Optik 125 (2014) 4039–4042

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Fast image enhancement using multi-scale saliency extraction in infrared imagery

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ARTICLE INFO

Article history:
Received 23 July 2013
Accepted 15 January 2014

Keywords:
Saliency extraction
Infrared image enhancement
Multi-scale

ABSTRACT

We propose a multi-scale saliency extraction based fast infrared image enhancement approach. A local frequency-tuned based saliency extraction technique is designed for highlighting the salient regions, firstly. Then, multi-scale saliency extraction is demonstrated, introducing multi-scale local windows with different sizes to extract regions of interest at different scales. Finally, the original image is enhanced with combining multi-scale salient image regions into one image. The experimental results prove the proposed approach is robust and efficient for infrared image enhancement.

1. Introduction

Image enhancement has been playing an important role in image processing. Since the complex imaging environment would decrease the quality of infrared image, especially in those target areas or regions of interest, it is important to enhance infrared image. And the image enhancement could be useful in many applications, such as target detection [1], and image fusion [2].

There are many image enhancement techniques. Actually, since the infrared image regions people interested are usually light or dark areas, histogram based algorithm are widely used [3,4], such as histogram equalization (HE) [3] and contrast limited adaptive histogram equalization (CLAHE) [4] method. Ni proposes an infrared image reconstruct method based on wavelet diffusion, which reduces noise in infrared images while enhancing and preserving edges [5]. However, this method could not well enhance low quality infrared image. With the help of knowledge of the physics of thermal diffusion, quantitative reconstruction is designed to enhance the thermal images [6], but increases noise levels. Bai has been tried to design multi-scale top-hat transform based infrared image enhancement algorithms [7,8]. However, the approach always runs slowly, which could not satisfy the demand of real-time application.

The visual saliency extraction is a popular topic recently [9], which could be widely used in target detection [10], image fusion [11,12]. Saliency detection could give out the image regions of interest, which is helpful for image enhancement. In this paper, we propose a fast infrared image enhancement algorithm using multi-scale saliency extraction. Firstly, we design a local frequency-tuned based saliency extraction technique to detect salient image regions. Secondly, with multi-scale local windows at different scales, multi-scale saliency extraction is proposed for extracting salient regions with different sizes. Finally, we finish image enhancement using multi-scale saliency extraction method. The experimental results indicate the proposed approach is robust and efficient for infrared image enhancement.

2. Mathematical theory

2.1. Visual saliency extraction

Visual saliency extraction plays an important role in image processing. For most of those methods, researchers usually utilize feature information to design algorithms, and the contrast of image regions relative to their surroundings is one of the most useful features. The frequency-tuned saliency region detection approach [9] could generate full resolution saliency maps, including well-defined boundaries of salient objects, and the largest salient objects in the image would be emphasized.

The visual saliency detection approach is derived from band-pass filter, with low frequency cut-off value υ_{low} and high frequency cut-off value υ_{high}. Two Gaussian functions are combined to design this model:

$$G(r, \sigma_1, \sigma_2) = g(r, \sigma_1) - g(r, \sigma_2) \qquad (1)$$

where $\sigma_1 > \sigma_2$. And $g(r, \sigma)$ is a Gaussian function, where $r^2 = x^2 + y^2$, standard deviation of the Gaussian function is σ. Furthermore, the

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http://dx.doi.org/10.1016/j.ijleo.2014.01.117
0030-4026/

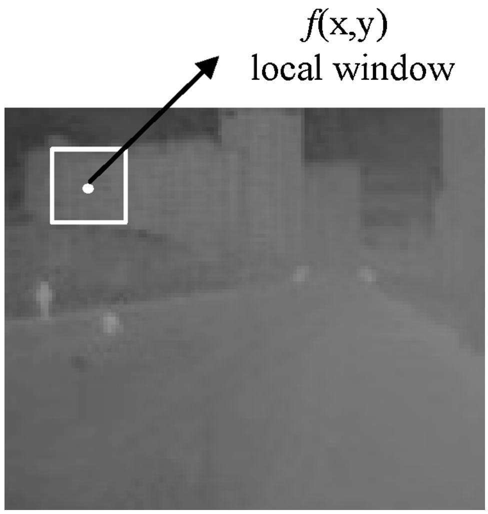

Fig. 1. For arbitrary pixel (*x*, *y*), the saliency value is calculated within a local $t \times t$ window, for single image.

low frequency cut-off value v_{low} is determined by σ_1, and v_{high} corresponding to σ_2.

For an arbitrary pixel (x, y), whose saliency value is determined by the difference of the band-pass result, then saliency map S is rapidly calculated:

$$S(x, y) = \left|f(x, y) * G(r, \sigma_1, \sigma_2)\right|^2 \quad (2)$$

where f is the original image, and * is convolution operator. And Eq. (2) could be expressed as

$$S(x, y) = \left|f_{\text{low}}(x, y) - f_{\text{high}}(x, y)\right|^2 \quad (3)$$

$$f_{\text{low}} = f * g(r, \sigma_1) \quad (4)$$

$$f_{\text{high}} = f * g(r, \sigma_2) \quad (5)$$

f_{low} and f_{high} are the results of Gaussian filter with low frequency cut-off value v_{low} and high frequency cut-off value v_{high}. S is saliency image with normalized value, $S \in (0, 1)$. This saliency map reflects the weight distribution of people's attention upon original image.

2.2. Local frequency-tuned based saliency detection

While in infrared imagery, the size of desired target areas and salient regions are usually uncertain under different condition [10]. Those targets sometimes are small, such as far distance objects. On the contrary, salient regions like roofs and buildings are large in image. We need a adaptive method to extract salient object with different sizes. Therefore, we improve this approach for further application.

For saliency analysis in infrared image, it is useful to apply the algorithm locally rather than globally, just as shown in Fig. 1. First, image statistical features are sometimes highly spatially nonstationary. Second, image saliency feature may or may not depend on the local image statistics, may also be space-variant. And finally, localized saliency analysis can provide a region-adaptively spatially varying saliency map of the image, which delivers more information.

As shown in Fig. 1, the saliency map is calculated within a local $t \times t$ window, which moves pixel-by-pixel over the entire image. The value of t has a great effect on saliency analysis. Just as shown in Fig. 2, saliency map is extracted with various t. According to the results in Fig. 2, different salient regions could be extracted with proper window size t.

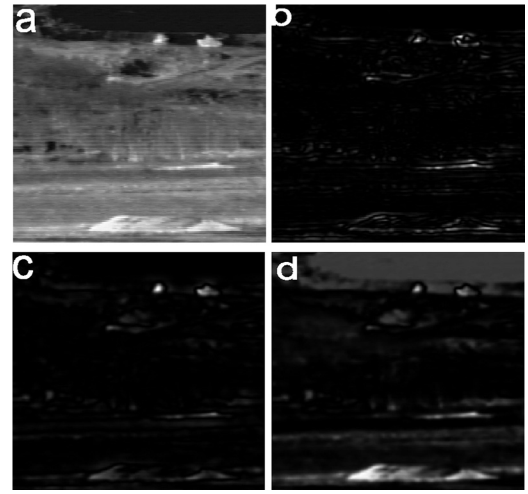

Fig. 2. Saliency extraction results with various t: (a) original image, (b)–(d) saliency map with local method (t = 10, 30, and 80).

3. Infrared image enhancement

3.1. Multi-scale saliency extraction

Multi-scale method has been an important theory in image processing [11,13]. With multi-scale method, the features of original image could be well detected. Using multi-scale theory, the above features would provide more information for various applications.

A new multi-scale saliency extraction method is designed for infrared image enhancement. With variable local window t, this method extracts regions of interest with different size. Local windows with different sizes will highlight different image regions at different scales. Therefore, this method using multi-scale local windows with different sizes would extract regions of interest at different scales, which is called saliency maps. These extracted multi-scale saliency maps could provide more useful image features for infrared image enhancement.

In this paper, square shape is adopted for local window. $t \times t$ is the size of local window. This multi-scale method could highlight image areas in infrared image with size corresponding to the size of local window. Suppose n scales are used, the size of the local window at each scale m $(1 \le m \le n)$ changes gradually as follows:

$$t = t_0 + m \times \Delta t \quad (6)$$

where t_0 is the basic size for local window, and Δt is the size increasing step for each scale. The used local window in the new saliency extraction is applied as shown in Fig. 1. With multi-scale saliency detection, we could obtain saliency maps at n scales, the mth $(1 \le m \le n)$ saliency map is calculated using Eq. (3):

$$Sm = S(f, m) \quad (7)$$

In Eq. (7), each pixel (x, y) of the saliency value $Sm(x, y)$ is calculated within a local $t \times t$ window, whose size can be obtain using Eq. (6).

3.2. Saliency based image enhancement

According to the definition of multi-scale saliency extraction, we need to enlarge the contrast for different image regions. The enhanced result at mth scale Em can be expressed as:

$$Em = f \circ Sm \quad (8)$$

where $\circ$ is component-wise multiplication operator. At each scale, image regions we interested with different size could be extracted