The image fusion of compressive sensing with adaptive deviation feature

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***Abstract*—In this paper, an adaptive fusion rule combining high frequency feature of image is proposed.First,making a NSCT decomposition to the infrared image and visible light image, and after that to fuse them using regional energy criterion for the low-frequency sub-bands to obtain a better fusion result than the traditional low frequency coefficients. Next,Since the decomposed high-frequency sub-band coefficients have high sparsity,they are compressed by CS and adopted adaptive fusion rule according to the standard deviation feature.Finally, it gets fusion image by reconstruction of compressive sensing and inverse NSCT transform for data which has been fused. The experimental results show that this paper solves the shortcomings of the traditional image fusion algorithm based on the compressive sensing method (CS), which makes the final fusion image take into account the background information and infrared target information of the image to be fused, effectively improve the integration effect and subjective feelings.**

Keywords-adaptive; NSCT; high frequency feature; compressive sensing; standarn deviation

I. INTRODUCTION

The two more common images in life are infrared images and visible images. These two types of images are obtained by different sensors. The imaging mechanism is different and the characteristics are different[1]. They have been widely used because of the fusion of infrared images and visible images with high research and application value[2]. At present, most of the field of image fusion to improve the quality of image fusion as the main consideration, but in the real life, the sensor image in the security monitoring, battlefield perception and other applications are mostly in the form of dynamic sequence output, these series of images need to be real-time fusion processing.If the traditional image fusion method is used to achieve the effect of real-time processing, not only the complexity of the implementation is increased, but also the cost of transmission, storage and reconstruction is greatly increased.Thus, the introduction of the compressive sensing theory (CS theory) [3] solves this problem.

In the image fusion algorithm based on compression perception, the spatial information of the original image is lost when it is observed by CS[4], so it can not use space-based selection rules and complex fusion rules when processing measurement coefficients. Most of the fusion rules choose the absolute value of large, information entropy weighting, similarity measure, standard deviation weighting and other simple methods. But because of the absolute value of the fusion image obtained by the contrast is too large, and there are significant noise.Information entropy can only calculate the information contained in the observation vector.The similarity measure can not get the classification interval accurately and cause the classification error.In contrast to other methods, fusion images based on standard deviation weights achieve better visual effects. However, when the standard deviation of the two images is not significant, it is likely that the image fusion effect will be deteriorated according to the weight of the coefficients, and the use of the absolute value to obtain the significant information of the respective transients of the two images[5].Therefore, this paper proposes an adaptive fusion rule, which takes into account the background information and infrared target information of the image to be fused, and effectively improves the quality of image fusion.

II. COMPRESSIVE SENSING MATHEMATICAL MODEL

If N vertex signal $x \in R^{N\times 1}$ is expanded under a set of orthogonal bases $\{\psi_i\}_{i=1}^{N}$:

$$x = \sum_{i=1}^{N} \theta_i \psi_i \tag{1}$$

The expansion coefficient $\theta_i = \langle x, \psi_i \rangle = \psi_i^T x$ is written in the form of matrix can be:

$$x = \Psi\theta \tag{2}$$

Where $\Psi = (\psi_1, \psi_2, ..., \psi_N) \in R^{N\times N}$ is an orthogonal base dictionary matrix.Assuming that the coefficient vector θ is K sparse,,that is, the number of non-zero sparsities $K << \mathrm{N}$,Then use another matrix Φ : $M \times N\ (M << N)$ that is not related to the orthogonal basis, and compress the observation of the signal X to obtain M linear projections, where $y \in R^M$ can be expressed as follows:

$$y = \Phi x = \Phi\Psi\theta = A^{CS}\theta \tag{3}$$

Obviously x recovery from y is an NP-hard problem, but as long as any column of the matrix is linearly independent,Then there is at least one K-coefficient θ coefficient

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vector satisfying $y = A^{CS}\theta$ .In other words, in the case of satisfying the above requirements, the reconstructed signa[6] X can be obtained from the observed y, the observation matrix Φ and the dictionary matrix Ψ by solving a nonlinear optimization problem.

III. THE BASIC FRAMEWORK OF IMAGE FUSION

In this paper, multi-scale decomposition of the fusion image using non-down-sampling contourlet transform (NSCT transform[7]. The image is transformed into a low pass subband and K direction subband by NSCT transformation.Since the low frequency coefficients do not have sparseness and the high frequency coefficients have high sparsity, the low frequency coefficients are preserved and only the high frequency coefficients are observed.Reconstructing the image by NSCT inverse transformation after reconstructing the high frequency coefficients using the reconstruction algorithm [8].

A. Low frequency coefficient fusion rules

Due to the hot targets have higher frequency in infrared image while it is backgrounds in visible image.Therefore, when fusion we use infrared image coefficients in hot targets while visible image coefficients in backgrounds Considering this requirement, this paper uses the block DCT high frequency energy rules .The criterion based on the DCT transform coefficient matrix, in which the low frequency coefficients are concentrated in the upper left corner, and high frequency coefficients to the lower right corner. It chooses the fusion coefficients according to the contrast of high frequency energy. If calculate the energy of the DCT block directly in which the high frequency energy will easily be masked by low frequency energy, but coefficients on the right side of deputy diagonal in block can basically reflect the high frequency information in source image[9]. So we define the high frequency energy in DCT transformation matrix as follows.

$$E = \sum_{u=0}^{N-1} \sum_{N-u-1}^{N-1} D(u,v)^2 \tag{4}$$

Where N is the image block size, is coefficients of DCT coefficient matrix.

In the fusion process, there is part of gray uniform areas in source image. Meanwhile, if just by high frequency energy of DCT coefficients for fusion, it will make miscalculation, and the region usually is background. Thus, if the difference value of DCT high frequency energy for two source images is less than the threshold T when fusion, coefficients of visible image has a high weight in fusion, as follows:

$$X_F(i,j) = a \times X_A(i,j) + (1-a) \times X_B(i,j) \quad |E_A - E_B| < T \tag{5}$$

Where a=0.8, $X_F(i,j)$ is the coefficient after fusion, $X_A(i,j)$ and $X_B(i,j)$ are pixels for two source image.

In the case of the difference value is greater than T, we will choose the visible image coefficients if visible image energy is bigger, otherwise, the infrared image coefficients are chosen. As following formula shows:

$$X_F(i,j)\begin{cases} X_A(i,j) & E_A - E_B > T \\ b \times X_A(i,j) + (1-b) \times X_B(i,j) & E_A - E_B < -T \end{cases} \tag{6}$$

Where b=0.2, E_A , E_B represent the DCT block energy coefficient matrix of visible image and infrared image respectively.

B. Boundary conditions

In general, a larger absolute coefficient represents more significant information about transient characteristics. However, the CS observation process is a linear projection of the original image. The observed vector is a linear combination of the coefficients in the observation matrix. The randomness of the observation matrix makes the information of the original image randomly distributed to the observation vector.When the image contains a large number of information, the image with a large absolute value is not necessarily an image having a large amount of information, but the standard deviation can represent the amount of image information.Because the standard deviation is the gray scale dynamic range, the larger the standard deviation, the more gray-scale distribution of the image, the higher the contrast of the image, the more information the image contains.But when the difference between the standard deviation of the two images is not large, it can not determine which image contains more information[10]. The weight of the coefficients is likely to cause the fusion effect to deteriorate, and the use of absolute values to obtain the larger law can obtain two images in the larger coefficient, the image transient characteristics of the significant information to improve the clarity of detail. Therefore, this paper uses standard deviation weighted and absolute value to take the combination of large image fusion method.

Specific steps are as follows:

(1) The standard deviations of the compressed infrared image and the visible light image of the high frequency component are calculated respectively, as shown in equation (7).

$$sd = \sqrt{\frac{\sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (F(i,j) - \overline{F})^2}{M \times N}} \tag{7}$$

Where $F(i,j)$ is the gray value of the fused image at point (i,j) and $\overline{F}$ is the average gray scale of the fused image.

(2) Calculate the difference between the standard deviation sd_A and sd_B of the two observed images, as shown in equation (8).

$$sd_t = \left| sd_A - sd_B \right| \tag{8}$$

Where sd_A, sd_B is the standard deviation of the visible and infrared image observations.

(3) Calculate the observed fusion value $Y_F(i,j)$,

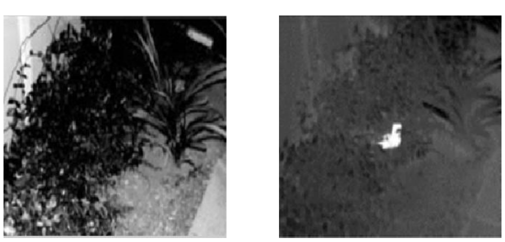
When the difference sd_t is greater than the threshold value T, it means that the difference between the two images contains the information amount. So to be more emphasis on large standard deviation of image fusion and the standard deviation is used as the fusion rule. When the difference is less than the threshold T, it means that the amount of information contained in the two images is not very different. In order to highlight their respective details, the absolute values is used to fuse the image. The specific fusion rules are as shown in equation (9):

$$Y_F(i,j)\begin{cases} Y_F(i,j)=Y_M(i.j)\ \ with\ \arg\max_{K=A,B}(|Y_K(i,j)|) & |sd|<T \\ Y_F(i,j)=a\times Y_{KA}(i,j)+b\times Y_{KB}(i,j) & |sd|>T \end{cases} \tag{9}$$

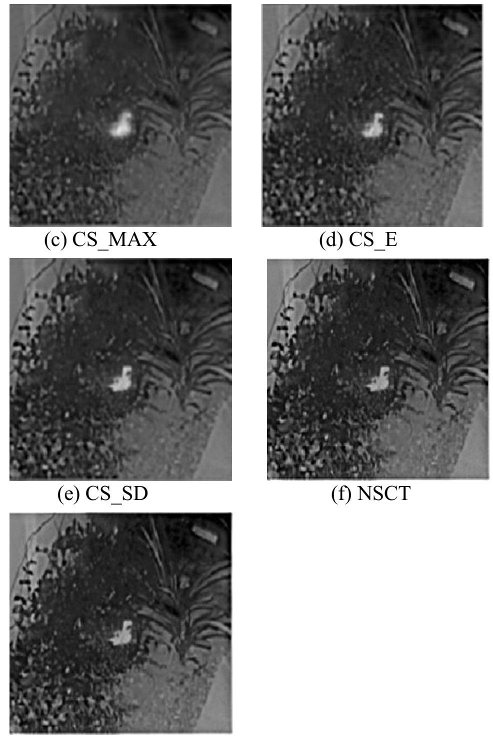
The fusion weights of the visible image are $a = \frac{|sd_A|}{|sd_A|+|sd_B|}$, b = 1-a. $Y_K(i,j)$ is the measured value of the original image, and $Y_F(i,j)$ is the measured value of the fused image.

IV. SIMULATION RESULTS AND ANALYSIS

Image fusion experiment simulation results shown in figure 1, figure 2.Three layers of NSCT are decomposed into two categories of images. The graphs (c),(d) ,(e)and (f) represent the effect graphs obtained by using the absolute value method, the information entropy weighting method,the NSCT is used in this paper and the standard deviation weighted method.figure (g) is the result of proposed algorithm fusion.



(a) the visible light image (b) the enhanced infrared image



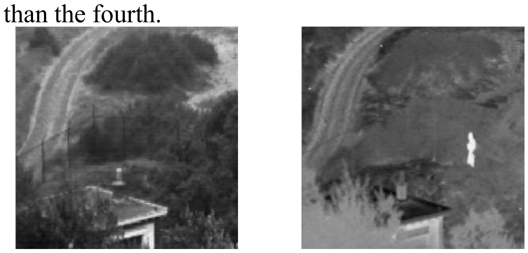
(c) CS_MAX (d) CS_E

(e) CS_SD (f) NSCT

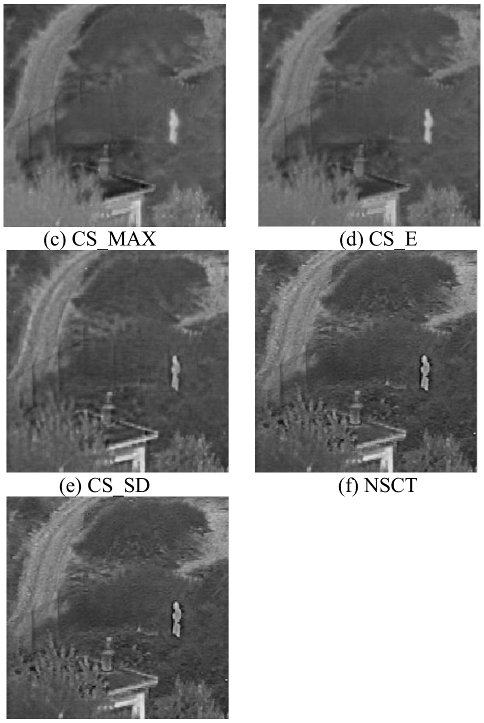
(g) Algorithm in this paper

Figure 1. The simulation results of the first group of images fusion

For the first group of images, the CS_MAX method extracts the infrared target, but the details of the image are blurred and the fusion effect is the worst.Then CS_E, because the information entropy is only to improve the richness of image information, but can not significantly improve the image clarity; CS_SD fusion effect is relatively good, not only more accurate extraction of the infrared target contour also improve the image clarity, but the details of the image is not clear enough; In the extraction of infrared target contours proposed on the algorithm fusion effect to be more accurate in the first three methods.The fusion of NSCT algorithm is the best in this paper. The fusion image details are rich, the infrared targets are clear and the background separation is obvious.However, the fusion results of arithmetic this paper chose to use is more accurate than the previous three arithmetic, and it has a very clear separation with the background boundary line, it significantly highlight the infrared target(duck)and clearly keep the details of the grass part of visible images, the sharpness of the background is higher than those three arithmetic, slightly less than the fourth.



(a) the visible light image (b) the enhanced infrared image



(c) CS_MAX (d) CS_E (e) CS_SD (f) NSCT (g) Algorithm in this paper

Figure 2. the simulation results of the second group of images fusion

For the second group of images,these three algorithms like CS_MAX, CS_E and CS_SD get the details of the fusion image is not clear. The edges of the arbor, the grass and the fence in the distance are blurred in different degrees. The results are shown in fig.2 (c),(d) and (e).The proposed algorithm makes the background of fusion more close to the visible image on the basis of accurately extracting the infrared target contour,such as the color of the arbor, the branches of the grass and the fence near the distant characters.Therefore, this algorithm retains more information about the visible light image than the first three algorithms.The NSCT algorithm in this paper are based on the precise extraction of infrared target profile, so that the background of the fusion is closer to the visible image.From subjective perspective, the two kinds of algorithm for infrared target extraction effect difference is small, highlight the image detail information and make the target in the image fusion after heat compared with the surrounding area has a good contrast characteristics.Therefore, this algorithm retains more information about the visible light image than the first three algorithms and compared with the fourth algorithm, the subjective difference is very small or even imperceptible.

The objective parameters of the five algorithms of the two sets of images are shown in Table 1.It can be seen from Table 1 that the fusion effect of this algorithm is superior to the first three algorithms in E (information entropy), Ag (mean gradient), SD (standard deviation) and slightly less than the fourth algorithm. Because this algorithm is based on the nature of the source image and choose different fusion rules for image fusion,which not only obtains the significant information of the image transient characteristic, but also enriches the information quantity of the image.The combination of the two makes the fusion image from the source image to get more information, enhance the details of the expressive force.Compared with the fourth algorithm, because of the introduction of the compressed sensing algorithm,the CS observation process is a linear projection of the high frequency component in original image. Therefore, this algorithm can not reconstruct the high frequency coefficients exactly as the fourth algorithm in the fusion of high frequency coefficients.So from the perspective of objective parameters, this algorithm compared to the fourth algorithm fusion effect slightly less.But from the amount of data point of view, to ensure a better integration on the basis of the effect,the M = 220 sampling point is used to compute the high frequency coefficients of the fused image in this paper.Due to the introduction of the compression sensing algorithm, the data volume of the high frequency coefficients of each layer is reduced and the data is 770K.The high frequency image data of uncompressed perception was 896K, which decreased by 14.1% . In summary, the algorithm in the guarantee of fusion image quality under the premise of effective savings in transmission, storage, reconstruction .

Table 1. Comparison of five algorithms for image fusion objective parameters

	method	E	SD	AG	Date
Fig.1	CS_MAX	5.91	27.52	6.75	770
	CS_E	6.24	29.88	7.02	770
	CS_SD	6.72	30.65	7.66	770
	NSCT	7.45	33.25	8.02	896
	Algorithm in this paper	7.02	31.71	7.93	770
Fig.2	CS_MAX	6.05	24.33	4.29	770
	CS_E	6.22	25.23	4.65	770
	CS_SD	6.40	27.69	4.97	770
	NSCT	6.95	32.18	5.74	896
	Algorithm in this paper	6.73	30.14	5.48	770

V. CONCLUSIONS

According to the different characteristics of the low frequency coefficients and the high frequency ,this paper puts it into application in the field of image fusion effectively and adopts different fusion rules. Low-frequency fusion selection block DCT high-frequency energy criterion can highlight the characteristics of infrared and visible light information. High frequency taking into account the traditional image fusion rules in the local information selection rules do not apply to the CS measurement processing.Therefore, it adopts the adaptive fusion rules combined with characteristics of high frequency observation to the fusion image.Compared with the traditional algorithm, this algorithm greatly reduces the amount of data needed for high-frequency fusion, and at the same time, The simulation results show that the algorithm can accurately extract the infrared target information and improve the effect of fusion image.

REFERENCES

[1] Li Haichao, Li Chenglong,Tang Jin,Luo Bin Research on Fusion Algorithm for Thermal and Visible Images.Journal of Frontiers of Computer Science and Technology, 2016,10(3):407-412.(in Chinese)

[2] Qian Xiaoyan, Han Lei,Wang Bangfeng.A Fast Fusion Algorithm of Visible and Infrared Images.Journal of Computer-Aided Design& Computer Graphics,2011,23(7):1211-1216. (in Chinese)

[3] Donoho D.L Compressed sensing[J]. IEEE Transactions on Information Theory,2006,52(4):1289-1306.

[4] Liu Cuiyin, Luo Hongli ,Li Xiaofeng, A Fusion Algorithm for Visible Image and Infrared Image Based on Compressive Sensing and Nonsubsampled Con-toulet Transform.Journal of science university (engineering science edition),2014,46(5):89-95.(in Chinese)

[5] Gong Ziping,Research on compressed sensing based image fusion with multiple blocking measurement[D].Guangzhou,2012.4.(in Chinese)

[6] Shao Wenze,Wei Zhihui, Advances and perspectives on compressed sensing theory.Journal of Image and Graphics,2012,17(1):1-10. (in Chinese)

[7] Hu Yucheng,WANG Chuangxin, An Image Fusion Algorithm Based on NSCT and PCNN.Electronic Sci.&Tech,2014,27(4):30-32.(in Chinese)

[8] Yuan Jin-lou,Wu Jin,Liu Jin, Image Fusion Based on Compressed Sensing of NSCT and DWT. Infrared Technology,2015,37(11):957-961.(in Chinese)

[9] Guo Ming, Fu Zheng Xi Xiaoliang, Novel fusion algorithm for infrared and visible images based on local energy in NSCT domain.Infrared and Laser Engineering,2012,41(8):2229-2235.(in Chinese)

[10] Qi Xinglan, Hu Zongqing, Liu Jian. Fusion Algorithms Comparison of SPOT-5 PAN and Multi-spectral Remote Sensing Images.Journal of Beihua University(Natural Science). 2011, 12 (2) :214-218.(in Chinese)