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An improved contrast enhancement algorithm for infrared images based on adaptive double plateaus histogram equalization

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HIGHLIGHTS

- An improved adaptive contrast enhancement algorithm for infrared images is proposed.
- A new parameter is introduced to characterize the level of contrast enhancement.
- The thresholds used in the algorithm is determined adaptively.
- The algorithm yields stable and satisfactory results under different scenarios.

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ABSTRACT

Infrared thermal images can reflect the thermal-radiation distribution of a particular scene. However, the contrast of the infrared images is usually low. Hence, it is generally necessary to enhance the contrast of infrared images in advance to facilitate subsequent recognition and analysis. Based on the adaptive double plateaus histogram equalization, this paper presents an improved contrast enhancement algorithm for infrared thermal images. In the proposed algorithm, the normalized coefficient of variation of the histogram, which characterizes the level of contrast enhancement, is introduced as feedback information to adjust the upper and lower plateau thresholds. The experiments on actual infrared images show that compared to the three typical contrast-enhancement algorithms, the proposed algorithm has better scene adaptability and yields better contrast-enhancement results for infrared images with more dark areas or a higher dynamic range. Hence, it has high application value in contrast enhancement, dynamic range compression, and digital detail enhancement for infrared thermal images.

1. Introduction

The contrast of infrared images that reflect the thermal-radiation distribution of a scene is usually low [1–3], making it difficult to distinguish the details from the background. Hence, it is necessary to enhance the contrast of infrared images to improve the extraction of scene details and targets of interest [4]. Histogram equalization (HE) is a popular algorithm for image contrast enhancement [5] and quite many newly developed contrast-enhancement algorithms are still based on it [6–11]. HE maps input gray levels to output gray levels based on the cumulative histogram of the original image so that the histogram of the enhanced image is as close as possible to a uniform distribution, thus enhancing the contrast of the scene. However, if the histogram equalization is directly used for enhancing the infrared images, the background and noise that occupy more pixels may be over-enhanced, whereas the targets and details that occupy fewer pixels may be constrained, thereby making the enhanced infrared images unsuitable for subsequent analysis [12].

To solve this problem, researchers proposed plateau histogram equalization and used a threshold value to limit the background and noise [13]. In 1996, a plateau equalization algorithm wherein the plateau value is adjusted based on the input parameter was proposed [14]. However, a complex iterative calculation procedure is required to obtain the plateau value and the result strongly depends on the input parameter. In 2005, a self-adaptive plateau histogram equalization (SPHE) algorithm was proposed [15,16]. Compared to the algorithm given in Ref. [14], fewer calculation steps are required in the SPHE algorithm and the plateau value can be adjusted more adaptively. However, image details that occupy fewer pixels might not be sufficiently enhanced. In 2008, a double plateaus histogram equalization algorithm was proposed [17]. In this algorithm, in addition to the upper plateau threshold,

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a lower plateau threshold is added to further improve the details. The upper and lower plateau thresholds are set as 20–30% and 5–10% of the total number of image pixels, respectively, based on experience. The disadvantage of this algorithm is that the plateau thresholds are calculated based on only the number of pixels, regardless of the image content. Hence, the thresholds cannot be changed based on the information from the observed scenes. In 2012, an adaptive double plateaus histogram equalization (ADPHE) algorithm was proposed [18]. Although the ADPHE yields satisfactory enhancement results for general scenes, the length of the one-dimensional local window affects the upper plateau threshold; moreover, there is no method to determine the appropriate window length [18]. Further, when objects with strong infrared radiation are present in the scene, the algorithm may fail to enhance the surroundings, implying that the adaptability of the algorithm is unsatisfactory. In 2014, FLIR corp. employed a contrast enhancement algorithm named information based histogram equalization (IBHEQ) in the image processing module of their long-wave infrared camera product Quark2 [19]. The algorithm is a different type of plateau histogram equalization wherein the pixels are weighted based on an information threshold [20]. As the plateau and information thresholds may not appropriately change according to scene content, the adaptability of the algorithm is somewhat limited.

In this study, an improved contrast enhancement algorithm for infrared images is proposed based on the ADPHE. Based on the principle of feedback and adjustment, the normalized coefficient of variation of the histogram (NCVH), which characterizes the level of contrast enhancement, is introduced as feedback information. The two plateau thresholds are constantly adjusted until the NCVH is limited to a desirable level. The experimental results show that the proposed contrast enhancement algorithm performs well and stably in enhancing different scenes. In addition to the contrast enhancement, the algorithm could compress the dynamic range of the infrared image data, which is usually from 14-bit to 8-bit, thus making the enhanced infrared images more suitable for conventional display devices to output and for human eyes to observe.

2. Contrast enhancement algorithm for infrared images based on ADPHE with limited NCVH

2.1. Double plateaus histogram equalization

The double plateaus histogram equalization is an improved version of the plateau histogram equalization. In the algorithm, two plateau thresholds T_{up} and T_{down} are used to modify the histogram. The statistic values of the histogram that are greater than the upper threshold T_{up} are set as T_{up}, whereas the ones smaller than the lower threshold T_{down} but larger than zero are set as T_{down}, and the rest remain unchanged. The algorithm can be expressed in the following equation [18]:

$$H_m(g) = \begin{cases} T_{up} & h(g) \geqslant T_{up} \\ h(g) & T_{down} < h(g) < T_{up} \\ T_{down} & 0 < h(g) \leqslant T_{down} \\ 0 & h(g) = 0 \end{cases} \tag{1}$$

where g is the gray level, $h(g)$ is the original histogram, and $H_m(g)$ is the histogram modified using the two plateau thresholds.

In the algorithm, the upper plateau threshold is set for avoiding over-enhancement of the background or noise with typical grayscales, and the lower plateau threshold is set for protecting details with atypical grayscales from being merged with other grayscales. Clearly, the double plateaus histogram equalization is similar to the histogram equalization, except that the modified histogram is used instead of the original to determine the cumulative histogram, and subsequently, generate the contrast-enhanced image. The equalization can be expressed in the following equation:

$$F(k) = \sum_{j=0}^{k} H_m(j) \quad (0 \leqslant k \leqslant M) \tag{2}$$

$$D(k) = \left\lfloor \frac{R \cdot F(k)}{F(M)} \right\rfloor \tag{3}$$

where $F(k)$ is the cumulative histogram, M is the total number of original gray levels, $D(k)$ is the reconstructed gray level of the original gray level with a value of k, R is the maximum gray level, which is generally 255 after grayscale mapping, and $\lfloor\ \rfloor$ rounds down a value to the nearest integer. When R is set to 255, the original gray levels are mapped to the interval [0, 255], which is exactly the range of 8-bit data. Because the data width of the original infrared image is generally 14-bit, the algorithm actually completes both the contrast enhancement and dynamic range compression at the same time.

2.2. Normalized coefficient of variation of the histogram

The coefficient of variation (CV) is a standardized measure of the dispersion of the probability distribution, which is defined as follows [21]:

$$CV = \frac{\sigma}{\mu} \tag{4}$$

where σ and μ are the standard deviation and mean value of the data, respectively.

In this study, the NCVH is defined as the ratio of the CV of the modified histogram to that of the original histogram:

$$R_{CV} = \frac{CV_1}{CV_0} \tag{5}$$

where CV_0 and CV_1 are the CVs of the original and modified histograms, respectively. There are two extreme cases after modifying the histogram:

(1) The modified histogram is exactly the same as the original histogram, i.e., $R_{CV} = 1$.
(2) The modified histogram becomes a uniform distribution, i.e., $R_{CV} = 0$.

With the decrease in the upper plateau threshold or the increase in the lower plateau threshold, the high and low outliers of the histogram are limited to the upper and lower plateau levels respectively, and the R_{CV} will change from 1 to 0 accordingly.

The results of the contrast enhancement experiments on many different infrared images show that R_{CV} can characterize the contrast enhancement level of the image to a certain extent. Moreover, the enhancement results are usually satisfactory when R_{CV} is approximately 0.5. As an example, Fig. 1 shows six different enhanced images of the same scene using the double plateaus histogram equalization with different R_{CV}s. Based on the order of the top to bottom and left to right, the upper plateau threshold T_{up} decreases accordingly whereas the lower plateau threshold T_{down} is set as 10, except in Fig. 1(a), wherein T_{down} is set as 0. The grayscale and display ranges of the original infrared image are [6397, 8192] and [0, 255], respectively. Fig. 1(a) shows that the global contrast of the enhanced image is the strongest among all the six images. However, in the high-brightness areas near the building and cars in the upper left of the image, the grayscale merge is pronounced, thus resulting in poor local contrast. Actually, when R_{CV} is equal to 1, the double plateaus histogram equalization becomes the global histogram equalization (GHE). With the decrease in the upper plateau threshold, R_{CV} decreases gradually. When R_{CV}