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Research Article

Infrared and Low-Light-Level Image Fusion Quality Evaluation Based on the Grey Correlation Analysis

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Abstract: In this study, we evaluate comprehensively the indexes of the five image fusion algorithms through the analysis of grey correlation degree. The result shows: HIS transform method shows a better correlation and the fusion image has the best quality; followed by the component transform method, wavelet transform method, weighed average method with an average fusion image quality and pyramid method shows a relatively poor fusion image.

Keywords: Algorithm evaluation, grey correlation degree, image fusion

INTRODUCTION

With the rapid development of image and computing technology, multi-sensor image fusion is one of the important phenomena. The target of image fusion is to fuse the complementary or redundant information obtained by multi-sensors into one image; the quality of the fusion image reflects the correctness and technical level of the adopted fusion methods; therefore, its evaluation has always been the focus of research in image field (Wang *et al.*, 2012).

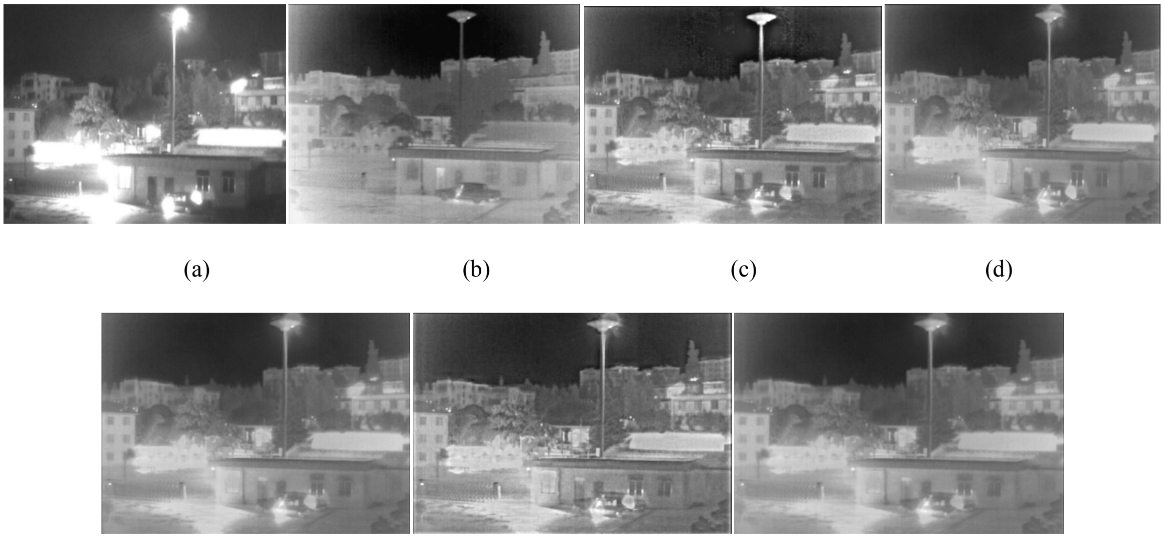
The evaluation on the image fusion effect can be divided into two categories: subjective effect evaluation and objective index evaluation. The subjective evaluation methods, such as MOS (Mean Opinion Score) (Pan *et al.*, 2010), is to enable the observers to score the same image in accordance with the visual effect and give a comprehensive score to the image quality through weighted average. This method may be impacted by various factors, including the knowledge background, mood, fatigue degree of the observer and has a complex procedure and will take much time and the stability and portability of the evaluation result are poor (Jiang *et al.*, 2010). The objective evaluation method for the image fusion effect is to quantitatively evaluate the image fusion effect by calculating certain indexes; this method is more intuitive and easier to compare, but the objective methods are various in types and there are greater differences between the corresponding calculation results; therefore, there is no well recognized reasonable evaluation method can be used by the researchers (Tian, 2010).

At present, a large number of image fusion methods have been put forward; the different characteristics, test environments and application conditions of these image fusion algorithms make it difficult to determine a specific algorithm for practical application; therefore, it is required to evaluate these algorithms, on one hand, the evaluation may provide different indexes performances to select appropriate image fusion algorithm in accordance with the demand; on the other hand, the evaluation may reveal the inadequacy of the algorithm to direct the corresponding improvement. On the basis of the evaluations on the various image fusion algorithms, this study calculates out the grey correlation degree between the reference sequence and comparative sequence and evaluates reasonably the advantages and disadvantages of each image fusion quality algorithm, providing a new method for image fusion algorithm evaluation.

In this study, we evaluate comprehensively the indexes of the five image fusion algorithms through the analysis of grey correlation degree. The result shows: HIS transform method shows a better correlation and the fusion image has the best quality; followed by the component transform method, wavelet transform method, weighed average method with an average fusion image quality and pyramid method shows a relatively poor fusion image.

METHOD OF STUDY

Analysis method of grey correlation degree: Grey system theory is first proposed in 1982 by Professor Deng Julong and is a new method (Zhang, 2012) for studying less data, poor information and uncertainty problems, among which, the grey correlation analysis is put forward in accordance with grey system theory and is an significant component of grey theory (Zhang, 2010). The grey correlation degree analysis is a quantitative description of the trend of the system change and development and is a comprehensive


(a) (b) (c) (d)

(e) (f) (g)

Fig. 1: Images of the results of the five types of fusions, (a) The original low-light-level image, (b) the original infrared image, (c) Contrast pyramid fusion, (d) HIS fusion, (e) Wavelet fusion, (f) Weighted fusion, (g) Main component

evaluation method by describing the strength, size and order of the relations between various factors through grey correlation. The grey correlation analysis is used to determine the similarity of different sequences according to the geometric shape and development trend of the reference sequence and comparative sequence, the more similarity between the geometric shapes the more similarity between their change trends, that usually indicates high correlation; and the more difference between the geometric shapes it is, the more difference between their change trends it will be, that often indicating low correlation. Therefore, the degree of the correlation between reference sequence and comparative sequence can be used to compare and rank the objects to be evaluated and draw a conclusion. The grey correlation comprehensive evaluation is simple in principle and calculation and has lower requirements for sample size.

The simulation test and the selection of evaluation index: The original low-light-level image and original infrared image are derived from literature (Tian, 2010), the test is carried out for simulation through MATLAB 7.0. Under the same test conditions, the image fusion algorithms of the HIS transform method (Tu *et al.*, 2001), wavelet transform method (Huntsberger and Jawerth, 1993), weighted average method (Tian, 2010), PCA transform method (Akerman, 1992), image pyramid method (Achalakul *et al.*, 2000), to generate fusion images, as are shown in Fig. 1 and the five fusion algorithms are denoted as F1, F2, F3, F4 and F5 orderly for the purpose of expression.

In practical application, it is hard to get perfect reference images usually and this study adopts information entropy, mutual information, cross entropy, correlation coefficient as the objective indexes of the fusion images to determine the quality of the fusion images.

- **Information entropy:**

$$H = -\sum_{i}^{L-1} P_i \ln P_i \qquad (1)$$

where,

P_i = Grayscale value and is equal to the ratio of pixel number of i to the total number of pixel of the image

L = The total grade of grayscale

The information entropy reveals the amount of the information contained in one image, indicating the richness degree of the image information. The larger the information entropy of the fusion information is, the richer its content is and the better the fusion effect will be.

- **Mutual information amount:** Mutual information amount is an important concept in information theory which can be taken as a measurement of the correlation between two variables, or as a measurement of the information of a variable contained in another variable and is used to measure the mutual information amount between fusion image and source image and to evaluate the effect of fusion.

The mutual information amount MI_{FAB} between fusion image F and source images A and B will be defined as:

$$MI_{FAB} = \sum_{k=0}^{L-1}\sum_{i=0}^{L-1}\sum_{j=0}^{L-1} P_{FAB}(k,i,j)\log_2 \frac{P_{FAB}(k,i,j)}{P_{AB}(i,j)P_F(k)} \quad (2)$$

where, PFAB (k, I, j) is the normalized joint histogram of images F, A and B, PAB (I, j) is the normalized joint histogram of source images A and B, the more mutual information amount will be followed by more information of original image obtained by the fusion image.

- **Cross entropy:** Cross entropy reveals the difference between the corresponding grey degree distributions of the two images and is the measurement of the information contained in the two images. The less the difference is, the more the information obtained by the fusion method from the original image will be. Therefore, the smaller index of cross entropy often denotes the better fusion effect of fusion.

Assume that the fusion image is *F* ant that the original images are *A* and *B*, then, the cross entropies between the two original images and the fusion image are restively:

$$CE_{A,F} = -\sum_{i=0}^{l-1} P_{Ai}\log(P_{Ai}/P_{Fi})$$
$$CE_{B,F} = -\sum_{i=0}^{L-1} P_{Bi}\log(P_{Bi}/P_{Fi}) \quad (3)$$

The average entropy based on comprehensive consideration is:

$$MCE = \frac{CE_{A,F} + CE_{B,F}}{2} \quad (4)$$

- **Correlation coefficient:** The correlation coefficient between the fusion image and the source image can reveal the degree of the similarity of the spectral characteristics of the two images and it is defined as follows:

$$\rho = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[F(x_i,y_j)-\overline{f}][A(x_i,y_j)-\overline{a}]}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}[F(x_i,y_j)-\overline{f}]^2[A(x_i,y_j)-\overline{a}]^2}} \quad (5)$$

where, $\bar{f}, \bar{a}$ is the average value of the fusion image and source image? The correlation coefficient rule is used to enable both the fusion image and the source image to be very close; the degree of the change of spectral information of the image can be seen by comparing the correlation coefficient of the image before fusion with the correlation coefficient of the image after fusion, the larger correlation coefficient ρ is preferable.

The above four objective evaluation indexes of the image fusion algorithms are very sensitive and important for the image fusion algorithm evaluation; therefore, it is practical to evaluate the image fusion algorithm through the change of the four index values. Table 1 shows the performance index values of the five image fusion algorithms.

Evaluation index standardization processing: It is hard to directly compare the dimensions of the factors in the system because they are not necessarily same; thus, it is required to process the various factors to eliminate the influences caused by each index dimension. This study adopts the "standardization" method to process the data:

$$x_{ik} = \frac{y_{ik} - \overline{y}_k}{S_k}\left(i = 1,2,\ldots,n, k = 1,2,\ldots,p\right) \quad (6)$$

Table 1: Evaluation indexes of the five fusion algorithms

	Evaluation			
Fusion	Information entropy	Mutual information amount	Average value of the cross entropies	Average value of the correlation coefficients
F1	7.9199	5.5366	10.4634	0.4872
F2	7.3158	4.8347	10.0143	0.5124
F3	8.1412	5.2068	11.5643	0.4120
F4	8.8905	6.1365	12.0167	0.39.28
F5	7.6321	5.2496	11.1322	0.4763

Table 2: Standardization of the evaluation Indexes of the five fusion algorithms

	Evaluation			
Fusion	Information entropy	Mutual information amount	Average value of cross entropies	Average value of the correlation coefficients
F1	0.4279	-0.1330	1.0264	-1.3213
F2	0.4079	-0.2068	1.0764	-1.2776
F3	0.3831	-0.2380	1.1077	-1.2528
F4	0.4116	-0.1464	1.0451	-1.3103
F5	0.3375	-0.1952	1.1200	-1.2624

where, $\bar{y}_k = \frac{1}{n}\sum_{i=1}^{n} y_{ik}$, $S_k^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_{ik} - \bar{y}_k)^2$, n is the sample number and p is the number of observed variables; in this study, $n = 5$, $p = 4$.

Standardization processing shall be carried out towards the evaluation indexes of the five fusion algorithms listed in Table 1 based on the formula (6) and Table 2 shows the results of the processing.

Determination of reference sequence and comparative sequence: When comparing the multiple objects in the same field through grey correlation degree analysis method, it is required to determine the current optimal level of each index, that is, the reference sequence of evaluation index and take it as the evaluation standard of the correlation degree, then make evaluation by comparing each object with the reference sequence.

Principle of the determination of reference sequence: Each element of the reference data sequence is composed of the optimal values in the technical and economic index data sequence of each system (Liu *et al.*, 2010). In Table 2, some larger indexes are preferable, such as correlation coefficient, mutual information amount and information entropy; while some smaller indexes are preferable, such as cross entropy. Therefore, the larger the information entropy is, the better the image fusion effect will be; and 0.4279 is selected; the larger the mutual information is, the more the information about the original image obtained in the fusion image will be; and -1.330 is selected; the smaller cross entropy index denotes the better fusion effect and 1.0264 is selected; the correlation coefficients can reveal the similarity degree of the spectral characteristics of the two images; the larger correlation coefficient is preferable and -1.2528 is selected.

Set the reference data sequence {x$_0$} as: {x$_0$} = {x$_0$(1),x$_0$(2),…,x$_0$(n)}={x$_i$(1),x$_j$(2),…,x$_k$(n)}, set the comparative data sequence {x$_i$} as: x$_i$ = {x$_i$(k)|k=1,2,…,m}, wherein, i , j , k ∈ the natural number field of [1,m].

The determined reference data sequence is:

$$\{x_0\} = \{0.4279, -0.1330, 1.0264, -1.2528\}$$

From Table 2, the comparative sequence is:

$$\{x_1\} = \{0.4279, -0.1330, 1.0264, -1.3213\}$$

$$\{x_2\} = \{0.4079, -0.2068, 1.0764, -1.2776\}$$

$$\{x_3\} = \{0.3831, -0.2386, 1.1077, -1.2528\}$$

$$\{x_4\} = \{0.4116, -0.1464, 1.0451, -1.3103\}$$

$$\{x_5\} = \{0.3375, -0.1952, 1.1200, -1.2624\}$$

Calculation of correlation coefficient and correlation degree: The deviation between the comparative sequence and reference sequence after processing:

$$\Delta_i(k) = |x_0(k) - x_i(k)| \tag{7}$$

According to formula (7), deviation matrix Δshall be as follows:

$$\Delta = \begin{bmatrix} 0.0000 & 0.0000 & 0.0000 & 0.0685 \\ 0.0200 & 0.0738 & 0.0500 & 0.0248 \\ 0.0448 & 0.1050 & 0.0813 & 0.0000 \\ 0.0163 & 0.0134 & 0.0187 & 0.0575 \\ 0.0904 & 0.0622 & 0.0936 & 0.0096 \end{bmatrix}$$

Determine the range:

$$\max_i \max_k \Delta_i(k) = 0.1050, \min_i \min_k \Delta_i(k) = 0.0000$$

Correlation coefficient $\xi_i(k)$:

$$\xi_i(k) = \frac{\min_i \min_k \Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)} \tag{8}$$

where, ρ is the identification coefficient, is a set number between 0 and 1, is to undermine the distortion caused by the excessive amount of the maximum absolute difference and improve the significant

Table 3: Correlation degree and quality sequence of the image fusion algorithms

Fusion algorithms	F1	F2	F3	F4	F5
Degree of correlation	0.8582	0.5828	0.5661	0.6935	0.5076
Quality sequence	1	3	4	2	5

difference between correlation coefficients, which is generally taken as ρ =0.5 (Chen *et al.*, 2012).

According to formula (8), correlation coefficient matrix R_ξ shall be as follows:

$$R_\xi = \begin{bmatrix} 1.0000 & 1.0000 & 1.0000 & 0.4339 \\ 0.7241 & 0.4157 & 0.5122 & 0.6792 \\ 0.5396 & 0.3333 & 0.3924 & 1.0000 \\ 0.7631 & 0.8015 & 0.7374 & 0.4473 \\ 0.3674 & 0.4577 & 0.3593 & 0.8454 \end{bmatrix}$$

Correlation degree r_i:

$$r_i = \frac{1}{N}\sum_{1}^{N} \xi_i(k) \tag{9}$$

Substitute correlation coefficient into formula (9) to get correlation degree R:

$$R = (r_1, r_2, r_3, r_4, r_5) = (0.8582, 0.5828, 0.5661, 0.6935, 0.5076)$$

RESULT ANALYSIS

The computation result for the five image fusion algorithms is: $r_1>r_4>r_2>r_3>r_5$ and as for the advantages and disadvantages of the five image fusion algorithms, refer to Table 3.

Where, F1, F2, F3, F4, F5, respectively represents HIS transformation method, wavelet transformation method, weighted average method, main component method and contrast pyramid method. From Table 3, we can know that HIS transformation method is the biggest in correlation degree, the image fusion algorithms is the best in fusion quality, the main component transformation method is the second, the wavelet transform method is the third, the weighted average is the fourth, the contrast pyramid method is the fifth and the image fusion quality is worse. The evaluation method for gray correlation degree image fusion could better reflect the connection between original image and image fusion; the bigger the coefficient is, the more information contained in original image will be; otherwise, the more information in the fusion process will be lost. The overall evaluation function of gray correlation analysis method can guarantee that the important information will not be ignored during the computation process to obtain more objective, accurate, reliable distinctive result.

CONCLUSION AND DISCUSSION

The result of study indicates that many fusion methods have been applied in the current image fusion studies. As for the same object, different effect fusion image can be got with different fusion methods. How to evaluate the quality of fusion image is an important step for image fusion, but now it is still lack of a system and comprehensive evaluation method for fusion effect. Based on the relevant technical analysis, this study applies the image fusion evaluation methods on the basis of the gray correlation degree and gets quality series for each image fusion algorithms and achieves the comprehensive and accurate evaluation for image fusion by calculating the gray correlation degree between comparative sequence and reference sequence and on the basis of the size of correlation degree to provide the new idea for resolving image fusion algorithms evaluation.

But errors still exist in the research process; the cause is analyzed as follows:

- Correlation degree is related to reference sequence and different correlation degrees often follow different reference sequences. As the standard image is not used in the study, the accuracy of the image fusion algorithms evaluation is influenced in some degree
- Image fusion algorithms index is an important measure indicator to evaluate the image fusion algorithms and the correctness for choosing index directly influences the evaluation result of image fusion quality; therefore, the evaluation effect will be better if a perfect image fusion evaluation system can be established
- The evaluation result has relative significance, that is, relative to the fusion images involved in the comparison

At present, the analysis method of gray correlation with an advantage to deal with part of the certain and uncertain information in the system is a good approach to get a comprehensive evaluation of image fusion. The gray correlation analysis provides a new way to solve the image problems of evaluating without complete information and reference standards when conducting fusion image evaluation.

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