Research of enhancement algorithm for infrared image based on the fuzzy set theory

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Abstract. Infrared image s is always company with various common defects such as the imaging blurring, poor contrast, and low discrimination rate between the target and the background, etc. According to the disadvantages, this paper discusses the traditional algorithm based on the fuzzy set theory proposed by Pal and King, moreover, we develop the algorithm to boost the fuzzy set theory in image details missing. For realizing the image contrast stretching adaptively, we employed the improved sine function as the membership functions well as select the pixels transit point of the infrared image adaptively by the average grey value and the standard deviation in terms of the infrared image. The results of the simulation by MATLAB show that the improved fuzzy algorithm conducted in this paper enhances the infrared image subtle details, improves the contrast of the infrared image and the visualization of the infrared image.

1 Introduction
The infrared technology with the outstanding advantages such as the penetration, the concealment, the strong anti-interference ability, the suitable for the night and bad weather as well as the infrared technology, has been extensively implemented in perceive navigation, security monitoring and other military or civilian fields. Nevertheless, the infrared image reflects the spatial distribution of the infrared radiation for the observed objects, and the scene temperature or radiation difference approximately. Defects such as imaging blurring, poor contrast, and low discrimination between the target and the background are always occurred by the small difference temperature, huge image system inflection by the transmission of the atmosphere, and optical and the electronic devices. For these reasons, improving quality of the infrared images, contrast, and the visual effects enhancement for the subsequent processing are become urgent challenges.

The image enhancement technology is facilitated to improve the visual effect of the images or transform the images to suitable for the human eyes or the machine analysis according to the theory by Pratt [4], and highlight the interest part information in the images by the technology of image enhancement. The common enhancement methods are include grey stretch, histogram equalization, correction, smoothing, and sharpening, etc. In recent years, many researchers have been investigated the image processing technology based on the fuzzy sets theory, because of the outstanding advantages in deal with uncertain information, and better result than traditional methods in the images enhancement. The fuzzy sets theory firstly applied to images enhancement is proposed by Pal and King, however the fuzzy sets theory of Pal and King decreases the quality of the infrared images by cutting so much lower grey value of the original image to the zero, and lost some grey information. Using the improved sine function as the membership function, selecting the pixels transit point of the infrared image adaptively by the average grey value as well as the standard deviation of the infrared image, our method realized the contrast stretching adaptively for the infrared images.
In this paper, part 2 describes the concept of the fuzzy sets theory and enhancement algorithm based on the fuzzy sets by the Pal and King; part 3.1 analyses the limitations of the fuzzy enhancement algorithm of Pal and King. According to these deficiencies, part 3.2 presents the sin function as the fuzzy enhancement membership function, and the part 3.3 uses the average grey value and the standard deviation of the infrared image as the transit point. According to the membership function in the Part 3.2 and the transit point of the infrared image in the Part 3.3, part 4 processes the fuzzy sets theory enhancement for the infrared image in the MATLAB experimental environment, and compare with the fuzzy enhancement algorithm of Pal and King. The result shows that the infrared enhancement images by the fuzzy sets theory algorithm in this paper have the higher contrast, sharper edges, and informative details, which is better than the enhancement algorithm based on the fuzzy sets theory by the Pal and King.

2 The fuzzy enhancement algorithm of Pal and King

In accordance with the concept of fuzzy sets, an image X which with the M × N-dimensions and L-gradations, can be treated as a fuzzy set point matrix, denoted X as:

\[
X = \begin{pmatrix}
\frac{p_{11}}{x_{11}} & \frac{p_{12}}{x_{12}} & \cdots & \frac{p_{1n}}{x_{1n}} \\
\frac{p_{21}}{x_{21}} & \frac{p_{22}}{x_{22}} & \cdots & \frac{p_{2n}}{x_{2n}} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{p_{m1}}{x_{m1}} & \frac{p_{m2}}{x_{m2}} & \cdots & \frac{p_{mn}}{x_{mn}}
\end{pmatrix}
\] (1)

Where: \(x_{mn}\)is the certain features level of the \(x_{mn}\), the \(x_{mn}\) is the\( mn-th\) pixel of the image \(X\), and \(p_{mn}(0 < p_{mn} < 1)\). The procedure which is transformed from the spatial domain \(x_{mn}\) to the fuzzy domain \(p_{mn}\) in the image often referred to as the image blurring, and in the process need to select a mapping \(G\) as a membership function, the commonly membership function always used the standard fuzzy S-function, the classic PAL, and the sine function and so on.

In classic fuzzy image enhancement algorithms, Pal and King select the membership function is[5]:

\[
\mu_{mn} = G(g_{mn}) = \left[1 + \frac{g_{max} - g_{mn}}{F_d}\right]^{-F_e}
\] (2)

Where: \(F_e\) and \(F_d\) are conversion coefficient, \(g_{max}\) is the maximum grey value of the image, \(g_{mn}\) is the grey value of the current pixels.

For amend the membership by using the return calls of the fuzzy enhancement operator to blur enhancement processing for the image. The convert formula is as following:

\[
T(\mu_{mn}) = \begin{cases} 
2[\mu_{mn}]^2, & 0 \leq \mu_{mn} \leq 0.5 \\
2[1 - \mu_{mn}]^2, & 0.5 \leq \mu_{mn} \leq 1
\end{cases}
\] (3)

Transformed the data from the fuzzy field to the spatial domain of infrared images by inverse transform to generate new grey level. The formula is:

\[
g'_{mn} = G^{-1}(\mu'_{mn}) = g_{mn} - F_d\left[\left(\mu'_{mn}\right)^{\frac{1}{F_e}} - 1\right]
\] (4)

3 Improvement of the fuzzy enhancement of algorithms

The fuzzy set theory of Pal and King cut the lower grey value of the original images to the zero, so the enhancement images lost a part of the grey information and affect the quality of the infrared images.
3.1 Analysis the fuzzy algorithm of Pal and King

As transit points when $\mu_{mn} = \mu_c$ and $T(\mu_c) = 0.5$ by the formula (2) (3):

$$F_{\mu} = \frac{\mu_{max} - \mu_c}{\mu_{c} - 1}$$

As can be seen in Figure 1, the minimum of $\mu_{mn}$ is not zero, which means there is no solution when inverses transform, lower grey value of the original images be cut to the zero, and lost a part of the grey information and affecting the quality of the enhancement images [1].

![Mapping curve of μ and x](image)

Fig.1. Mapping curve of $\mu$ and $x$

As the following 4 deficiencies according to analysis the fuzzy enhancement algorithm by Pal and King [3]:

1) The selection of fuzzy enhancement threshold (transit point) is random getting through the experience or several attempts, but different thresholds will have great influence for the fuzzy enhancement algorithm;

2) The fuzzy set theory of Pal and King lose lower grey value of the original images to the zero, and lost a part of the grey information and affecting the quality of the enhancement images;

3) The algorithm used the complex fuzzy membership function in the transformed processing from the grayscale space to fuzzy space and the inverse transformation $F(\bullet)$ and $F^{-1}(\bullet)$, and there are disadvantages as great computation, time-consuming and more. In addition, the choice of the iterations is blind in the processing of the fuzzy enhancement;

4) The fuzzy enhancement algorithm by Pal and King cannot meet the enhancement requirements for the different types of the infrared images, when the value of the $\mu_c$ is equal to 0.5 in $F_{\mu}$ transformation. There are huge different enhancement results for the different images by this algorithm.

3.2 The selection of the membership function

Select the relative grey level as a fuzzy feature, and chose the sine membership function to the fuzzy enhanced according to the gradation characteristics of the infrared images, which can avoid losing numbers of grey-scale information. In the meaning time, the selection of the optimal parameters speedily, ensures the quality of the enhanced images and improve the viability and efficiency of the algorithm. The definition of the sine membership function is[9]:

$$\mu_{mn} = \left[\sin\left(\frac{x_{mn} - x_{\min}}{x_{\max} - x_{\min}}\right)\right]^{\frac{1}{2}}$$

(6)
\(x_{\text{max}}\) is the maximum gradation and \(x_{\text{min}}\) is the minimum gradation of the infrared image, the \(r\) is the iterations. The membership function can improve the computing speed, and reduce losing the information of grey-scale which relative to the exponent of the Pal and King’s algorithm, in order to enhance the image contrast, select \(r = 2\) according to empirical values.

### 3.3 The selection of adaptive coefficient

Since dynamic range of the grey value is small of infrared image, with rarely fill the entire grayscale space, and the most of pixels concentrated in the certain adjacent pixel grayscale, which means the others are outside of the range have few or no pixels. The average grey value \(\bar{X}\) reflects the level of light and dark, and the standard deviation \(\sigma\) reflects the contrast of the infrared images. As long as the \(\bar{X}\) and \(\sigma\) of the infrared images can be valued automatically, which can achieve the processing adaptively [7]. In order to achieve enhanced adaptively, the selection of the transit point \(x_{t}\) is based on the idea in this paper. The definition of the average grey value and standard deviation of the infrared images are [10]:

\[
\bar{X} = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} x_{i,j}
\]

\[
\sigma = \frac{1}{m \times n} \left( \sum_{i=1}^{m} \sum_{j=1}^{n} (x_{i,j} - \bar{X})^2 \right)^{1/2}
\]

Take advantage of the average grey value and standard deviation of the infrared images to selected the transit point \(x_{t}\), to realize the adaptive infrared images enhancement. The selection of the adaptive coefficient \(x_{t}\) is:

\[
x_{t} = \bar{X} + \sigma
\]

### 4 Result and conclusion

The experimental environment:

- **Hardware**: Processor Intel (R) Core (TM) i5-2450M CPU @ 2.50GHz
  - Memory 8.00GB
- **System Environment**: Windows 10 Professional Edition
- **Software**: MATLAB R2015a

The selection of the membership functions and the adaptive coefficient according to the formula (6) and the formula (9), and the simulation result shows as the fig.2 and the fig.3.
Fig. 2 The original image of the house, the fuzzy enhancement image of Pal & King, this paper algorithm and the histogram.

Fig. 3 The original image of the tree, the fuzzy enhancement image of Pal & King, this paper algorithm and the histogram.
The image entropy of the two original images, comparison between the fuzzy enhancement images by the Pal & King and algorithm in this paper, and the entropy of the infrared image are show in table 1.

Table 1. The table of the entropy comparison

| image | original | Pal & King | this paper |
|-------|----------|------------|------------|
| house | 5.4420   | 5.9676     | 6.0290     |
| tree  | 5.6687   | 5.7905     | 5.9539     |

Compared to the Pal and Kings’ original method, the enhancement fuzzy algorithm in this paper is demonstrates a preferable performance in the figure.2 and figure.3, it also reserves detailed information of the original infrared images shows as the table 1. Therefore, the image enhancement algorithms in this paper performs expresses a higher contrast, sharper edges, detailed and human eye discrimination.

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