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Real-time visual enhancement for infrared small dim targets in video

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HIGHLIGHTS

- Temporal cues are incorporated to perform visual enhancement.
- The target intensity is enhanced via accumulating along the trajectory extracted by DPA.
- An adaptive manner is presented to eliminate the sharp edge in merging.
- The target's prior shape information is adopted in clutter suppression and adaptive merging.

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ABSTRACT

Visual enhancement for infrared small dim targets is a standing problem in infrared image processing. Existing approaches cannot enhance the target well and suppress the background simultaneously, especially for targets which are so faint that they are hardly visible. This paper proposes a novel real-time visual enhancement algorithm for infrared small dim targets in video by introducing temporal cues. In this work, Dynamic Programming Algorithm (DPA) is used to detect the target's trajectory in the video and the target is enhanced through energy accumulation along the trajectory. The shape prior of the small dim target is adopted for background suppression and adaptive merging. Experimental results on real infrared small dim target videos indicate that the proposed algorithm can improve the visual quality of these types of images notably, especially for cases in which the target is hardly visible. In addition, the proposed algorithm takes on average 8.35 ms to process a $320 * 256$ image, and thus meets the needs of real-time applications.

1. Introduction

Due to its advantages of all-weather operation, detecting and anti-jamming abilities, infrared imaging equipment has been widely used in military reconnaissance, traffic monitoring, weapon guidance, space target surveillance, etc. This paper focuses on the visual enhancement of small dim infrared targets in video captured during space target surveillance in order to obtain high-quality images. In space target surveillance, infrared imaging equipment is often used in long-distance space target detection to compensate for the deficiency of visible light equipment. As a result of long distance imaging, the target's energy is affected heavily by air turbulence, scattering, etc., and thus it is weak, while the Signal to Noise Ratio (SNR) of the captured image is low. This results in low quality images which are difficult to interpret. Visual enhancement for infrared small dim target has a great significance in extending the observation distance of infrared imaging equipment.

Infrared image enhancement has been studied for a long time. Traditional methods use the global information of the image to perform the enhancement, e.g. histogram-based methods, gradient domain-based methods, etc. These enhancement methods are not specifically designed for infrared images with small dim targets. In these types of images, the target constitutes only a small part of the infrared image while the background is the dominant component. Global information-based algorithms tend to over-enhance the background but the target is not highlighted properly. Infrared small dim target detection has been well studied. Target enhancement (e.g. mathematical morphology-based algorithms, filtering-based algorithms, etc.) is often used as a preprocessing step during detection to improve the Signal-to-Clutter Ratio (SCR) of the local region which contains the target. However, it does not focus on improving the visual quality of the infrared small dim image. The background is often completely removed in the enhanced result

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and in turn the result cannot be visually interpreted. To the best of our knowledge, no existing visual enhancement algorithm is specially designed for infrared small dim target in video, especially for extreme cases in which the targets are so faint that hardly visible. Additionally, existing enhancement algorithms mainly depend on spatial cues captured from a single image. However, spatial cues may be inadequate to perform visual enhancement for extreme cases in which targets are so weak that hardly visible. Therefore, existing algorithms do not improve the visual quality of infrared small dim target images in a satisfactory manner. Temporal cues in image sequences should be introduced in visual enhancement for infrared small dim target.

This paper tackles the problem of visual enhancement of infrared small dim targets in video by using the spatial and temporal information contained in the image sequence and the prior of the target shape. We attempt to improve the visual quality of the image further by enhancing the target and at the same time appropriately suppressing the background. In typical images of this type, the target's energy is very weak as a result of long-distance imaging, and, in extreme cases, the observer cannot distinguish the target from the background. Determining by the characteristic of the infrared sensor, the small dim target is often modeled as a Gaussian spot.

Based on the above analysis, this paper proposes a new visual enhancement algorithm for infrared small dim targets in video. First, we adopt DPA to track the target and enhance the latter through accumulation of the target-centered local regions along its trajectory. Next, the accumulated target-centered local region is weighted by a Gaussian mask to suppress clutter around the target. Finally, the processed target-centered local region is embedded back into the input image in an adaptive merging manner. During this merging operation, the intensities of the pixels in the local region are selected as adaptive weights.

We evaluated the proposed algorithm on real infrared videos including small dim targets. Comparisons between our algorithm and typical enhancement algorithms are also performed. Experimental results show that the proposed algorithm can notably enhance the target and suppress the background appropriately. The visual quality of the infrared video was markedly improved, even for videos in which the targets are so faint that hardly visible.

The rest of the paper is organized as follows: related works are summarized in Section 2. Section 3 contains an analysis of the characteristics of the target and the background in infrared image sequences containing small dim targets. We explain the proposed algorithm in detail in Section 4, while in Section 5 experimental results are presented. Finally, Section 6 concludes the paper.

2. Related works

Histogram Equalization (HE) [1] is widely used in infrared image enhancement. However, it is unsuitable for the enhancement of infrared small dim target images, as the background is the dominant component of the image and occupies most of the valid gray levels, while the target only uses few gray levels. Thus, equalizing the histogram of the whole image causes the over-enhancement of the background. Plate Histogram Equalization (PHE) [2] introduces a plate value to control the equalization. Contrast Limited Adaptive Histogram Equalization (CLAHE) [3] performs the plate histogram equalization in local parts of the input infrared image. Modifications to HE, PHE, CLAHE, etc., also tend to over-enhance the background. Hu et al. [4] adopted adaptive median and homomorphic filtering for infrared image enhancement. In [5], Kim et al. performed contrast enhancement in the gradient domain. Their algorithm enhances local contrast and preserves global contrast simultaneously.

The wavelet transformation plays an important role in image processing. Zhang et al. [6] introduced the Discrete Stationary Wavelet Transform (DSWT) to enhance the contrast of infrared image. Wang et al. [7] suppressed noise by manipulating the wavelet coefficients. Then, a nonlinear transformation was applied to the wavelet coefficients based on Weber theory to enhance the target. The wavelet transformation based methods suffer from the ringing effect and the under-enhancement of the details. The contourlet transformation is more powerful than the wavelet transformation in representing contours and textures. Shi et al. [8] use the contourlet transformation to decompose the infrared image at different scales and directions. The beta function is applied in the low frequency domain to enhance global contrast. A non-linear gain function is adopted to process the coefficients at the different scales. The enhanced image is obtained through the transformation of the processed coefficients back to the spatial domain.

Lee et al. [9] tackled infrared small dim target enhancement from the perspective of saliency analysis. The authors enhanced the target based on the assumption that the target is brighter that the surrounding background and that the target's shape can be modeled as a Gaussian distribution. The enhanced result was obtained by merging the temperature and the Difference of Gaussian (DoG) maps. Motivated by models of the visual attention mechanism, Qi et al. [10] introduced the quaternion Fourier transformation in infrared small dim target enhancement.

As mentioned in Section 1, enhancement is often treated as a preprocessing step in infrared small dim target detection. Mathematical morphology operations are simple and have been widely used in small infrared target processing [11–15]. Zhou et al. [12] used the top-hat filter group to enhance the target and suppress the background at the same time. Bai et al. [11] extended the top-hat transformation to the top-hat selection transformation for infrared small dim target enhancement, where the parameters used in the transformation were calculated based on the properties of the target region. In [15], the authors pointed out that in infrared images the target's intensity is higher than that of the surrounding background's, and designed a structuring element used in erosion and dilation specifically for infrared small target enhancement. The hit-or-miss transformation [13] and toggle contrast operator [14] have also been used to enhance infrared small dim target images. A local kernel method for small infrared target detection was proposed in [16]. The authors trained a weighted local model to preserve background while removing target in infrared images. In order to suppress the strong edges in infrared images, modifications [17,18] were made on the infrared patch image model. Dai et al. [17] incorporated structural prior information in separating small target from background. The weight is adaptive for each column according to structure prior in the weighted infrared patch image model. [18] adopted non-negative constraint and separated the target from the background via minimizing the partial sum of singular values. Xie et al. [19] proposed a novel algorithm called accumulated center-surround difference measure to detect small target in heterogeneous area. These algorithms are designed to improve the performance of infrared small dim target detection, not the visual quality of the input image.

The algorithms discussed above perform target enhancement using cues from a single image. However, the infrared small dim target may be so faint that hardly visible to the observer in extreme cases, the above mentioned algorithms may not yield satisfactory results. What's worse, the small dim target may be lost in the output enhanced result. The spatial cues from a single image are inadequate for the visual enhancement of infrared small dim target, especially for hardly visible small dim targets. The visual enhancement for infrared small dim targets may benefit from the temporal cues contained in image sequences. Temporal cues have been widely used in visual target tracking [20,21]. Unfortunately, the