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Detail enhancement of blurred infrared images based on frequency extrapolation

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HIGHLIGHTS

- Novel detail enhancement method for infrared images.
- Reverse prediction of creating higher frequency component using pyramid decompensation of infrared images.
- Effective on blurred infrared images.
- Fast calculation speed of processing.

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ABSTRACT

A novel algorithm for enhancing the details of the blurred infrared images based on frequency extrapolation has been raised in this paper. Unlike other researchers' work, this algorithm mainly focuses on how to predict the higher frequency information based on the Laplacian pyramid separation of the blurred image. This algorithm uses the first level of the high frequency component of the pyramid of the blurred image to reverse-generate a higher, non-existing frequency component, and adds back to the histogram equalized input blurred image. A simple nonlinear operator is used to analyze the extracted first level high frequency component of the pyramid. Two critical parameters are participated in the calculation known as the clipping parameter C and the scaling parameter S. The detailed analysis of how these two parameters work during the procedure is figure demonstrated in this paper. The blurred image will become clear, and the detail will be enhanced due to the added higher frequency information. This algorithm has the advantages of computational simplicity and great performance, and it can definitely be deployed in the real-time industrial applications. We have done lots of experiments and gave illustrations of the algorithm's performance in this paper to convince its effectiveness.

1. Introduction

In recent years, many researchers focused on how to enhance the digital details of a raw infrared images captured by an infrared thermal imager. The modern thermal imagers provide images with very wide dynamic range of 14-bit or even more. This somehow exceeds the traditional 8-bit sensitivity of a typical monitor. Lots of dynamic-range compression algorithms have been raised to improve the image visual quality. For example, the widely used gamma correction methods [1], the automatic gain control (AGC) [2,3] and the histogram equalization (HE) based methods [4–8]. These methods are recognized as the fundamental methods of infrared image enhancement because of the simplicity. However, these methods works only at the histogram level to adjust the contrast of the raw infrared images, which makes them ineffective to enhance the digital details hide in the high dynamic infrared images.

The recent researches not only concentrate on the histogram level to adjust the contrast of the infrared images, but also focus on enhancing the details [9]. For example, in 2011, Zuo et al. [10] proposed a method of displaying and detail enhancing for high dynamic range infrared images called BF&DDE. This method used a bilateral filter to separate the raw image into different components as the detail layer and the base layer. These two layers were then processed separately and finally added back together to acquire an enhanced image. The visual improvement is significant according to the results. Meanwhile, this method still has a drawback, that is, when using the bilateral filter, the gradient flipping artifacts are doomed to appear. Although the adaptive Gaussian filter (AGF) has been applied, the "ghost edges" cannot be fully elim-

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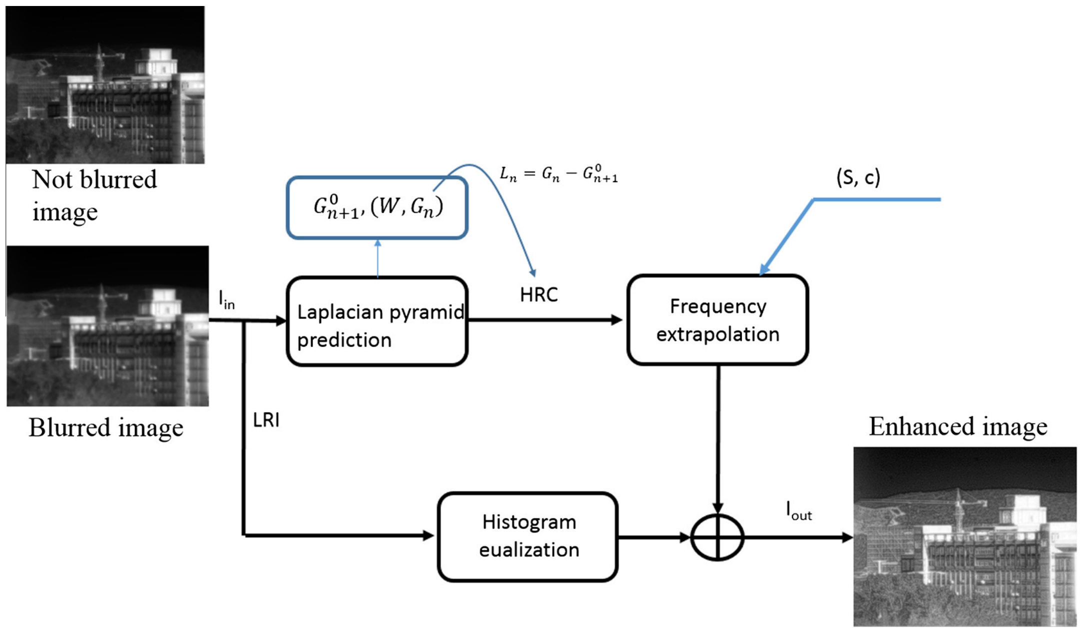

Fig. 1. Processing scheme of the proposed algorithm. Blue arrows indicate the corresponding parameters or procedure during the whole process. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

inated. In 2014, we proposed a novel method which could both enhance the detail and eliminate the "ghost edges" [11], because this method was based on a guided image filter (GIF) [12], we called it the GIF&DDE. In our method, we used a guided image filter to separate the raw images. The basic differences between guided image filter and the bilateral filter is that, the guided image filter is a linear filter, while the bilateral filter is a nonlinear filter. With the guided image filter, the strong edges can be separated from the raw image smoothly, and the AGF is not necessarily be used. The GIF&DDE greatly improves the enhancing quality and the computational efficiency. During our newest research, we find some existing problems of enhancing the images and will discuss them in this paper.

First, all the proposed methods are dealing with the unambiguous images with perfect in- focus setup. If the images are blurred because of the optical setup or the system motion, both these methods are failed. The figure demonstration will be shown in the following chapters. Second, the computational time of these methods are still time-consuming. Although the GIF&DDE has significantly reduce the processing procedure and the fast bilateral filter has been applied in BF&DDE, the computational time is still not that satisfying. In this paper, we propose a novel detail enhancement algorithm to conquer the raised problems. We design a new method that could enhance the blurred images and greatly reduced the computational time using the frequency extrapolation. The newly raised method uses a Laplacian pyramid to separate the original blurred images into low-resolution images (LRI) and high-resolution components (HRC). The HRC will be extrapolated in the frequency domain and used to retrieve the potential high-frequency information. The original input image will be properly histogram equalized at the same time. The frequency extrapolated HRC will be added back to the input image to create a clear, sharp and detail enhanced image. Experimental tests show that this method works effectively and efficiently.

2. The principle of the proposed algorithm

The basic strategy of our proposed algorithm is that, a high-resolution image can be obtained from a lower resolution one by adding a bandpass high frequency component. Moreover, a high-resolution component (such as an ideal edge) can be predicted from a low-resolution one. The processing scheme is shown as Fig. 1 as follows:

The whole procedure can be recognized as that, considering a blurred image, we use a bandpass Laplacian filter to create the pyramid of it. The resulting Laplacian pyramid consist of bandpass filtered versions of the blurred image, with each stage of the pyramid constructed by the subtraction of two corresponding adjacent levels of the pyramid. The pyramid can be characterized as Eq. (1):

$$\begin{aligned} G^0_{n+1} &= W \times G_n \quad n = 0 \ldots N-1 \\ L_n &= G_n - G^0_{n+1} \end{aligned} \tag{1}$$

where G^0_{n+1} represents the low resolution image series in the pyramid, G_n represents the input image series in each adjacent pyramid level, W represents the Laplacian bandpass filter. In this paper, a two dimensional filter module has been adopted as Eq. (2):

$$W = \frac{1}{256} \times \begin{bmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 1 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 1 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix} \tag{2}$$

L_n represents the high resolution component separated from adjacent pyramid levels. According to the pyramid structure, the next level of G_n should be the subsample of G^0_{n+1}. In this case, the next level of G_n can be described as Eq. (3):

$$G_{n+1} = Subsampled(G^0_{n+1}) \quad n = 0 \ldots N-1 \tag{3}$$

where G_{n+1} represents the next pyramid level of G_n. Once the value of n is determined, the n level of Laplacian pyramid can be acquired through Eqs. (1) and (3).

The whole pyramid structure is basically decomposed from top to bottom. That is to say, the original image can be separated into many levels, and each level contains the high resolution component and the low resolution image. This could be used to decompose a high resolution image into different low resolution