Infrared Physics & Technology 66 (2014) 152–159

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Variational infrared image enhancement based on adaptive dual-threshold gradient field equalization

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HIGHLIGHTS

- Transforming the infrared image into its gradient domain to get the gradient histogram.
- The gradient field equalization with dual-threshold is obtained using the histogram equalization technique.
- Adopting the total variational model while constructing the objective function.
- Using the variational method, the enhanced image is reconstructed from the target gradient field.

ARTICLE INFO

Article history:
Received 24 February 2014
Available online 19 June 2014

Keywords:
Images processing
Infrared image enhancement
Gradient histogram equalization
Adaptive dual-threshold
Total variation

ABSTRACT

Infrared images are characterized by low signal to noise ratio (SNR) and fuzzy texture edges. This article introduces the variational infrared image enhancement algorithm based on gradient field equalization with adaptive dual thresholds. Firstly, we transform the image into gradient domain and get the gradient histogram. Then, we do the gradient histogram equalization. By setting adaptive dual thresholds to qualify the gradients, the image is prevented from over enhancement. The total variation (TV) model is adopted in the reconstruction of the enhanced image to suppress noise. It is shown from experimental results that the image edge details are significantly enhanced, and therefore the algorithm is qualified for enhancement of infrared images in different applications.

1. Introduction

Infrared images are widely applied in military, scientific, medical and other fields. However, infrared images have shortcomings of noise, low contrast and blurred texture details due to the uneven photosensitive response of infrared detector and non-ideal optics system. These affect the application of infrared images. To give qualified image information in applications, it is necessary to enhance the faint edge details of infrared images [1–3].

The technique of histogram equalization (HE) is an important method for enhancing image details [4–6]. It makes the image gray level values to appear approximately equally distributed in the corresponding histogram, which extends the dynamic range of the image. However, it is easy to produce over-enhancement, where the background noise with typical gray level values gets amplified while the detailed information with typical gray level values is constrained. To overcome the shortcomings of HE, many improvements have been proposed such as platform histogram equalization (PHE) [7] and double platform histogram equalization (DPHE) [8]. They suppress background noise by setting one or two platform thresholds. For infrared image enhancement, there are some other methods, such as using multiscale new top-hat transform [9], multi-scale decomposition [10] and human visual system [11]. In recent years, the method of variational partial differential equations (VPDE) [12–14] is applied to image enhancement by many scholars. They design the adaptive diffusion coefficients by judging whether smoothing or enhancing of different pixels to achieve image enhancement.

Local changes of image often correspond to the edge details information. In VPDE theory, the local variations of images can be expressed using the corresponding gradients. If the gradient value is large, image edge texture details will be clear. In this paper, we enhance infrared image edge details by the transformation of gradient field. The histogram equalization technology is applied to image gradient domain, increasing the small gradient values to enhance image texture details while suppressing the large gradient values to prevent over-enhancement. In order to

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http://dx.doi.org/10.1016/j.infrared.2014.05.018
1350-4495/

improve the SNR of infrared images, we adopt the TV constraint in constructing the objective function. Therefore, the proposed algorithm effectively enhances infrared image edge details while suppressing noise.

2. The proposed method

In this section, a novel enhancement algorithm of infrared image texture details is proposed. The process of this algorithm includes four steps. Fig. 1 shows the framework of this method.

The following subsections give a detailed description of each part of the algorithm respectively.

2.1. Gradient field equalization with adaptive dual-threshold

To a point $p(x, y) \subset \Omega$ of the infrared image $I(x, y((x, y) \subset \Omega = [0, N-1] \times [0, M-1])$, where Ω represents the size of the image, and N and M are the length and width of the image, respectively, the gradient $\nabla p(x, y)$, gradient magnitude value $|\nabla p(x, y)|$ and gradient direction θ are defined as:

$$\nabla p(x,y) = \left[\frac{\partial p(x,y)}{\partial x}, \frac{\partial p(x,y)}{\partial y}\right] \quad (1)$$

$$|\nabla p(x,y)| = \sqrt{\left|\frac{\partial p(x,y)}{\partial x}\right|^2 + \left|\frac{\partial p(x,y)}{\partial y}\right|^2} \quad (2)$$

$$\theta = \arctan\left[\left|\frac{\partial p(x,y)}{\partial y}\right| \Big/ \left|\frac{\partial p(x,y)}{\partial x}\right|\right] \quad (3)$$

where ∇ is the gradient operator, $\nabla p(x, y)$ reflects the changes of adjacent gray level values of $p(x, y)$, $|\nabla p(x, y)|$ indicates the size of the changes and θ indicates the direction of the maximum change of gray level values. So, gradients of each point of the image form a vector field, which is the gradient field. We calculate the histogram of the image using the gradient values instead of the gray level values. In the histogram, the horizontal axis represents the gradient values and ordinate represents the frequency of the gradient values (the number of pixels). Fig. 2 shows an example of gradient magnitude field and gradient histogram of the infrared image.

To infrared images, most of the gradient values are small. And in the gradient histogram, the small gradient values have a high probability. However, the histogram equalization technology just tends to enhance the high probability information, increasing the small gradient values. Therefore, gradient histogram equalization can enhance the faint edge details. Gradient histogram equalization is defined as Eq. (4),

$$\begin{cases} s_k^g = \sum_{j=0}^{k} P_r(r_j^g) = \sum_{j=0}^{k} \frac{n_j}{n} \\ k = 0, 1, \ldots, |\nabla u_0|_{\max} - 1 \end{cases} \quad (4)$$

where s_k^g means the transformed probability which corresponded to the gradient value k, n is the total number of image pixels, $|\nabla u_0|_{\max}$ means the maximum gradient value, n_j means the number of gradient value j and $P_r(r_j^g)$ means the probability of the gradient value j. Equalization image $E^g[|\nabla u_0|]$ is expressed as Eq. (5):

$$E^g[|\nabla u_0|] = \left[\sum_{j=0}^{u_0^g(x,y)} P_r(r_j)\right] \cdot |\nabla u_0|_{\max} = \left(\sum_{j=0}^{u_0^g(x,y)} \frac{n_j}{n}\right) \cdot |\nabla u_0|_{\max} \quad (5)$$

where $u_0^g(x, y)$ represents gradient values of the image u_0. Gradient field of the image u_0 after equalization is represented as:

$$\mathbf{E} = \frac{\nabla u_0}{|\nabla u_0|} \cdot E^g[|\nabla u_0|] \quad (6)$$

where $\mathbf{E}$ is the gradient field after equalization, u_0 is the original image, $|\nabla u_0|$ stands for the gradient value of u_0, $E^g[|\nabla u_0|]$ represents the gradient histogram equalization and $\frac{\nabla u_0}{|\nabla u_0|}$ is to keep the direction of image gradient field unchanged.

For gradient field equalization, the enhancement effect is obvious to the image whose gradient values are uniform distribution. But for the infrared image with low contrast and fuzzy edge details, the gradient histogram shape is a narrow single peak and the gradient values are small. As shown in Fig. 2(c), the gradient values are about 0–50. Because the gradient histogram equalization makes the image gray level values to appear approximately equally distributed in the corresponding histogram, it excessively extends the dynamic range of the gradient values. So the enhancement image, reconstructed from the equalization gradient field, produces white spots due to the over-enhancement. Fig. 3 is an example of image enhancement. Fig. 3(a) is the gradient magnitude after equalization of the original image in Fig. 2(a), and Fig. 3(b) is the correspondent gradient histogram. It can be seen that the gradient values are extended to 0–200. So the reconstructed image is sharpened and has white spots as shown in Fig. 3(c).

In order to overcome above problem of gradient field equalization, we set two adaptive thresholds to increase small gradient values while suppressing the large gradient values. In this way the revised gradient values after histogram equalization are extended to 0–110 as shown in Fig. 3(e). Thus the reconstructed image has clear edge details and the over-enhancement is avoided, as shown in Fig. 3(f). This can also be seen from the gradient magnitude (Fig. 3(a) and (d)), where the revised gradient magnitude is not excessively enhanced. The revised gradient value is expressed as follows:

$$g' = \begin{cases} g_1 & |\nabla u_0| < g_1 \\ |\nabla u_0| & g_1 \leqslant |\nabla u_0| \leqslant g_2 \\ g_2 & |\nabla u_0| > g_2 \end{cases} \quad (7)$$

where g' represents revised gradient value, and g_1 and g_2 represent adaptive thresholds. To the selection of upper threshold g_2, if g_2 is too large, it will not effectively limit the high gradient value, and cannot prevent over-enhancement; if g_2 is too small, it will restrict the enhancement of image texture details. Therefore, this article makes g_2 less than the maximum gradient of image and greater than the average value of the maximum gradient of each column. The lower threshold g_1 is to enhance small targets and weak edge detail information. If g_1 is too small, the targets and weak edge

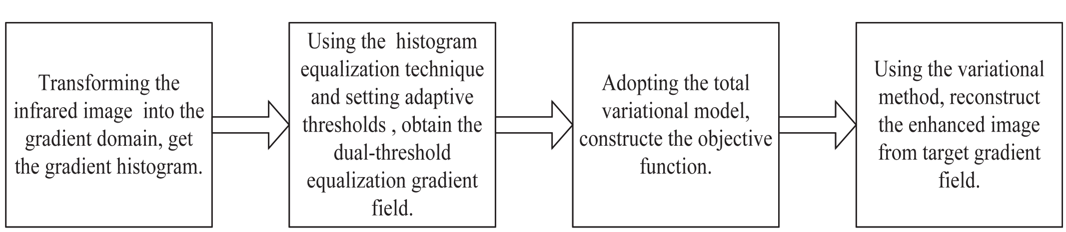

Fig. 1. The framework of infrared image texture details enhancement method.