Imaging the optical part of a web cam

TOADERE FLORIN, NIKOS E. MASTORAKIS

INCDTIM Cluj Napoca
Str. Donath, nr. 65-103,
ClujNapoca, 400293, ROMANIA
Florin.Toader@bel.utcluj.ro

WSEAS Research Department
Agiou Ioannou Theologou 17-23
Zografou, 15773, Athens, GREECE
mastor@wseas.org

Abstract: - In this paper we study the image illuminations and the reflected light propagations through a web camera pipeline. We focus our analysis to illumination using a spectral image; the reflected light is captured by an achromatic doublet which focuses the light to a CCD sensor. We design the achromatic doublet; we use the aperture and the transfer function of a CCD. Several images are taken in rapid succession, at different exposure levels, and we blend the images in order to obtain a HDR (high dynamic range) image. We consider the image capture system to be axial and the light is orthogonal to the system.

Key-Words: - spectral image illumination, achromatic doublet design, CCD transfer function, HDR image, photon shot noise, colors enhancement

1 Introduction
Imaging systems are complex and require to transforms signals through a number of different devices. Consequently, understanding components in isolation, without reference to the characteristics of the other system components, provides only a limited view. In these types of complex systems a controlled simulation environment can provide the engineer with useful guidance that improves the understanding of design considerations for individual parts and algorithms [3].

The exposure of the image sensor depends on the lens f/number, sensor exposure time, scene illumination level, and scene reflectance, as well as many other secondary factors.

Our system consists of an EG&G PerkinElmer lamp which tries to copy the sun illuminations [10], a spectral image [9] used as input object, an achromatic doublet which captures the reflected light and focuses the output light on a CCD sensor. Several images are taken in rapid succession, at different exposure levels, when the user depresses the camera shutter button halfway down [5, 11]. We blend together the images in order to obtain a HDR image. In the low illuminated images we have visible photon shot noise. The photon shot noise represents the photon to charge conversion noise and is directly related to the illumination degree. We made a HDR image by blending together the noisy low illuminated images with no noise light saturated images. We sharp to enhance the clarity of details in the image; we make the histogram adjustment and colors saturation in order to improve the image colors and to reduce the photon shot noise [3, 5].

2 The image capture system

2.1 The illumination algorithm
If we perceive light that is reflected from a surface, instead of light that is directly emitted from a light source, our eyes receive result of the scalar product of reflectance and radiance spectrum [5, 7, 9]. In continuous case the human eye response is:

$$c_i = \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} S_i(\lambda) r(\lambda) d\lambda, \quad i = S, L, M$$

where:

- $S_i(\lambda)$ is the function of sensitivity of the $i$-th type of cones,
- $r(\lambda)$ is the fraction of the reflected illuminant energy,
- $l(\lambda)$ is the spectral distribution of light.

$L, M$, and $S$ are the responses of the long, medium, and short cones of the eye [7].

The image obtained using equation 1 is not enough from the monitor’s colors possibilities of representation. In order to remediate this deficiency we have to make compatibility between monitor
possibility of colors generation and how the human eyes cones perceive the colors’ radiance. We need to specify how the displayed image affects the cone photoreceptors [3, 7]. To make this estimate we need to know: the effect that each display primary has on your cones and the relationship between the framebuffer values and the intensity of the display primaries (gamma correction). To compute the effect of the display primaries on the cones, we need to know the spectral power distribution of the display; a CRT (cathode ray tube) monitor (Fig. 2), and the relative absorptions of the human cones (Fig. 1) [3, 5, 7]. Having this data, we can compute the $3 \times 3$ transformation that maps the linear intensity of the display R, G, B signals into the cone absorptions L, M, S.

$$
\begin{bmatrix}
14.0253 & -13.5154 & 0.7385 \\
-4.1468 & 10.1490 & -1.3618 \\
-0.7385 & 13.5154 & 7.3776
\end{bmatrix}
$$

(2)

In addition, the characteristics of the display device (screen display) where the digital image is viewed also affect the intensity distribution and interrelationship of contrast between light and dark regions in the specimen. Phosphors of monitors do not react linearly with the intensity of the electron beam. For CRT display monitors and televisions, the luminance produced at the face of the display is a power function, which is proportional to the voltage applied to the faceplate grid raised to an exponential power. The numerical value of the exponent of this power function is known as gamma [1, 5].

$$
V_{out} = V_{in}^\gamma
$$

(3)

In conformity with the equation (1:3) we have the next algorithm steps:
1. Load the data into Matlab (spectral image, lamps spectrums and cones response) [7, 9, 10]
2. For each lamp spectrum illumination, we compute the human eye color response using equation 1.
3. We make compatibility between monitor possibility of colors generation and how the human eyes cones perceive the colors radiance using equation 2. 
4. We make gamma correction, to correct the monitor luminance using equation 3.

### 2.2 The achromatic doublet design

In order to determine the doublet impulse system response and the transfer function, we use a LSI (linear shift invariant system) which is characterized by:

$$
g(x, y) = H[f(x, y)]
$$

(4)

$H$ is an operator representing a linear, position (or space) invariant system.

$$
g(x, y) = \int \int f(\alpha, \beta)H[\delta(x-\alpha, y-\beta)]d\alpha d\beta
$$

$$
h(x-\alpha, y-\beta) = H[\delta(x-\alpha, y-\beta)]
$$

is the impulse response of $H$; in optics, it is called the point spread function (PSF) [1, 2, 4, 6].

The sensor PSF is a multiple convolution of individual response from: the doublet, the aperture and the transfer function of a CCD

$$
PSF = PSF_{\text{doublet}} * PSF_{\text{aperture}} * PSF_{\text{CCD}}.
$$

(6)

The PSF characterize the image analyses in space but also we can characterize the image in frequency using the modulation transfer function (MTF).

The MTF is defined as the ratio of the contrast of the output image to that of the input image:

$$
MTF = \frac{\text{contrast of output image}}{\text{contrast of input image}}
$$

(7)

$$
MTF = MTF_{\text{doublet}} \cdot MTF_{\text{aperture}} \cdot MTF_{\text{CCD}}
$$

(8)
In general, the contrast of any image which has gone through an imaging system is worse that the contrast of the input image. We compute the doublet merit function which can be seen as the MTF.

### 2.2.1 The achromatic doublet glasses

An achromatic doublet [2, 4, 6], is composed of two lenses made from different glass types, one a low-dispersion crown glass \( (V > 50) \) and the other a high-dispersion flint glass \( (V < 50) \). The combination is required to have total power \( f \) and zero axial chromatic aberration. Crown in front is preferred because crown glasses are harder and less susceptible to abrasion or weathering than flint glasses. We propose to design an achromatic doublet with a front positive lens of crown glass with BK10 glass (from Schott 497670) and a focal length of 12.2 mm. We should find what flint glass will use and to determine the power for that second lens to achieve an overall focal length of 23 mm.

We have the next mathematical relations for the total power of the systems:

\[
\phi = \phi_1 + \phi_2.  
\]  

Individual power of each lens function of total power is:

\[
\phi_1 = \frac{V_1}{V_1 - V_2} \phi  
\]

\[
\phi_2 = -\frac{V_2}{V_1 - V_2} \phi.  
\]

We change the values: \( V_1 = \frac{1}{f_1} = \frac{1}{12.2} \); \( V_2 = \frac{1}{f_2} \);

\[
V_1 - V_2 = \frac{1}{23}; \quad \text{and we obtain:} \quad V_2 = 39.75 \text{ and} \quad f_2 = -22.9\text{mm}. 
\]

Using the formulation for the power of the first lens relative to the overall power gives an Abbe number for the second lens of 39.8. From the Schott catalog, the closest Abbe number to this is 39.4 for N-BASF6. Using the fairly common F5 glass (less expensive and more available) would lead to a focal length of 23 mm. It point to the fact that we may have to compromise somewhat on design based on the glasses available and how customized we want to figure the lens.

### 2.2.2 The aberrations analysis

In this paper we simulate the doublet functionality [2, 4, 6]. In order to analyze aberration we consider the exit pupil to be the mechanical finite dimension of the lenses. We use the Seidel aberrations formula:

\[
W(x, y) = W_{020}r^2 + W_{111}hx + W_{200}h^2 + W_{040}r^4 + W_{131}hyr + W_{220}h^2r^2 + W_{311}h^3y + W_{400}h^4.  
\]

Using this formula we can express the thin lenses aberrations function of power, in our analyses we use: axial chromatic, coma and spherical aberrations

\[
W_{020} = \frac{1}{2}\frac{\phi^2}{V},  
\]

\[
W_{131} = \frac{1}{4}\frac{\phi^2}{V^2}L(a_1B - a_6M),  
\]

\[
W_{040} = \frac{1}{16}\frac{\phi^4}{V}((a_1 + a_2)(B - a_6M)^2 - a_1M^2).  
\]

\( \lambda \) is the wave length, \( y \) is the aperture, \( \phi \) is the power, \( V \) is the Abbe number, \( L = -nu_yy_c \) is the Lagrange invariant, \( B = \frac{c_1 + c_2}{c_1 - c_2} \) is the bending, \( n_g \) is the glass refraction indices, \( M = \frac{1 + m}{1 - m} \) is the magnification,

\[
a_1 = \left(\frac{n_g}{n_g - 1}\right)^2, \quad a_2 = \frac{n_g + 2}{n_g(n_g - 1)^2}, \quad a_3 = \frac{2(n_g^2 - 1)}{n_g + 2}, \quad a_4 = \frac{n_g}{n_g + 2}, \quad a_5 = \frac{n_g + 1}{n_g(n_g - 1)}, \quad a_6 = \frac{2n_g + 1}{n_g}.  
\]

### 2.2.3 The aberrations correction

We have the mathematical relation that describes the optical design which implies Seidel aberrations [2, 4, 6]. The defect vector \( f \) is a set of \( m \) functions \( f \) that depend on a set on \( n \) variables. The function is of the type:

\[
\sigma^2 = f^T \cdot f  
\]

\( A \) is a \((m \times n)\) matrix of first derivatives:

\[
A_{ij} = \frac{\partial f_i}{\partial x_j}  
\]

and \( s \) are changes in the variables from the current design. The gradient \( g \) is a \((n \times 1)\) vector given by:

\[
g = \frac{1}{2} \nabla \sigma^2  
\]

its components are:

\[
g_i = \frac{\partial \sigma^2}{\partial x_i} = 2\left( f_1 \frac{\partial f_1}{\partial x_i} + f_2 \frac{\partial f_2}{\partial x_i} + \ldots + f_m \frac{\partial f_m}{\partial x_i} \right) 
\]

\[
g = A^T \cdot f.  
\]

Method of Least Squares

\[
g = A^T (f_0 + As)  
\]
\[ g = g_0 + A' As \]
\[ C = A' A \]
\[ g_0 + Cs = 0 \]

is a set of simultaneous linear equations known as the normal equations of least-squares. Providing that the matrix \( C \) is not singular, these equations can always be solved, and the formal solution \( s \) may be written:
\[ s = -C^{-1} g_0. \quad (19) \]

The basic idea of the damped least-squares is to start with the basic equation for the least squares condition. \( g_0 \) is the gradient at the starting point and augment the diagonal of the matrix \( C \) by the addition or factoring of a damping coefficient. Modifications of the form \( C + p \) for example, are called additive damping. In the case of additive damping, the equation for the damped least-squares solution reduces to:
\[ g_0 + ps + Cs = 0. \quad (20) \]
As the damping factor \( p \) increases, the third term in the equation above becomes small and the solution vector becomes parallel to the gradient vector.
\[ s = -\frac{1}{p} g_0. \quad (21) \]

2.2.4 The merit function
We make the lens focal length 23 mm with an f/2 aperture (\( y_a = 5 \) mm). Let the half field angle \( \alpha \) be 0.1 (5.73°) and the wavelength be 555 nm. Let the glass index of refraction \( n_g = 1.5 \). Assume the object is at infinity (\( M = 1 \)).

The defect functions are longitudinal chromatic, coma and spherical aberrations. The wave front errors are equations 13-15. To solve this problem we must solve the next equation system:
\[
\begin{align*}
\phi_1 &= \phi - (\phi_1 + \phi_2) \\
\phi_2 &= \frac{\phi_1}{V_1} + \frac{\phi_2}{V_2}
\end{align*}
\]
\[ (22) \]

2.2.5 The aperture
In order to take a photo we need an aperture. The aperture let to pass light only when it is open. If we want to film we keep the aperture open for the entire period of filming. If we take a photo we set the integration time, which tell us how long the aperture should be kept open in order to take a photo [2, 4].

Usually the aperture has a circular shape, and is defined as:
\[ \text{circ}(r) = \begin{cases} 
1 & r \leq 1 \\
\frac{1}{2} & r = 1 \\
0 & \text{otherwise}
\end{cases} \quad (23) \]
r is cutoff frequency.

A perfect optical system is diffraction limited by relation:
\[ d = 2.44 \lambda N. \quad (24) \]
\( N \) is the focalization ratio and increase progressively by \( \sqrt{2} \), taking values: 1.4, 2, 2.8, 4, 5.6 ...
d is the aperture diameter,
\( \lambda \) is the wavelength.
The constant 2.44 is used because it corresponds to the first zeroes of the Bessel function \( J_1(r) \) for a circular aperture.

![Fig. 3 a) the doublet MTF, b) the doublet PSF](image)

![Fig. 4 a) the aperture, b) the aperture PSF](image)

2.3 The CCD analysis
We analysis that part of the CCD sensor responsible with conversion from photons to charges. We treat the transfer function of the CCD, the photon shot noise, the dynamic range and the exposure time. We do not treat Bayer sampling, interpolation and blooming.

2.3.1 The CCD transfer function
Our interest is to see what happens to an image that passes through the optical part of a CCD image sensor [2, 8]. We start by computing the MTF and the PSF. We consider a 1-D doubly infinite image sensor (Fig. 5) where: \( L \) quasi neutral region, \( L_d \) depletion depth, \( w \) aperture length and \( p \) pixel size.
To model the sensor response as a linear space invariant system, we assume \( n^+/p_{-sub} \) photodiode with very shallow junction depth, and therefore we can neglect generation in the isolated \( n^+ \) regions and only consider generation in the depletion and \( p \)-type quasi-neutral regions. We assume a uniform depletion region. The monochromatic input photon flux \( F(x) \) to the pixel current \( i_{ph}(x) \) can be represented by the linear space invariant system.

\[
M_{TF}(f) = \frac{H(f)}{H(0)} = \frac{D(f)}{D(0)} w^2 \sin c(wf) \tag{25}
\]

\( D(0) \) is called the diffusion MTF and \( \text{sinc}(wf) \) is called the geometric MTF. We also have:

\[
M_{TF_{CCD}} = M_{TF_{diffusion}} \cdot M_{TF_{geometric}} \tag{26}
\]

Note that \( D(0) = n(\lambda) \) with \( n(\lambda) \) the spectral response of the CCD. By definition: spectral response is a fraction of photon flux that contributes to photocurrents as a function of wave length. Thus \( D(f) \) can be viewed as a generalized spectral response (function of spatial frequency as well as wavelength). In our analyses we use 2D signals (images) and we shall generalize 1D case to 2D case. We know that we have square aperture at each photodiode with length \( w \).

\[
M_{TF} = \frac{|H(f_x, f_y)|}{H(0)} = \frac{D(f_x, f_y)}{D(0)} w^2 \sin c(wf_x) \sin c(wf_y) \tag{27}
\]

The smallest detectable signal is set by the root mean square of the noise under dark conditions. \( DR \) can be expressed as:

\[
DR = 20 \log_{10} \frac{i_{\text{max}}}{i_{\text{min}}} = 20 \log_{10} \frac{qQ_{\text{max}}}{\sqrt{q_i i_{\text{dc}}^2 + q \left( \sigma_{\text{read}}^2 + \sigma_{\text{DNSU}}^2 \right)}} \tag{30}
\]

where \( q = 1.6 \times 10^{-19} \) is the electron charge, \( Q_{\text{max}} \) is the effective well capacity; \( \sigma_{\text{read}}^2 \) is the readout circuit noise and \( \sigma_{\text{DNSU}}^2 \) is the offset FPN due to dark noise.
current variation, commonly referred to as \( DSNU \) (dark signal nonuniformity).

Integration time \( t_w \) tells us how much time the aperture is open and function of this how much light enter in the CCD.

### 2.3.4 Parameters of the optical systems

To find the maximum size of a pixel in the CCD image sensor we use equation 21. The sensor is located in focal plane of the lenses, the wavelength \( \lambda = 555\, \text{nm} \) and the magnifying coefficient \( M = 1 \). Applying these values to equation 21, we obtain:

\[
d = 2.44 \cdot 555 - 11 = 10.833 \, \mu\text{m} ;
\]

\[
d_t = d \cdot M = 10.833 \, \mu\text{m} .
\]

To deliver sufficient sampling the pixel size should be smaller then:

\[
p = \frac{d_t}{2} = \frac{10.833}{2} = 5.4 \, \mu\text{m} .
\]

In our analyses we use the next parameter values:

\[
p = 5.4 \, \mu\text{m} , \quad Ld = 1.8 \, \mu\text{m} , \quad L = 10 \, \mu\text{m} , \quad w = 4 \, \mu\text{m} ,
\]

\[
\lambda = 550 \, \text{nm} , \quad y = 2.3 \, \text{mm} .
\]

1/2 inch CCD with C optical interface is selected, i.e. its back working distance is \( 23 \pm 0.18 \) mm. The visual band optical system has 60° FOV, \( f/ \)number 2.5. According to the relation between the FOV of object space and image height shown in equation 28, if FOV and the size of CCD are selected, the effective focal length is determined.

\[
2y = 2f \tan \omega
\]

2y is the diagonal size of CCD,

\( f \) is the effective focal length,

\( 2\omega \) is the full field of view in object space.

It is important to know the pixel dimensions because in function of this, we can control the amount of light that enter in to the CCD and therefore we can control the photon shot noise [3].

### 2.4 The colors enhancements

After the image has gone through our optical system it is noisy blurred and its contrast is degraded. We try to improve the image colors characteristics by blending the different exposed images, histogram adjustment, sharpening and colors saturations.

#### 2.4.1 The colors blending

This method is defined as that each pixel in the resulting image is an average of the pixels from all the exposures, but the weight for each pixel is different. This algorithm works for sets of multiple images even with just two images. With two exposures, there is a long (L) exposure and a short (S) exposure. We use the grayscale value of the long exposure as the weight of the short exposure because the bright pixels in the long exposure may be blown out or actually a bright object. In other cases, we would want to use the pixel value in the short exposure. For each pixel, the resulting pixel is a weighted average of the short and long exposure pixel where the grayscale value of the long exposure pixel is the weight for the short pixel. The pixel is scaled such that energy of the pixels is not increased. This easily extends to multiple images. First, blend the two images with the longest exposure as described. This is repeated until all the images are used. This method works well, is computationally easy and in general does a pretty good job at blending the multiple exposures [3, 11].

#### 2.4.2 The sharpening

We sharpen the image, in order to eliminate the blur caused by the optical system components. Sharpness describes the clarity of detail in a photo. We use a Laplacian filter [1, 3, 5, 6]:

\[
L = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} . \tag{32}
\]

#### 2.4.3 The colors saturation

In color theory the saturation or purity refers to the intensity of a specific hue. The saturation of a color is determined by a combination of light intensity and how much it is distributed across the spectrum of different wavelengths [3, 5, 6]. Image color saturation is obtained by multiplying the images with matrix \( A \):

\[
A = \begin{bmatrix} 1.4333 & -0.2667 & -0.2667 \\ -0.2667 & 1.4333 & -0.2667 \\ -0.2667 & -0.2667 & 1.4333 \end{bmatrix} . \tag{33}
\]

### 3 The simulation results

In this paper we try to image the optics of a web cam. We cover the web cam pipeline related to light propagations and photons to charges conversion. We use a spectral image which is illuminated with an EG&G PerkinElmer lamp (Fig. 7 a)), the object reflected light is captured by a doublet lenses (Fig. 7 b)), we sharp (Fig. 8 a)) and we focused on a CCD. Function of the integration time durations, the

\[
\text{Integration time } t \text{ tells us how much time the aperture is open and function of this how much light enter in the CCD.}
\]

\[
\text{To deliver sufficient sampling the pixel size should be smaller then:}
\]

\[
p = \frac{d_t}{2} = \frac{10.833}{2} = 5.4 \, \mu\text{m} .
\]

\[
in \text{our analyses we use the next parameter values:}
\]

\[
p = 5.4 \, \mu\text{m} , \quad Ld = 1.8 \, \mu\text{m} , \quad L = 10 \, \mu\text{m} , \quad w = 4 \, \mu\text{m} ,
\]

\[
\lambda = 550 \, \text{nm} , \quad y = 2.3 \, \text{mm} .
\]

\[
1/2 \text{ inch CCD with C optical interface is selected, i.e. its back working distance is } 23 \pm 0.18 \, \text{mm.}
\]

\[
1/2 \text{ inch CCD with C optical interface is selected, i.e. its back working distance is } 23 \pm 0.18 \, \text{mm.}
\]

\[
2y = 2f \tan \omega
\]

\[
2y \text{ is the diagonal size of CCD,}
\]

\[
f \text{ is the effective focal length,}
\]

\[
2\omega \text{ is the full field of view in object space.}
\]

\[
\text{It is important to know the pixel dimensions because in function of this, we can control the amount of light that enter in to the CCD and therefore we can control the photon shot noise [3].}
\]

\[
\text{After the image has gone through our optical system it is noisy blurred and its contrast is degraded. We try to improve the image colors characteristics by blending the different exposed images, histogram adjustment, sharpening and colors saturations.}
\]

\[
\text{This method is defined as that each pixel in the resulting image is an average of the pixels from all the exposures, but the weight for each pixel is different. This algorithm works for sets of multiple images even with just two images. With two exposures, there is a long (L) exposure and a short (S) exposure. We use the grayscale value of the long exposure as the weight of the short exposure because the bright pixels in the long exposure may be blown out or actually a bright object. In other cases, we would want to use the pixel value in the short exposure. For each pixel, the resulting pixel is a weighted average of the short and long exposure pixel where the grayscale value of the long exposure pixel is the weight for the short pixel. The pixel is scaled such that energy of the pixels is not increased. This easily extends to multiple images. First, blend the two images with the longest exposure as described. This is repeated until all the images are used. This method works well, is computationally easy and in general does a pretty good job at blending the multiple exposures [3, 11].}
\]

\[
\text{We sharpen the image, in order to eliminate the blur caused by the optical system components. Sharpness describes the clarity of detail in a photo. We use a Laplacian filter [1, 3, 5, 6]:}
\]

\[
L = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} . \tag{32}
\]

\[
\text{In color theory the saturation or purity refers to the intensity of a specific hue. The saturation of a color is determined by a combination of light intensity and how much it is distributed across the spectrum of different wavelengths [3, 5, 6]. Image color saturation is obtained by multiplying the images with matrix } A:
\]

\[
A = \begin{bmatrix} 1.4333 & -0.2667 & -0.2667 \\ -0.2667 & 1.4333 & -0.2667 \\ -0.2667 & -0.2667 & 1.4333 \end{bmatrix} . \tag{33}
\]

\[
\text{In this paper we try to image the optics of a web cam. We cover the web cam pipeline related to light propagations and photons to charges conversion. We use a spectral image which is illuminated with an EG&G PerkinElmer lamp (Fig. 7 a)), the object reflected light is captured by a doublet lenses (Fig. 7 b)), we sharp (Fig. 8 a)) and we focused on a CCD. Function of the integration time durations, the}
\]
aperture is open and we can take several light exposed pictures. The short time exposed images have visible photon shot noise and the long time exposed images tend to be saturated. We blend together the long exposed and low exposed images in order to get a HDR image.

We present a critical situation when we use only two images: one with low illumination which has visible photon shot noise (Fig. 8 b)) and other with light saturation (Fig. 9 a)). If is to much light we can mask the photon shot noise but the blended image is light saturated and shine too much. If the short exposed image is preponderant then the noise is visible and the image keeps its original colors. It is a balance between the two images light intensities. If we want to have a better contrast in the HDR image, we need to use more intermediate exposed pictures. Then we histogram adjust in order to improve the image contrast and we saturate the colors. In Fig. 9 b) we have the HDR image.

4 Conclusion

In this paper we image the optical part of a web cam. From the simulated images we see the good quality of the illuminated object. The reflected light is captured bay a doublet and is focalized on a CCD. During this process the optics deteriorates the resolution and the CCD introduces the photon shot noise. Using properly the colors processing techniques we can recover the image colors characteristics and we minimize the photon shot noise effect.

References:
[7] Lee H. C., Introduction to color imaging science Cambridge, 2005
[11] Toadere F., Conversion from a spectral image to a HDR image, ATOM-N 2008 The 4th international conference advanced topics in optoelectronics, microelectronics and nanotechnologies, 29-31 August, Constanta, Romania
[12] Toadere F., Simulation the optical part of an image capture system, ATOM-N 2008 The 4th international conference advanced topics in optoelectronics, microelectronics and nanotechnologies, 29-31 August, Constanta, Romania