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# Investigation of self-adaptive LED surgical lighting based on entropy contrast enhancing method

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ABSTRACT

Investigation was performed to explore the possibility of enhancing contrast by varying the spectral distribution (SPD) of the surgical lighting. The illumination scenes with different SPDs were generated by the combination of a self-adaptive white light optimization method and the LED ceiling system, the images of biological sample are taken by a CCD camera and then processed by an 'Entropy' based contrast evaluation model which is proposed specific for surgery occasion. Compared with the neutral white LED based and traditional algorithm based image enhancing methods, the illumination based enhancing method turns out a better performance in contrast enhancing and improves the average contrast value about 9% and 6%, respectively. This low cost method is simple, practicable, and thus may provide an alternative solution for the expensive visual facility medical instruments.

## 1. Introduction

Surgical lighting system (SLS) is a kind of lighting technique that is usually used to help doctors to distinguish organs or tissues more accurately during the surgery. At the very beginning, the rudiment of surgical lamp is a heap of candles posed around the operating table. With the development of optical and electrical technology, halogen lamp, which can used to achieve surgical lighting with different luminance level, are widely employed in the operation theater. However, more and more researches reveal that the halogen lamp emits a mass of infrared rays and ultraviolet rays which could threaten the health of the patient and the doctor [1]. Besides, many other shortcomings, such as un-tunable correlated color temperature (CCT), large volume, low efficiency and short lifetime, all suggest that the halogen lamp may not be the best solution to the SLS [2,3].

Due to its prominent advantages, LEDs are adopted more frequently in medical use [4,5]. For example, Wang et al. reported that a color image reconstruction method enables both direct visualization and direct digital image acquisition from one oral tissue by using various light sources and color compensating filters [6–8]. Lee et al. proposed spectrum-based optimal illumination to efficiently discriminate objects with distinct spectral absorption and scattering characteristics [9]. Of course, LEDs have been used in the commercialized products of SLS, many of which possess adjustable CCTs and lighting feedback system [10,11]. However, the number of different LEDs employed in the present products is always limited, and the selection of LEDs is usually based on the theory of color rendering index (CRI) but without considering the visual perception of the doctor. To improve the surgeons' visual experience, video cameras are employed in some of the surgical lighting systems. With this technique, both the spectral composition of the tissue and the spatial information can be obtained [12], and thus many diseased tissues, such as cervical cancer [13] and lesions [14], can be detected according to the variation in color, appearance, and spectral composition. But, this method is not very practical due to its complicated procedures, high expense, and fails to offer the immediate visual contrast needed for surgical guidance in real time because it usually takes several minutes to acquire and process the images recorded by the camera. Luckily, tissue contrast can also be enhanced by modifying the illumination of the SLS just like what people used to do in the narrow band imaging (NBI) technique [15–19]. But there is still few studies about the relationship between the surgical lighting and the surgeon's visual perception, and to the author's knowledge, no related standards have been proposed in the industry, for example, which color of LEDs should be adopted and what is the best SPD for the surgical occasion.

In this work, investigation is conducted to study the influence of the LED surgical lighting on the tissue's contrast, and try to provide the best light solution for SLS with the present LED technique from the perspective of contrast enhancement. Based on a LED ceiling system, the biological samples are exposure under single color LEDs and the self-adaptive white light, respectively, the images of the specimen are captured by a digital camera, the

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SPD of the light is self-adjusted to maximum the image contrast according to the feedback signal. To achieve a more appropriate result, in Section 2, we also proposed an 'Entropy' based contrast evaluation model. Then, the contrast information together with spatial frequency analysis are provided in Section 3. After a detailed discussion in Section 4, conclusion is given at last.

## 2. Equipment and methods

In order to conduct the experiments, four technical aspects are integrated in this work, contrast evaluation model, LED ceiling system, a digital camera, and a spectrometer. The imaging camera used here can provide the grayscale information of the specimens, the spectrometer can acquire absolute spectral reflectance, the contrast evaluation model is used to evaluate the tissue contrast, and the LED ceiling system can generate target light with specific spectral distribution by a matching algorithm

### 2.1. Contrast evaluation model

In a study of contrast enhancement in biomedical imaging, Burton [19] used the 'Entropy' to evaluate the contrast. Entropy, which is usually adopted to evaluate uncertainty, is a most important concept in information theory. Based on the previous study, Sporring [20] introduced the Entropy theory into the field of image processing, and from then on image Entropy was frequently used. Image Entropy, which not only describes the average amount of information about the image source, but also reflects the statistical characteristics of image data, can be described as the properties of image features and image processing basis. Higher Entropy values indicate a wider distribution of grayvalues in an image, which corresponds to higher contrast between pixels, and in all cases Entropy correlated with perceived contrast. However, Entropy is a global measure of the whole regions of interest (ROI), and thus other evaluation function must be involved if specific features need to be emphasized. In this way, a more appropriate evaluation criteria of image contrast for surgical use still needs to be further studied. To achieve this goal, we establish a contrast evaluation model for surgical lighting, which is given by

$$\begin{cases} F = kA^2 + B^2 \\ A = \sum_i P_i \log_2 P_i, \;\; B = \left( \sum_{(i=1,j=1)}^{(m,m)} {g^v}_{ij}/m^2 \right) \Big/ \left( \sum_{(i=1,j=1)}^{(m,m)} {g^t}_{ij}/m^2 \right) \end{cases} . \tag{1}$$

where $A$ is the Entropy of a grayscale image which means a statistical measure of randomness that can be adopted to characterize the texture of the input image, and $P_i$ is the proportion of the pixels with the grayscale $i$ with respect to all pixels. The contrast evaluation model shown in Eq. (1) is integrated with image Entropy and the grayscale contrast of blood vessels with respect to the surrounding tissues. Before the Entropy analysis, all the images are first converted to grayscale and then some ROIs are selected from the images. As shown in Fig. 1, within each ROI, two special points ($V$ and $T$) were found for the mumerator and denominator of $B$ in the way that sum of the grayvalue ($g_{ij}^v$) of $m \times m$ surrounding pixels' around the point $V$ is the minimum within the whole blood vessels region, while point T located right in the $V$'s neighbor tissue and sum of grayvalue ($g_{ij}^t$) of its $m \times m$ surrounding pixels' is maximum within a $n \times n$ matrix region ($n \gg m$). Therefore, $B$ represents the contrast of blood vessels with respect to surrounding tissues and each ROI has one unique value of $B$. $k$ is an adjustable coefficient and here we make $k = (B_{max} / A_{max})^2$ to assure $A$ and $B$ be comparable. In this way, the contrast evaluation function $F$ can involve not only the whole texture information of the ROI but also the specific detail around the blood vessels.

However, the effects of spatial frequency on apparent contrast is not taken into account by the contrast $F$ defined by Eq. (1), which is known to be higher for edges than for more diffuse features with the same range of grayscale values. Besides, human's visual contrast sensitivity is highly depend on spatial frequency, especially at threshold, and contrast for each spatial frequency band should be calculated separately. Thus, in the frequency domain $W(u,v)$, the band limited image can be represented by Eq. (2).

$$W(u,v) = W(r,\theta) = F(r,\theta)H(r) \tag{2}$$

where $u$ and $v$ are, respectively, the horizontal and vertical spatial frequency coordinates and $r = \sqrt{u^2+v^2}$ and $\theta = \tan^{-1}(u/v)$, respectively, represent the respective polar spatial frequency coordinates, $F(r,\theta)$ is the Fourier transform of the image $f(x,y)$, and $H(r)$ is a radically symmetric bandpass filter. The bandpass profile used here is the Gaussian envelope of the Gabor function and 1 octave bandwidth is used. Then, the contrast of bandpass filtered version of images are evaluated with the $A$ part of Eq. (1), Entropy, because $B$ part cannot applied on the diffuse features of the low pass image, and this is shown by Eq. (3).

$$Entropy \;=\; \sum_i P_i \log_2 P_i \tag{3}$$

### 2.2. LED ceiling system, camera and spectrometer

The light source used here is the LED ceiling system constructed by Zhejiang University [21], which is an LED panel with

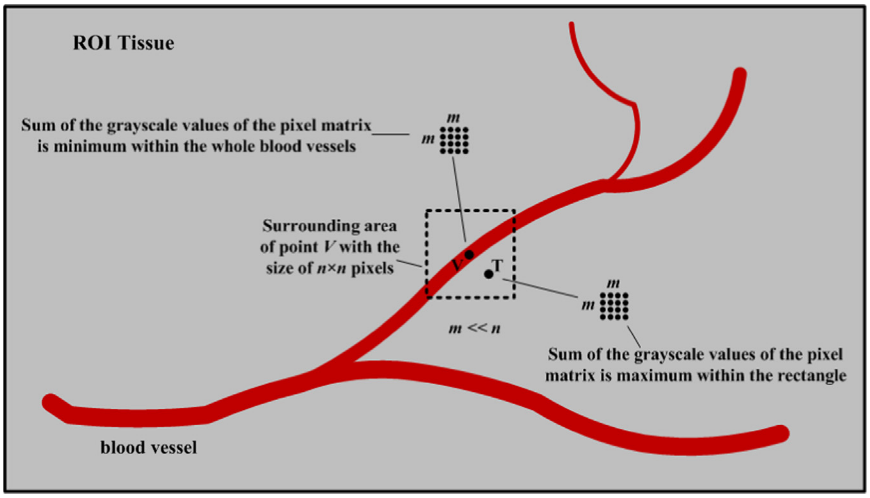

**Fig. 1.** Determination of points $V$ and $T$.