029996	2.652513802		
25311597.33							
B = slope							
-1.583932431							
Resulting Illuminance Equation:							
lux = A * Resistance^B							

3.2 Phototransistor Calibration

Similar to the LDR except we measured the collector current while changing the intensity.

Response time is terrible and there is always a rapid influx of electron at the instant you start to point the light at it and then it slowly decreases till it reaches a steady state. And it operates in the range of lux up to 5000 lux then it operates in saturation region.

Therefore, the equation is only valid in the first region of the graph that is approximately linear. $Lux = 881.862 \cdot I(mA) - 131.475$



	A	C	D	G	H	I	J
1		current (mA) x-axis	lux (y-axis)	lux (x-axis)	current (mA) (y-axis)	Log(I)	log(lux)
2	This line calculation comes from the plot of lux as a fn of current till the point of saturation	0.08	77	77	0.08	-1.09691	1.88649
3		0.42	281	281	0.42	-0.37675	2.44871
4	Slope	1.01	500	500	1.01	0.00432	2.69897
5	881.8616092	1.4	1022	1022	1.4	0.14613	3.00945
6	Y-intercept	1.8	1500	1500	1.8	0.25527	3.17609
7	-131.4749801	2.3	2013	2013	2.3	0.36173	3.30384
8		2.43	3580	3580	2.43	0.38561	3.55388
9		2.45	6100	6100	2.45	0.38917	3.78533
10		2.48	35000	35000	2.48	0.39445	4.54407

3.3 IR Photodiode

Since its peak response is near the infrared and not the visible light region we didn't use it.

4. Results

4.1 Phototransistor

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X (lux)	113.81	96.15	96.15	113.81	96.15	113.81	96.15	113.81	113.81	113.81

Mean = 106.746 lux

Theoretical = 258 lux

Max precision = Max-mean = 7.064 lux

Min Precision = mean-Min = 10.596 lux

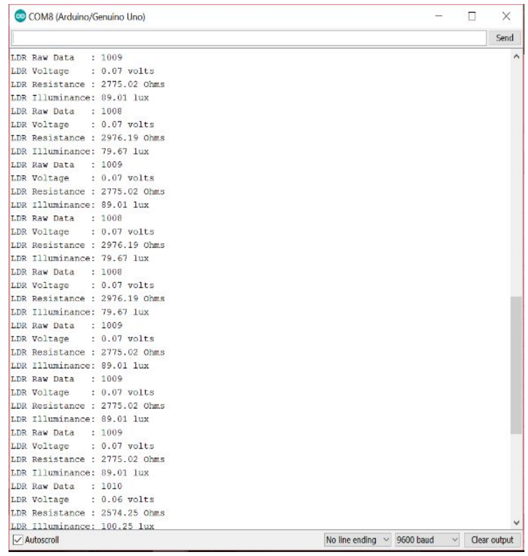
Precision = +7.064 & -10.596 lux

Absolute error = abs(theoretical -mean) = 151.254 lux

Relative error = absolute/theoretical = 58.6%

Relative accuracy = 1-relative error = 41.37%

4.2 LDR



Theoretical Illuminance = 106 lux

Mean = 87.332 lux

Max precision = Max – Mean = 12.918 lux

Min precision = Mean – Min = 7.662 lux

Precision = +12.918 & -7.662 lux

Absolute error = abs (mean -theoretical) = 18.668 lux

Relative error= absolute error/ theoretical = 17.6 %

Relative Accuracy = 1- relative error = 82.4%

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X (lux)	89.01	89.01	79.67	89.01	79.67	79.69	89.01	89.01	89.01	100.25
D= X - mean	1.678	1.678	-7.662	1.678	-7.662	-7.662	1.678	1.678	1.678	12.918
D^2	2.816	2.816	58.706	2.816	58.706	58.706	2.816	2.816	2.816	166.875

Standard Deviation = sqr(359.889/9) = 6.323 lux.

Using general uncertainty analysis, multiple measurement resultant experiment as we are calculating the intensity of light as a function of resistance that is measured and neglecting systematic error. The uncertainty can be calculated as the uncertainty due to random error only.

$$u_r^2 = \sum_{i=1}^{J} \theta_i{}^2 S_{B_i}^2 + 2\sum_{i=1}^{J-1} \sum_{j=i+1}^{J} \theta_i \theta_j S_{B_i,B_j} + \sum_{i=1}^{J} \theta_i{}^2 S_{P_i}^2 + 2\sum_{i=1}^{J-1} \sum_{j=i+1}^{J} \theta_i \theta_j S_{P_i,P_j},$$

Where

$$S_{P_i}^2 = \sum_{k=1}^{M_P} (S_{P_i})_k^2,$$

B relating to systematic and P relating to random. And since there is no dependency we can neglect the covariance term. And theta is the sensitivity coefficient from the equation used.

Therefore, ur = Ө * Sp , where Sp = Px is $P_{\bar{x}} = t_{\nu_{P_x},C} \cdot S_{P_{\bar{x}}} = t_{\nu_{P_x},C} \cdot S_{P_x}/\sqrt{N}.$

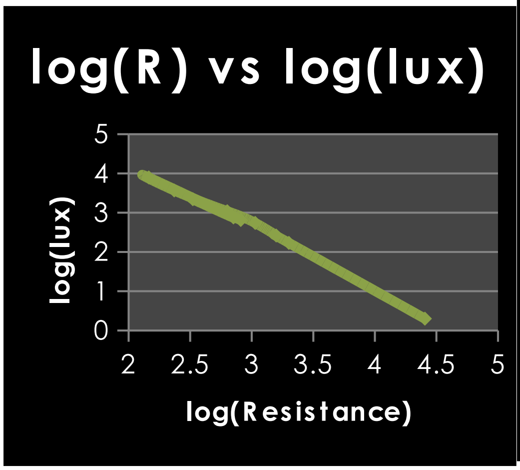
V= N – 1, N is number of measurements.

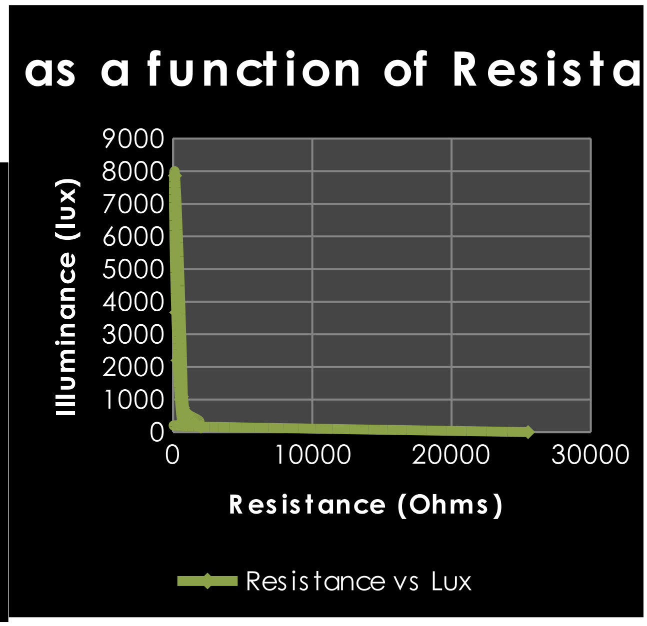
Equation used is: Lux = 25311597.33 * $R^{-1.58393}$

Therefore $\Theta = \frac{dLux}{dR} = \frac{25311597.33 \cdot -1.58393}{R^{2.584}}$, *where R is mean R value* = 2815.294

$\Theta = -0.0491$

Using a confidence level of 95%, t approximately = 2 as $V_{eff} > 9$



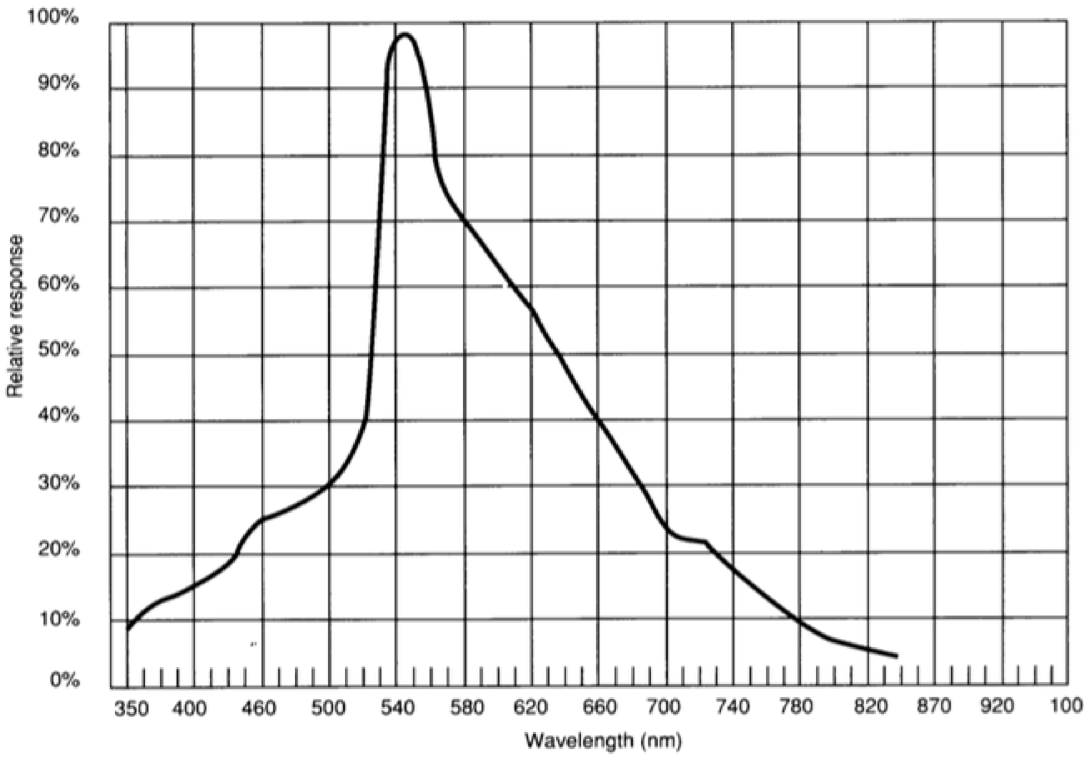


Therefore u_r = 0.3927 lux.

From graph we can say that sensitivity = -1.583932431 lux/ohm in dB scale.

5. Used sensor

The preferred sensor for our application is the LDR because its response mimics the response of the eye and its sensitivity to light the best. As shown in the figure.



Also, out of the sensors used the phototransistor's response time is very slow and its operation range is too small as it enters saturation at a relatively low level of lux when compared to that of the sun (can reach 100000 lux), the values also fluctuate too much. And the IR photodiode has a bad response to visible light and needs amplification circuit.

6.References

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