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Morphological infrared image enhancement based on multi-scale sequential toggle operator using opening and closing as primitives

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HIGHLIGHTS

- Proposing the sequential toggle operator.
- Extracting features by sequential toggle operator.
- Applying the feature extraction for infrared image enhancement.

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ABSTRACT

Infrared image enhancement is a crucial technique for improving the quality of infrared images. And, the clear image details are important information for infrared image analysis. To effectively enhance infrared image and make image details clear, a multi-scale sequential toggle operator based algorithm is proposed in this paper. Firstly, the sequential toggle operator, which uses opening and closing as primitives, is constructed and discussed. Secondly, the feature extraction in infrared image through the sequential toggle operator is given, and the multi-scale extension of the feature extraction is discussed in details. Finally, the extracted final features of infrared image are constructed and imported into the original infrared image to produce the enhanced image. In the enhanced image, the image features are enhanced well and the image details are clear. Infrared images which obtained from different environments are used in the experiment. The results show that, the proposed algorithm is very effective for infrared image enhancement.

1. Introduction

Infrared image is one type of very important information in infrared based optical applications, such as infrared imaging system [1], infrared surveillance system [2,3] and target recognition [4–6]. However, because of the effect of imaging equipment or environment, the obtained infrared image is usually not clear and has low contrast. Especially, the important regions in infrared image do not usually protrude. These would affect the analysis of these images. Therefore, enhancing infrared image would be very important.

Actually, in many cases, the infrared image which really needs to be enhanced usually has low quality, and the contrast and details of the image are not good. So, the crucial of infrared image enhancement is enhancing image well while making the details clear. To enhance infrared image and details, many methods have been proposed. Increasing the resolution of image is always useful for image based applications [7]. Also, modeling the physical imaging procedure may enhance infrared images [8,9]. But, if the imaging environment is bad or the grey distribution of the image is limited, the performances of these methods may be affected. Enhancing image through enhancing the visual effect is effective in some cases [10,11]. However, they usually need the color information, which may be not appropriate for enhancing infrared image with grey values. Noise filtering or edge enhancement has been used to enhance infrared image [12]. But, the performance would be ineffective if the quality of infrared image is low. Although histogram based algorithms [13–16] are used widely for image enhancement, the performance for enhancing image details is not good. This may affect the application of the enhanced image for image analysis or target recognition. Contrast adjustment is an effective way for enhancing infrared image [17–19]. However, the image details in the enhanced image may be unclear. Mathematical morphology is an important theory in image processing [20], which has been also used in infrared image

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processing, including the infrared image enhancement [18,20–22]. Enhancing small target in infrared image is useful for infrared target detection [21,22]. But, they are not easy to be extended for enhancing other types of infrared image. Constructing effective morphological operators by using the properties of infrared image is a useful way for infrared image enhancement [23]. But, some image details may be smoothed and the atmosphere effect may affect the performance of the algorithm. In summary, most of the algorithms could not be used effectively for enhancing infrared image, especially for enhancing the infrared image details.

Toggle operator is a useful morphological operator which could identify image details [20,24–26]. Moreover, redefining the toggle operator using opening and closing as primitives may extract the important image details [24]. These mean the toggle operator may be used well for detail maintained infrared image enhancement. Therefore, based on the toggle operator using opening and closing as primitives, an effective algorithm which could enhance infrared images and image details may be constructed.

In light of this, an effective algorithm for infrared image enhancement based on multi-scale sequential toggle operator is proposed in this paper. Firstly, the sequential toggle operator using opening and closing as primitives is shown. Secondly, the feature extraction of infrared image using the sequential toggle operator is proposed, and the multi-scale feature extraction through multi-scale extension is given in details. Finally, the extracted final features of infrared image are calculated based on the extracted multi-scale features, and the enhanced infrared image is produced by importing the extracted final features into the original infrared image. The main contributions of this paper are: (1) proposing the sequential toggle operator; (2) multi-scale extension of the feature extraction by sequential toggle operator; (3) applying the feature extraction for the application of infrared image enhancement. Experimental results on infrared images show that, the image features are enhanced well and the image details are clear. Therefore, the proposed algorithm could be used for detail maintained infrared image enhancement.

2. Mathematical morphology

2.1. Basic definitions

Most of the morphological operations are derived from two basic operations: dilation and erosion [20]. Dilation of image $f(x, y)$ using the structuring element $B(u, v)$ is defined as follows.

$$f \oplus B = \max_{u,v}(f(x-u, y-v) + B(u, v)).$$

$\oplus$ denotes the dilation operation. (x, y) and (u, v) are the coordinates of pixels in image f and structuring element B, respectively.Erosion of image $f(x, y)$ using the structuring element $B(u, v)$ is defined as follows.

$$f \ominus B = \min_{u,v}(f(x+u, y+v) - B(u, v)).$$

$\ominus$ denotes the erosion operation.

Opening and closing, which are the combinations of dilation and erosion through different ways, are defined as follows.

$$f \circ B = (f \ominus B) \oplus B,$$

$$f \bullet B = (f \oplus B) \ominus B.$$

$\circ$ and $\bullet$ represent the opening and closing operations, respectively. Opening and closing are usually used to smooth bright and dim image regions, respectively. This property could be used for feature extraction.

2.2. Toggle operator with opening and closing as primitives

Toggle operator has been a useful tool in image processing applications after being proposed [20,24,25]. Primitive and rule are two main factors in toggle operator. Suppose $f_1(x, y)$ and $f_2(x, y)$ are the primitives, one type of toggle operator is defined as follows [20,24,25].

$$TO(f)(x,y) = \begin{cases} f_1(x,y), & \text{if } f_2(x,y) - f(x,y) < f(x,y) - f_1(x,y) \\ f_2(x,y), & \text{if } f_2(x,y) - f(x,y) > f(x,y) - f_1(x,y) \\ f(x,y), & \text{else} \end{cases}.$$

The selection rules in this toggle operator indicate that, this operator extracts the image pixels which are more different from the original image f in the primitives $f_1(x, y)$ and $f_2(x, y)$. These image pixels usually represent the important features in image. So, this type of toggle operator would be useful for feature extraction.

The definition of the primitives in *TO* affects the performance of *TO* for feature extraction. Opening and closing are effective operators to smooth image features. Using opening and closing as primitives in *TO* would be very useful for extracting the important features [24]. This is effective for identifying the details of infrared image. The toggle operator using opening and closing as primitives could be expressed as follows [24].

$$TO(f)(x,y) = \begin{cases} f \circ B(x,y), & \text{if } f \bullet B(x,y) - f(x,y) < f(x,y) - f \circ B(x,y) \\ f \bullet B(x,y), & \text{if } f \bullet B(x,y) - f(x,y) > f(x,y) - f \circ B(x,y) \\ f(x,y), & \text{else} \end{cases}. \quad (1)$$

In this definition, the difference between the original image and the result of opening or closing is compared. And, the pixels in the result of *TO* are from the result of opening or closing. Each pixel has a relatively larger difference between the original image and the result of opening or closing. A larger difference indicates that the smoothed image features by opening or closing is more protruding in image. These features are important features in image. So, this definition of *TO* would be more useful for feature extraction.

Actually, the important image features in infrared image are usually protruding regions comparing with other regions. And, enhancing infrared image should enhance the image features which are different from other regions. *TO* in expression (1) could be used to extract features which protrude in image. So, the definition of *TO* in expression (1) could be used for enhancing infrared image.

3. Infrared image enhancement

3.1. Constructing sequential toggle operator

Image contains features at different scales. Extracting the multi-scale features would be effective for image processing. In mathematical morphology, using multi-scale structuring elements with increasing sizes is a good way to extract the multi-scale features [23,24,26–28]. Suppose $B_1, \ldots, B_n$ are the multi-scale structuring elements with increasing sizes. $B_i = \underbrace{B_1 \oplus B_1 \cdots \oplus B_1}_{\text{dilation } i \text{ times}}$, $1 \leqslant i \leqslant n$. Based on these multi-scale structuring elements, the sequential toggle operator could be defined as follows.

$$TO_i(f) = TO_i(TO_{i-1}(f)).$$

$$TO_0(f) = f.$$

An illustration of the sequential toggle operator TO_i using the multi-scale structuring elements is shown in Fig. 1. In this definition, the sequential toggle operator uses the multi-scale