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Employment of the appropriate range of sawtooth-shaped-function illumination intensity to improve the image quality

Jianping Yu[a,b], Gang Li[a,b], Shaohui Wang[c], Ling Lin[a,b,*]

[a] State Key Laboratory of Precision Measuring Technology and Instruments, Tianjin University, Tianjin, 300072, China
[b] Tianjin Key Laboratory of Biomedical Detecting Techniques and Instruments, Tianjin University, Tianjin, 300072, China
[c] Jinan Central Hospital Affiliated to Shandong University, Jinan, 250013, China

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ABSTRACT

The medical image quality determines the accuracy of diagnosis. To acquire higher signal-to-noise ratio (SNR) and higher quality image, based on the sawtooth-shaped-function (SSF) illumination technique and frame-accumulation algorithm, this paper presents a method of selecting the appropriate range of SSF illumination intensity. By avoiding the weak light intensity and strong light intensity near the camera saturation area, an appropriate range of illumination intensity is gotten, where the SNR of image is higher. The experimental results show that, compared with the previous SSF illumination and constant illumination methods, this proposed method can obtain the image with higher SNR and gray-scale resolution that is to obtain higher quality image. Moreover, this illumination method provides a reference for improving the medical image quality from the point of image acquisition.

1. Introduction

High-quality images have great importance in many fields of scientific research, such as biomedical imaging [1], military target recognition [2], food inspection [3], and so on. Especially in the field of clinical medicine, the quality of medical images has determined the level of diagnosis and treatment [4,5]. Therefore, how to acquire high-quality medical image has always been an important topic for modern medical research. Nowadays, there are mainly two ways to enhance the image quality. One is the hardware approach to improve the precision of the image acquisition system, and some are to improve the acquisition circuit [6] and some are to improve the internal structure of imaging sensor [7]. The other is the software approach to improve the acquired image itself by using complex image processing technology, and the common image processing methods include image enhancement and restoration [8], image transformation [9], image coding [10], and so on.

As mentioned above, most researchers are aimed at improving the spatial resolution of images rather than the gray-scale resolution [11,12]. In clinical medicine, there is little difference in gray-scale between normal tissue and early diseased tissue. By improving the gray-scale resolution of medical images, it is possible to make an early and accurate diagnosis [13,14]. As a result, some methods [15–18] have been proposed previously from the perspective of light source by our group. The frame-accumulation algorithm and shaped-function signal technique were used to change the intensity of the light source and acquire images, which can effectively improve the gray-scale resolution and signal-to-noise ratio (SNR) of image that is to improve the image quality.

Specifically, in the field of low-light-level image detection, frame-accumulation algorithm may not be considered when the light intensity is lower than the least significant bit (LSB) identified by image sensors. So Refs. [15] and [16] proposed the method of

* Corresponding author at: State Key Laboratory of Precision Measuring Technology and Instruments, Tianjin University, Tianjin, 300072, China.
E-mail address: linling@tju.edu.cn (L. Lin).

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adding the auxiliary light (i.e. shaped-function signal) to low-level-light signal and employing the frame-accumulation algorithm. The experimental results proved that the method has good performance in terms of surpassing the limitation of the image sensor's sensitivity and can improve the SNR of image largely. But the auxiliary light needs to be removed finally, which increases the computational complexity. Therefore, Refs. [17] and [18] presented the method for image acquisition, which used sawtooth-shaped-function (SSF) optical signal to illuminate the object directly and made light intensity range from the darkest to the brightest. Compared with the constant light intensity, the method in Refs. [17] and [18] not only effectively improved the gray-scale resolution of images, but also saved the energy of the light source.

Thus, based on the original method of using SSF illumination and frame-accumulation algorithm, this paper proposes a method of selecting the appropriate range of light intensity to further improve the SNR of image. In other words, under the illumination of the SSF signal, we should avoid the weak light intensity and strong light intensity near the camera saturation area, and make the camera work in the linear response region to acquire higher image quality. Compared with the previous SSF illumination and constant illumination methods, this proposed method can offer the image with higher SNR and gray-scale resolution under the condition of the same image acquisition device. Moreover, the illumination method of changing the light intensity range provides a reference for improving the medical image quality from the point of image acquisition.

2. Theories and methods

2.1. Why change the light intensity range of SSF signal illumination

The SNR of the image reflects the quality of the image, which is related to the effective signals and all kinds of noises in the image. Firstly, in the static image acquisition system, only quantization noise is considered. Under the illumination of the constant signal, the quantization noise is approximately a constant. Multiple sampling and cumulative mean can't improve the measurement accuracy. Because the error of the mean value is the same as that of the single sampling. However, under the illumination of the SSF signal, the quantization noise is approximately linear. The error of its mean value is zero mean random number, which is $\sqrt{N}$ (N is the number of samples) times lower than that of the single sampling [17,18]. Thus, using SSF illumination technique can effectively reduce the error of the signal and improve the measurement accuracy compared with the constant light intensity.

In addition, there are other noises in the static image acquisition system using SSF signal, such as the shot noise related to the incident photon and dark current, the amplifier noise and the fixed pattern noise (FPN), [19] etc. It is assumed that these noises change little relative to the effective signal, so the SNR of the image will be increased when increasing the light intensity. However, the light intensity response curve of CCD will have obvious saturation nonlinearity [20] when the light intensity is too strong, which leads to lower SNR of the image.

Therefore, in the imaging system using SSF signal as the exposure light source, the camera should be made to work in the linear response region, and avoid approaching the regions of low energy and camera saturation to improve the measurement accuracy and the SNR of the image. And a method of changing the light intensity range of SSF signal illumination is proposed by this paper, which is combined with frame-accumulation algorithm to acquire higher image quality.

2.2. How to select the appropriate range of light intensity

In this paper, the SSF signal is used to directly modulate the light source to obtain the image information. And how to select the appropriate range of light intensity was explored through single pixel analysis. We assume that the single pixel signal is uniformly sampled in a period T of the SSF signal, the number of sampling points is N ($N >> 1$) and the sampled value is denoted as x_i, $x_i = s_i + n_i$ ($i = 1,2,\ldots, N$), where s is the useful signal or the true signal, and n is the noise signal. In the above case, the SNR is defined as a logarithm of a ratio of the mean signal $\bar{x}$ to the root-mean-square (RMS) σ of the noise signal, as shown below.

$$SNR_a = 20\log_{10}\left(\frac{\bar{x}}{\sigma}\right)(db). \tag{1}$$

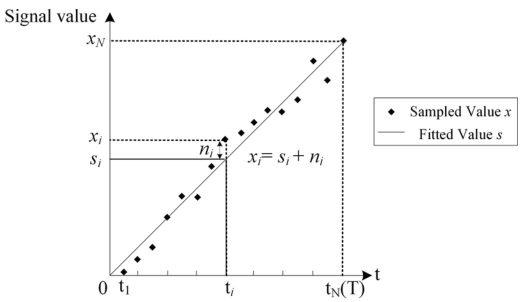

Fig. 1. Diagram of the relationship between the sampled value and the fitted value. The x-axis represents the sampling time and the y-axis represents the signal value. The total sampling time is T and the total sampling point is N. And the sampled value is equal to the fitted value plus the noise value, xi = si + ni (i = 1,2,…, N).