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Infrared super-resolution imaging method based on retina micro-motion

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HIGHLIGHTS

- We adopted the achievement that the human retina micro-motion results hyperacuity.
- An infrared super-resolution imaging method based on retina micro-motion is proposed.
- We used the piezoelectric ceramic equipment to control the detector moving variably.
- Four sub-images are used to generate a high spatial resolution infrared image.
- We predicted image edges by response time tag of different pixels on the same objects.

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ABSTRACT

With the wide application of infrared focal plane arrays (IRFPA), military, aerospace, public security and other applications have higher and higher requirements on the spatial resolution of infrared images. However, traditional super-resolution imaging methods have increasingly unable to meet this requirement in technology. In this paper, we adopt the achievement that the human retina micro-motion is the important reason why the human has the hyperacuity ability. Based on the achievement, we bring forward an infrared super-resolution imaging method based on retina micro-motion. In the method, we use the piezoelectric ceramic equipment to control the infrared detector moving variably within a plane parallel to the focal plane. The motion direction is toward each other into a direction of 90°. In the four directions of the movement, we get four sub-images and generate a high spatial resolution infrared image by image interpolation method. In the process of the shifting movement of the detector, we set the threshold of the detector response and record the response time difference when adjacent pixel responses are up to the threshold. By the method, we get the object's edges, enhance them in the high resolution infrared image and get the super-resolution infrared image. The experimental results show that our proposed super-resolution imaging methods can improve the spatial resolution of the infrared image effectively. The method will offer a new idea for the super-resolution reconstruction of infrared images.

1. Introduction

Infrared imaging has the advantages of all-weather working ability, good concealment and good anti-jamming capability. Since its inception, the military and civilian departments all over the world have focused on them until now. Infrared imaging technology has been the indispensable detecting means in the modern battlefield, production and livelihood. The spatial resolution is an important indicator for the evaluation of infrared imaging performance [1]. The higher the spatial resolution of the infrared image is, the stronger the ability of the goal of early detection, precise positioning and effectively identify are [2]. Continuously improving infrared image resolution has become more and more pressing needs in infrared imaging field. It has great significance in military, aerospace, public security, civil and other fields [3].

Infrared super-resolution imaging method is an effective technology of improving infrared image spatial resolution [4]. However, traditional methods face many insurmountable problems in increasing spatial resolution of ten times of original images. For example, for the controllable super-resolution imaging method, improving spatial resolution and improving imaging performance are conflicting when the spatial resolution has been increased to some extent. The higher the spatial resolution is, the shorter the integration time is. This causes that the pixel receives smaller energy and the signal to noise ratio (SNR) gets smaller. Non-controllable super-resolution imaging method needs to rely on micro-motion generated by the movement of the imaging device or scene [5]. However, the imaging device or scene cannot keep moving in the entire imaging process. Besides, in non-controllable super-resolution imaging method, registration algorithm and recovery algorithm are complex and hard to be real-time realized. For example, Manuel Guizar-sicairos put forward the fast sub-pixel registration method, but the method still cannot be real-time completed in

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miniaturized processors [6]. Wei tong studied the accurate registration method of noisy image. But it was not always effective to noisy images [7]. In the super-resolution recovery algorithm, Peyman Millanfar [8,9] of University of California and Katsaggelos [10,11] of Northwestern University both brought forward many recovering algorithms which have noise-suppressing ability. But they are lack of enough stability. In summary, the application of traditional super-resolution method is limited.

In recent years, the causal relationship of micro-motion characteristics of the human eye retina and the human eye's hyperacuity becomes clearer. This makes it is possible that the researchers study the super-resolution reconstruction method based on retina micro-motion, and greatly improve the spatial resolution infrared images.

In 1830, scientists have found that when the human eye stares at an object, the retina will execute tiny scanning motion with the frequency and amplitude that the human himself cannot detect. This micro-motion is called as fixational eye movement. In the end of the 19th century, scientists found that the human eye have the hyperacuity ability [12]. The hyperacuity ability is described as follows. In the most sensitive fovea of the retina, the minimum central angle of two photoreceptor cells is $30''–1'$. In theory, the spatial distinguishing ability of the human eye is restricted by the retinal photoreceptor cells density. However, psychophysical experiments show that, stimulated by some graphics, the human eye can distinguish two points whose spatial angle is only $5''–6''$. Westhemer and Mckee [13] in vernier caliper experiments confirmed that the human eye could distinguish two points whose spatial angle was only $2''$, which greatly exceeded the maximum array density than of fovea cells. However, limited by experimental means backward, the research stalled. Until recent years, with the adoption of advanced experimental methods, a large number of research results emerged. Susana and Ziad points that: The micro-motion of the retina of the human eye is the direct cause of the human eye has the hyperacuity capability [14,15]. Since then, the causal relationship of micro-motion characteristics of the human eye retina and the human eye's hyperacuity becomes clearer.

Based on existing research, we bring forward an infrared super-resolution imaging method based on retina micro-motion in this paper. This method will overcome the defects of traditional methods and improve spatial resolution greatly. In Section 2, we introduced the theoretical basis of improving resolution for micro-motion characteristic. Section 3 talked about the detail of our method. The experiment comparison was in Section 4. Section 5 concluded the paper.

2. Theoretical basis of improving resolution for micro-motion characteristic

For convenience of illustration, we take one dimensional signal for example. For a photoreceptor cell, if the scene function is $f(x)$, the point spread function (PSF) of the human eye is $o(x)$, the response of single sensitive cell is rectangular function $rect(x/b)$($rect(x/b)$ indicates that the response centre point is at coordinate origin, the length of the rectangular function is b), the output signal $g(x)$ is:

$$g(x) = f(x) * o(x). \tag{1}$$

During the moving process of photoelectric receiver, rectangular function $rect(x/b)$ will smooth $g(x)$. After the scanning by $rect(x/b)$, the output $J(x)$ of the photoelectric receiver at different position is:

$$\begin{aligned} J(x) &= \frac{1}{b} g(x) * rect(x/b) = \frac{1}{b} f(x) * o(x) * rect(x/b) \\ &= f(x) * \left(\frac{1}{b} o(x) * rect(x/b)\right). \end{aligned} \tag{2}$$

If the position sensitivity function of the photoelectric receiver is

$$s(x) = \frac{1}{b} o(x) * rect(x/b), \tag{3}$$

then

$$J(x) = f(x) * s(x). \tag{4}$$

when the photoelectric receiver executes tiny scanning motion, the small changes at abscissa will results the changes of $J(x)$. If the photoreceptor sensitivity function in the retinal obeys Gaussian distribution [16], that is

$$s(x) = 2.5 \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \tag{5}$$

and the parameter μ and σ are 0,1 separately, then Eq. (5) is amended to

$$s(x) = 2.5 \frac{1}{\sqrt{2\pi}} e^{-\frac{(x)^2}{2\sigma^2}}. \tag{6}$$

Supposing the sensitivity of the other photoelectric receiver is $s_2(x)$ and the distance of the two photoelectric receivers are 1, then

$$s_2(x) = 2.5 \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-1)^2}{2\sigma^2}}. \tag{7}$$

If the scene is rectangular pulse $f(x) = rect(x/1)$, then the response image $J(x)$ and $J_2(x)$; are shown in Fig. 1.

From Fig. 1, we can find that when the photoelectric receiver moves a little, i.e. the photoreceptor sensitivity function varies, the response $J(x)$ and $J_2(x)$ of the photoelectric receiver changes. In other words, the slight movement of the photoelectric receiver will result in the response change of the photoelectric receiver. When the scene moves a distance of 0.3 (in Fig. 1(c) and (d)), comparing Fig. 1(a) and (c) (also (b) and (d)), we can find that, $J(x)$ and $J_2(x)$ also vary. This indicates that the response function $J(x)$ and $J_2(x)$ are sensitive to objects positions. By moving photoelectric receiver, we can change the relative position of photoreceptors and objects. So, we may acquire the accurate spatial position of an object by analyzing the output response of the photoreceptors.

3. Imaging method of micro-motion

According to Section 2, we know that the micro-motion of the detector can change its response. Then, we adopt the following motion pattern (Fig. 2) to carry through super-resolution reconstruction.

In Fig. 2, the blocks filled with white represent the position of the original pixels, and the blocks filled with black represent the position of the pixels after micro-motion. In the micro-motion, the pixel o1 is moved to four positions, m1, m2, m3 and m4. Supposing the pixel pitch of the detector is d_{pixel}, the distance d_{micro} between original pixel o1 and the motioned pixel m1 (or m2, m3, m4) is $5d_{pixel}/4$. So, in the reconstruction process, four sub-motion images are used to recover a high-resolution image. In the micro-motion, we move sensitive elements by variable motion to acquire the edge of the targets and enhance them. In the entire imaging process, the super-resolution recovery process in use of four sub-images is called as interpolation process. The process of image o1 moving to the position of m1, m2 m3 or m4 is called micro-scanning process. Now, we analyze the two processes.

3.1. Interpolation process

It is assumed that the scene signal sampled by the detector is expressed as $f(x)$. The space of sampling point is x_s. At any point (for example $x = x_s$), $f(x)$ is expressed as [17]