Solutions to light pollution based on Principles of spectroscopy and normal distribution

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Abstract. In order to study the main ways of light pollution and factors affecting light pollution, this paper first determines light pollution from the main source, namely lighting pollution, and lighting mainly refers to the light emitted by LED lamps. Therefore we come to study the light intensity of LED lamps to study light pollution. Secondly, we simplified the spectrum of LED lights into three chromatograms of red, yellow and blue, and we gradually reduced the proportion of blue light in our study to observe the intensity changes of the chromatograms. Next, we investigated the relationship between the stars visible to the naked eye and the light intensity of the illumination, and the technical indicators of sky pollution were translated into stars visible to the naked eye to further determine the intensity of light pollution. Finally, we carried out a sensitivity analysis of the model and the results showed that the model is more adaptable and easier to generalise.

Keywords: Light pollution, Solutions, Gaussisk fordeling, Spektroskopiske modeller.

1. Introduction

Light pollution was first introduced by the international astronomical community in the 1930s as a new source of environmental pollution. With the development of society, light pollution, including light trespass, over-illumination, and light clutter, is becoming more and more serious, which has a significant impact on our lives.

Light pollution has a great impact on human beings, it is very harmful to human eyes and brain nerves, living in a light pollution environment may lead to anxiety, increase stress, and even cause headaches and fatigue. The reflection of light on the exterior of a building can lead to intense local warming and even to traffic accidents. At the same time it will have a great impact on the normal life of plants and animals, the life pattern of plants and animals by the deployment of day and night, the occurrence of light pollution will disrupt their biological clock, or even make them day and night, seriously affecting the growth of plants, migration and hibernation of animals.

As a result, many measures have been taken in various places to control light pollution. However, with the rapid economic development and the spread of modernization, it is important to consider the population and environmental factors to combat light pollution without affecting people's normal life. Therefore, the strategy of light pollution control should be professionally evaluated to minimize the impact and find the best value between urban development and pollution reduction.

In this paper, we adopt a new strategy that differs from the traditional treatment methods to give an optimized solution for light pollution treatment at the spectral level.Most of the traditional light pollution quantification focuses on the brightness and illuminance level, without considering the influence of chromatic indexes of light sources on the light pollution degree.We combine the physical quantities of light sources, including luminous flux, xxx, and so on, and perform a normal fit analysis of light sources at the spectral level, and combine the physical quantity of "number of stars visible to the naked eye" to transition the model to different regions.The model can be dynamically adjusted according to the different parameters of different regions, and finally gives an optimal solution for the region from the spectral level.

2. Materials and Methods

2.1. Data Sources and Analysis

In this paper, the Light pollution problem in the Interdisciplinary Contest In Modeling of 2023 (https://www.contest.comap.com/undergraduate/contests/) is analyzed and studied. We studied light pollution by using the 2015 World Map from the Light Pollution Map and the 2016 VIIRS. And on the basis of the existing research results, using the results of 39 building facade light sources measured by Wang Hongbing et al., quantitative analysis of light pollution is carried out by using spectroscopy and normal distribution principle. The results show that the intensity of red, blue and yellow light decreases with the increase of blue proportional coefficient.

2.2. Method introduction

2.2.1. LED light source

LED light source is the light-emitting diode (LED) for the light source. LED is made of several layers of very thin adulterated semiconductor material, a layer with excess electrons, another layer due to the lack of electrons and the formation of positively charged "holes", when there is a current through, electrons and holes combined with each other and release energy, thereby radiating light [1].

The main source of light pollution is led lighting, the study of the led spectrum is an important part of quantifying light pollution. Because the wavelength of led light is in the range of 380-780 nm, while the wavelength of visible light is in the range of 360-830 nm, the wavelengths of led light are all in the range of visible light. [2] This is shown in Figure 1.

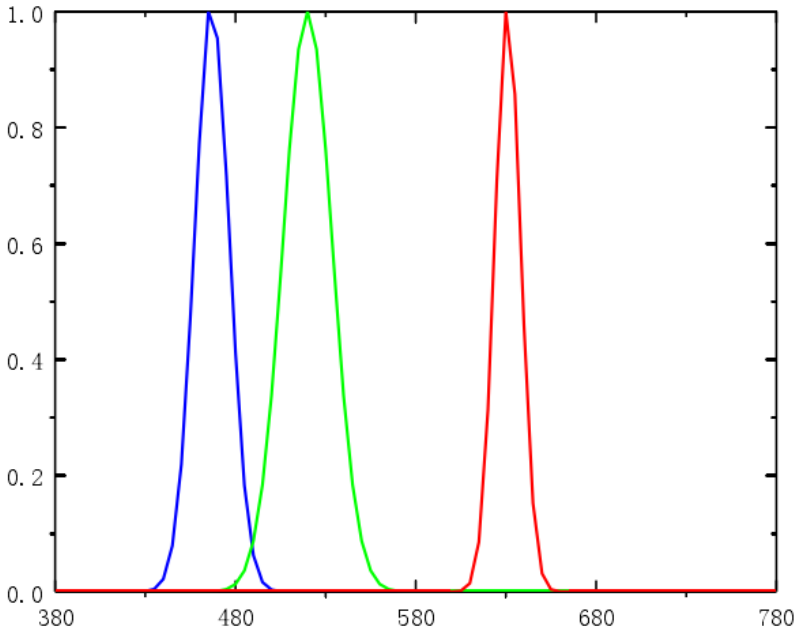


Figure 1. Spectral diagram of led light sources

3. Establishment and solution of the model

3.1. Spectral analysis models

3.1.1. Physical quantities related to light source

Luminous flux is the physical quantity used to express the light power in lumen, abbreviated as 1m. 1 unit lumen refers to the light energy emitted by the light source or absorbed by the irradiated body in 1 unit of time. In other words, the luminous flux refers to the portion of the radiated power that can be perceived by the human eye and is equal to the integral of the radiated energy of a

wavelength of the light source per unit time as a function of the spectral optical efficiency of that wavelength.[3]

The luminous flux expression is:

$$\Phi = K \bullet \int_0^\infty \frac{d\Phi(\lambda)}{d\lambda} \bullet \nu(\lambda) d\lambda \tag{1}$$

K represents the number of degrees of light or the ability to perceive light, for the human eye k=683.002lm/w. represents the wavelength λ, the wavelength of light visible to the human eye is partially between 380nm~780nm, and the sensitivity is different for different wavelength positions.[4]

The brightness fork of the light source is called the luminance, the symbol is B, the unit is nits or candela per square meter(cd/m^2).This represents the actual perception of the intensity of light from a luminous body or reflector by the human eye.Daily displays, lamps, etc. can be characterized by the size of this unit, such as the brightness of a computer screen is about 300 cd/m^2, he brightness of a home TV is about is 500 cd/m^2. It is worth noting that brightness is independent of distance. [5] The formula for calculating luminance is:

$$L = \frac{d\Phi}{d\Omega \bullet ds\cos(\theta)} \tag{2}$$

In the formula, the luminous flux, for the stereo angle, for a given direction and the angle of the direction normal to the unit area yuan ds

Illuminance refers to the amount of luminous flux received per unit area and can be measured by an illuminance meter in lux , 1 lux is equal to 1 lumen/m^2. The size of the illuminance depends on the luminous intensity and the distance between the light source and the illuminated body. [6] When the luminous intensity of the light source is certain, the further the distance between the surface of the illuminated body and the light source, the smaller the illuminance of the illuminated body.

The smaller the illuminance is. The distance between the object and the light source and the surface illuminance follows the "inverse square" relationship, the distance becomes n times the original water distance, the surface illuminance becomes the original 1/n^2.

The CIE1931 chromaticity coordinate of a light source with a spectral power distribution of P(λ) is calculated as

$$\begin{aligned} x &= \int_{580}^{780} p(\lambda)\bar{x}(\lambda)d(\lambda) \Big/ \left(\int_{580}^{780} p(\lambda)\bar{x}(\lambda)d\lambda + \int_{580}^{780} p(\lambda)\bar{y}(\lambda)d\lambda + \int_{580}^{780} p(\lambda)\bar{z}(\lambda)d\lambda \right) \\ y &= \int_{580}^{780} p(\lambda)\bar{y}(\lambda)d(\lambda) \Big/ \left(\int_{580}^{780} p(\lambda)\bar{x}(\lambda)d\lambda + \int_{580}^{780} p(\lambda)\bar{y}(\lambda)d\lambda + \int_{580}^{780} p(\lambda)\bar{z}(\lambda)d\lambda \right) \end{aligned} \tag{3}$$

Where P(λ) is the spectral power distribution of the light source, $\bar{x}(\lambda), \bar{y}(\lambda)$, and $\bar{z}(\lambda)$are the above isochromatic functions.

According to the mixing theory, if the relative spectral power distribution of several monochromatic light sources are $s_1(\lambda), s_2(\lambda), \ldots,$ and $s_n(\lambda)$,and their corresponding mixing ratios are $k_1, k_2 \ldots k_n$, the mixed light source spectrum is $s(\lambda)$

$$s(\lambda)=k_1 s_1(\lambda)+k_2 s_2(\lambda)+...+k_n s_n(\lambda) \tag{4}$$

Gaussian model, Lorentzian model, and Double s model are commonly used in colorimetry to describe/fit the shape of single-peak spectra.

Gaussian equation model equation is

$$S(\lambda)=e^{-4\ln 2(\frac{\lambda-\lambda_0}{\Delta\lambda})^2} \quad (5)$$

Where λ_0 represents the peak wavelength position and $\Delta\lambda$ is the half-height full width.

The Lorentz model equation is

$$S(\lambda)=\frac{1}{\pi\cdot\Delta\gamma[1+(\frac{\lambda-\lambda_0}{\Delta\gamma})^2]}=\frac{1}{\pi}\left[\frac{\Delta\gamma}{(\lambda-\lambda_0)^2+\Delta\gamma^2}\right] \quad (6)$$

Where $\lambda_0$represents the peak wavelength position and $\Delta\gamma$ is the half height and half width.

The Lorentz function and the function intersected at s(λ)=0.5 for the single-peak spectrum fitted with a Feng wavelength of 500nm and a half-width of 30nm, proving that both of them can describe the spectral shape better. The Gaussian function is often used to fit the luminous spectrum of LEDs in practical operations, and the method will be used in this study.[7]

3.1.2. Spectral distribution on the building facade

Here we say the building facade, we analyze the source of light pollution for city lighting, city lighting for LED lights. The spectrum of LED lamp mainly consists of red, yellow and blue spectra. The three lights are mixed in different proportions to form the colorful lights. According to the action spectrum of the light pollution ring around high-rise buildings, combined with the light source information mainly used in the light pollution environment, the action spectrum curve and the measured spectrum of the light source spectrum and other information, the light pollution degree of the light source spectrum can be accurately quantified and visually expressed. [8] This is shown in Figure 2.

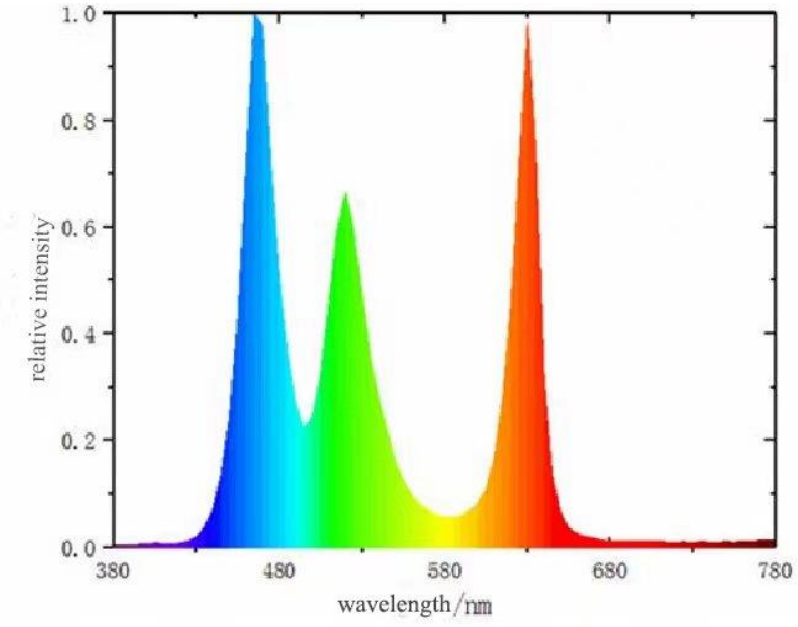


Figure 2. Relative spectral power distribution and chromaticity coordinates of red, green and blue monochromatic LEDs on building façades

3.1.3. Fitting Gaussian distributions to spectra

By analysing the spectral distribution of the led, we find that its shape roughly follows a Gaussian or Lorentzian distribution. The Gaussian distribution function and the Lorentz distribution function were used to fit the spectral shape of a unimodal light source, respectively, and it was found that a better fit could be obtained using the Gaussian distribution. Therefore, we chose to fit the spectral distribution to a Gaussian distribution to obtain the relative intensity of LED light in different wavelength ranges. [9] This is shown in Figure 3.

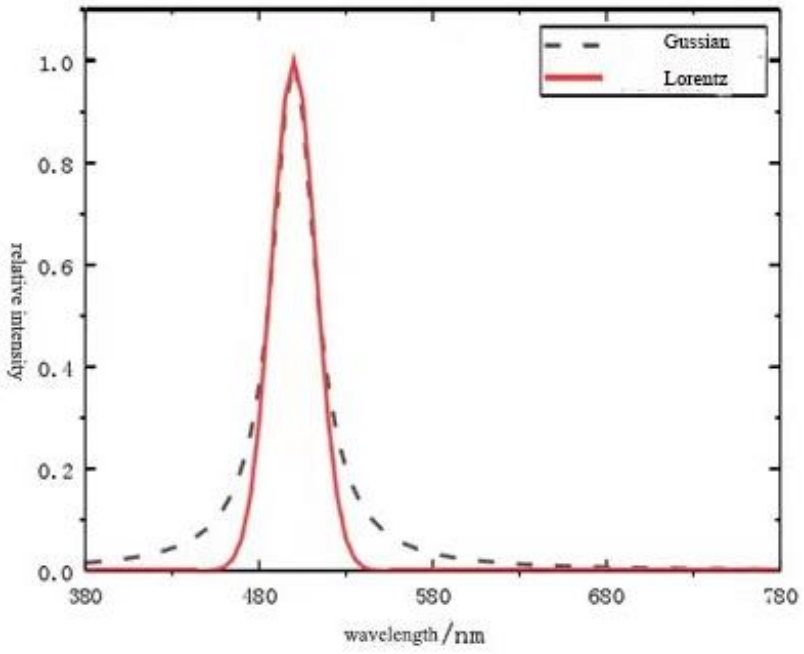


Figure 3. Lorentz and Gaussian functions separate fitted spectral shapes for single-peaked sources

3.2. Function and Benefit Analysis of Forest Ecosystem Model

We already have a method for quantifying the level of light pollution risk in cities. Now we need to discuss how this indicator can be applied to different areas. It is well known that the level of light pollution can have a large impact on the number of stars visible to the naked eye in an area. Therefore, we assume that the light pollution indicator is inversely proportional to the number of stars visible to the naked eye in the region.

3.2.1. Forest Ecosystem Model

By building and solving for the specific parameters of the model, we can extend the level of light pollution in cities to other areas such as rural areas, suburban areas and protected land locations. As the spectrum of any city can consist of a mixture of blue, green and red in different proportions. By fitting the spectral distribution curve with a Gaussian distribution and calculating the integral, we can obtain the proportion of each Gaussian spectrum required to synthesise a unit absolute spectrum. The graph below shows the results of fitting a spectrum with a Gaussian distribution for different parameters.

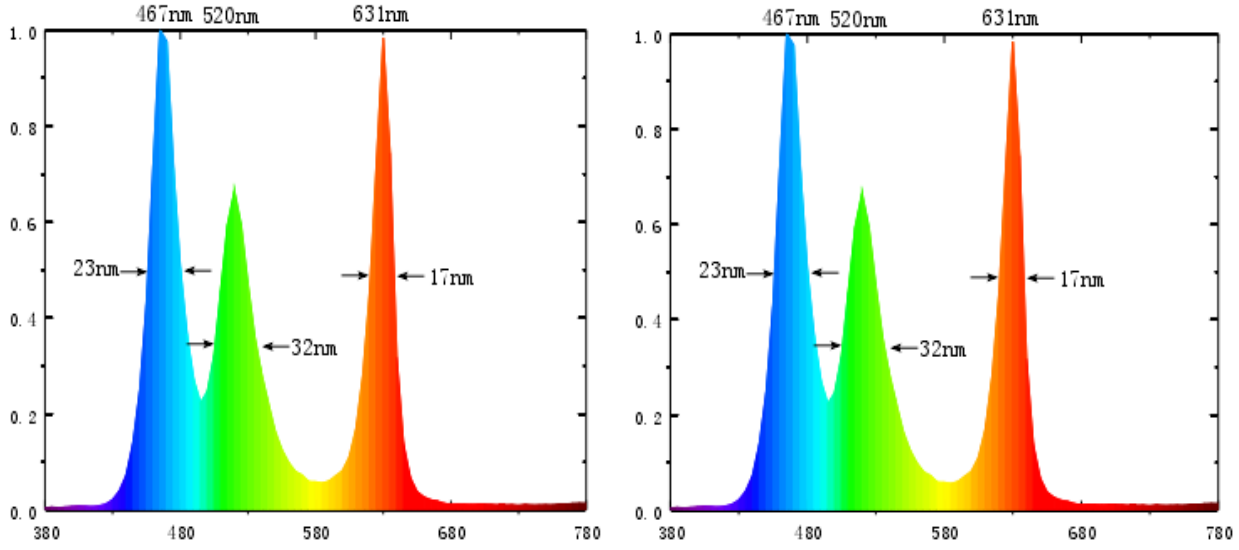


Figure 4. Gaussian distribution fitting of spectrograms

In this paper, the proportion of the Gaussian spectrum occupied by three different colours of light is defined as the relative intensities of that colour, denoted by K_1, K_2, K_3 respectively. As discussed above, the light pollution caused by light at different wavelengths is of different magnitudes. We therefore assign different weights to the relative intensities of the three colours of light. In order to later transition the model to different regions, we need to multiply different light density factors ρ according to the different light densities in different regions. we then obtain the formula for quantifying the total light pollution of the building.

$$E = \rho \sum_{i=1}^{3} (K_i \times E_i) \tag{7}$$

The following is an extract from a map showing the relative intensity of trichromatic light and the distribution of light pollution levels for different buildings in the city.

Table 1. Three colored light relative intensity of different buildings in a city of light pollution effect level distribution table

Name of the glass curtain wall	Proportion of each Gaussian spectrum required to synthesise a unit absolute spectrum			
	Percentage of blue laser	Percentage of green laser	Percentage of red laser	Total intensity
GCIC Mansions	1	0.43	0.63	604.67
Baoan Centre Plaza	1	0.46	0.72	672.125
Grand Sky Cloud Hotel	1	0.12	0.73	600.0525
Neptune House	1	0.03	0.12	169.1225
Han Guo Centre	1	0.34	0.65	597.2575
Hanking Mansions	1	0.21	0.38	385.6225
Evergrande Group	0.13	0.13	1	712.9725
Red Star Macalline	0.38	1	0.23	417.3375
China Merchant Bank	0.63	0.72	1	890.455
Next door to the Chinese Bank	1	0.58	0.49	545.3175
The next building next door to Hwashang Bank	1	0.45	0.32	400.9075
Jinmao Marriott Hotel	0.19	0.41	1	782.7525
Long Guang Mansions	1	0.49	0.68	652.1875
The next building next door to Hwashang Bank	1	0.30	0.51	493.8725
Penrhyn Mansion	1	0.41	0.86	754.6525
Next door to Penrhyn Building	0.74	0.70	1	894.785
Pudong Bank	0.74	0.70	1	894.785
Civic Centre Number 1	1	0.15	0.03	136.43
Ping An Financial Building	0.57	1	0.27	459.7125
Civic Centre Number 2	1	0.53	0.82	755.5725
Civic Centre Number 3	1	0.47	0.71	667.72
Civic Centre Number 4	0.7	0.61	1	870.6675
Civic Centre Number 5	1	0.46	0.73	678.8475
Civic Centre Number 6	1	0.46	0.69	651.9575
Civic Centre Number 7	0.06	0.28	1	742.03
Civic Centre Number 8	0.23	1	0.15	351.3325
Civic Centre Number 10	0.19	1	0.13	334.6275
Che Kung Miu No. 1	1	0.53	0.79	735.405
Shenzhen Bay No. 1	0.17	0.09	1	706.9625
Civic Centre Number 11	1	0.41	0.61	586.59
Che Kung Miu No. 2	0.16	0.04	1	694.56
Civic Centre Number 12	1	0.50	0.86	775.51
Cheung Shui Mansion	1	0.21	0.42	412.5125
Xinrui Mansion	1	0.94	0.39	561.5225
One Square City	0.14	0.19	1	727.6925
Ying Long Mansion	1	0.63	0.81	772.025
China High Speed Rail	1	0.52	0.97	854.0925
China High Speed Rail Next Door	0.21	0.25	1	747.3025
Zhongzhou Mansion	0.21	0.29	1	756.5725

3.2.2. The relationship between stars and lighting intensity

First we use the conclusion that the number of stars visible to the naked eye is inversely proportional to the degree of light pollution in the area, and using the statistical quantities of the two areas we can find the density factor ρ, and then extend the above pollution levels in urban areas to other areas. This method is more feasible and innovative, which is shown in Table 2.

Table 2. Relationship between the light pollution value and the number of stars table

Number of stars	Light pollution level
25	626.8851
250	62.68851
2400	6.530053
7000	2.238875

Then we simplified the source of light pollution to lighting pollution, while the lighting lamps were mainly LED lamps. We then investigate the spectrum of LED lamps. We carry out the analysis by reducing the proportion of the spectrum occupied by blue light. Then we build an analytical model of the building façade light and finally draw conclusions. For the treatment of the spectrum, we take the Gaussian and Lorentzian distributions. The Table 3 shows the decrease in light intensity with the blue light scaling factor.

Table 3. The decrease in light intensity with the blue light scaling factor table

Percentage of blue light reduction	Light Intensity
0	653.39
0.1	612.76
0.15	611.99
0.2	642.79
0.25	655.62
0.275	642.49
0.3	629.37
0.5	533.41

4. Conclusion

We first simplified the source of light pollution to lighting pollution, while the lighting lamps were mainly LED lamps. We then investigate the spectrum of LED lamps. We took the approach of analysing the spectrum by reducing the proportion of blue light in the spectrum. We then set up an analytical model of the light on the building façade and finally we can draw conclusions. For the treatment of the spectrum, we take the Gaussian and Lorentzian distributions. Next, we study the relationship between the stars visible to the naked eye and the intensity of the illumination. We translate the technical indicators of sky pollution into stars visible to the naked eye. This approach is more feasible and innovative.

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