Research of Multi-sensor Images Based on Color Fusion Methods

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Abstract—With the development of image sensor technology, multi-sensor image fusion technology emerged and was widely used in the field of military surveillance, medical diagnosis, remote sensing, intelligent robot and so on. However, the current image fusion technology mainly focuses on the research of gray images, the color image fusion is rarely. Because color image contains more information compared with gray image, the research on color image fusion technology is becoming more and more urgent. In this paper, the realization of several typical color image fusion algorithms were discussed, the principle and their respective advantages and disadvantages were analyzed. Secondly, according to the different characteristics of visible image and infrared image, this paper proposes a color image fusion algorithm based on Curvelet transform, this algorithm will combine visible image, infrared image with its negative respectively fusion, color mapping rules are in couple with the human visual characteristics. Experiments show that color fusion images obtained are richer in color, they contains more details and recognize easily.

Index Terms—Color Image Fusion; Color Transfer; Region Recognition; Multi-Scale Normalized Cut

I. INTRODUCTION

Multi-sensor image fusion is aimed to obtain two or more than two sensors on a specific scene images, the image sequence information used a certain algorithm to be integrated [1]. The image fusion result has a higher reliability and less ambiguity, it is suitable for detection, classification, recognition, computer vision, which can improve the detection and recognition ability of image detection system [2]. Considering the fact that the fused color images false method was not natural, a novel region-based color mapping method is proposed to render the image fused multi-sensor images [3]. Multi-sensor image fusion changed the traditional single channel backward method of displaying and processing, it can extract the information characteristics of multi-channel image effectively, forming a unified image or the image characteristics, provide display discrimination center display or decision mechanism [4, 5].

Multi-sensor image fusion system has broad spatial and temporal coverage area, excellent target resolution capability, good fault tolerance ability, excellent reconstruction and system detection performance and high measurement dimension [6]. It was used in military target detection and recognition. At the same time, multi-sensor image fusion technology has a variety of application in air traffic control, surveillance, robot vision, harbor high speed transport driving, natural resources, weather forecast, remote testing [7]. Therefore, all kinds of multi-sensor image fusion technology is developed rapidly, the aim is to collect more information from several single sensor, the supplementary information was merged into a new data set [8, 9].

However, for the current image fusion technology, the most fusion result of given image is gray scale image [10]. Study on the characteristics of human vision found that human vision is quite sensitive to color; there are only a few dozen gray which eyes can distinguish, while color resolution is up to a thousand. The color provides much more information than gray to the human eye. With respect to the gray information, the human eye can be more quickly, accurately identify the color coded information [11]. In 1992, Walraven and Lucassen fused two images of different frequency image with the method of pseudo color mapping. Forth the fused image, they use the observer performance evaluation. The results found that the information of the pseudo-color coding, improve the recognition rate of 30%, the recognition error rate is reduced by 60% [12].

With the development of color image processing, high speed data acquisition, transmission and storage technology, people gradually converted to image color expression from the gray level representation, color image processing technology has been widely used in medical image fusion, remote sensing image and night vision image [13]. Multi-sensor image color fusion can improve the ability of target detection of the same scene for multispectral observations, reveals the characteristics of the target in a single sensor observation cannot be detected [14]. It can improve the recognition speed and accuracy. In addition, the technique of color image fusion can also help doctor’s diagnosis of disease accurately [15-18]. It used in various fields of computer assisted micro neurosurgery operation and image and information encryption. You can believe that, with the continuous development of color multi-sensor image fusion technology, color image fusion technology will be more widely used [19, 20]. In this paper, the realization of several typical color image fusion algorithms were discussed, the principle and their respective advantages and disadvantages were analyzed. Secondly, according to the different characteristics of visible image and infrared image, this paper proposes a color image fusion algorithm...
based on Curvelet transform, this algorithm will combine visible image, infrared image with its negative respectively fusion, and color mapping rules are in couple with the human visual characteristics. Experiments show that color fusion images obtained are richer in color, they contains more details and recognize easily.

II. STUDY OF COLOR FUSION METHOD

A. Color Image Fusion Technology of Multi-Sensor

In recent years, the international research on model and algorithm of image fusion in different levels. But because the application environment (target and scene), many of the features of images of various diversity, task requirements are also different, so the image fusion algorithm is also a variety of. There is not yet found a variety of tasks in the fusion effect of the algorithm. By the use of a color image fusion algorithms can be divided into three categories: gray fusion using the pseudo-color encoding fusion, color fusion based on RGB color space, color fusion based on HIS color space.

Pseudo-color processing through the pixels of different gray levels are arranged in a different color, the gray eye cannot differentiate into can distinguish color, detail resolution improving. Therefore, false color image display is a very effective and commonly used image processing technology. Its basic integration frame is shown in Figure 1. In fusion research mainly in thermal image and LLL image of CCD, in order to make the fusion result is natural some, the corresponding high gray level image fusion image temperature warm colors, such as yellow, red, and the low gray level corresponding to the cold tone.

![Figure 1. Multi-sensor image fusion based on false color.](image)

Gray color image data fusion algorithm based on RGB color space from different sensors, after preprocessing and registration, is sent to the RGB color channels are synthesized as a false color image fusion in a combination way, in the fusion image with different color performance details of the difference. The basic facts according to the principle of this algorithm are shown as follows: the images from different image sensor always exist differences, gray distribution and always with different sensors of different characterization. The realization process is shown in Figure 2. The principle of this method is intuitive, simple calculation, fast speed, convenient for hardware implementation; disadvantage is the fusion of color characterization of the detail of image fusion will be the lack of predictability. The fusion image details characterization and conventional see images tend to be quite different; in order to obtain relatively the best fusion results, color palette to undergo several tests to compare.

![Figure 2. Color fusion algorithm based on RGB color space.](image)

B. Gray Hierarchical Method

Gray Hierarchical technique is one of the most simple method of pseudo color image processing. This kind of technology can be concluded as following:

\[
f(x, y) = \sum_{i} f_i(x, y) \in R_i
\]

L0 represent black (f (x, y) = 0), L1-1 represent write (f (x, y) = L-1).cK is defined by the plane associated with the Rk region of color. Figure 3 is the experimental result of gray hierarchical method. The (a) and (b) are visible and infrared images, (c) is the wavelet transform of image fusion based on (a) and (b), image fusion method can also be used commonly used weighted average method, logical filtering method, multi-resolution tower type algorithm, Calman filtering algorithm, the simulated annealing method. The gray level of (c) is divided into 16 layers and (d) is divided for color image gray layer.

![Figure 3. The (a) and (b) are visible and infrared images, (c) is the wavelet transform of image fusion based on (a) and (b), (d) is divided for color image gray layer.](image)

This method firstly grayscale image fusion into a gray image, then the pseudo-color coding using pseudo color technology, the final color display for the false color image fusion image. Although gray hierarchical method is ocular, simple, the principle is contained by the technical, color type can be mapped is less, and the treatment effect is poor, it is not conducive to the human eye.
C. Image Fusion Algorithm Based on HIS Color Space

When people observe a color object, RGB color model cannot well adapt to the understanding of people. For example, it does not involve the percentage of each color of an object. In addition, the color image is not composed of three primary color images. RGB is the ideal to generate image, but there is more to the limits on the application of color description. When viewing a color object, the description by brightness intensity, hue and saturation is much more precise. Brightness intensity is proportional to the object reflectance, and color information of the image is irrelevant. For the color image, the color mixing white is more, the brightness is bigger. The incorporation of black is more, the brightness is smaller. Hue is associated with the main wave length mixed spectrum, mainly embodies the color information. Saturation is associated with the purity of color, pure spectral color is completely saturated, with the addition of saturation white gradually reduced. Research shows that spherical transform fusion are excellent, the following are the sphere transformation formulas:

\[ I = \frac{(M+m)}{2}, \quad S = \frac{(M-m)}{2-M+m} \]  

\[ H = 60(2 + b - g) \quad \text{when} \quad r = M \]  

\[ H = 60(4 + r - b) \quad \text{when} \quad g = M \]  

\[ H = 60(6 + g - r) \quad \text{when} \quad b = M \]  

\[ r = \frac{(\text{Max}-R)}{\text{Max}-\text{Min}} \quad r' = \frac{(\text{Max}-G)}{\text{Max}-\text{Min}} \quad r'' = \frac{(\text{Max}-B)}{\text{Max}-\text{Min}} \]  

\[ \text{Max} = \text{max}[R, G, B] \quad \text{Min} = \text{min}[R, G, B] \]  

In practice the transformation formula was used commonly:

\[ \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{-1}{\sqrt{3}} \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \]  

\[ H = \tan^{-1} \left( \frac{V_2}{V_1} \right) \]  

\[ S = \sqrt{V_1^2 + V_2^2} \]  

HIS transform for image fusion using a variety of forms, first proposed by Haydn et al HIS fusion method which is one of classic algorithms, the algorithm steps are as follows:

1) The low spatial resolution multispectral image is transformed into HIS space, get the brightness, chroma and saturation of I, H, S three components;

2) The high resolution SPOT panchromatic image contrast stretching, and make the I components have the same mean and variance, or histogram matching high resolution images and I components, the histogram of the high resolution image generated with I component histogram approach, to increase the correlation between;

3) The I components transformed to I’ component with SPOT images from replacement;

4) The fused image is formed with I’, H, S, HIS inverse transform.

This system is called HIS color system; the system can eliminate the luminance component in color images from the color information. Therefore, HIS color system is an ideal tool for the development of image processing based on color description method, the color description is natural, intuitive for people. There are several models from RGB color space to HIS color space transform: sphere transform, cylinder transform, triangle transform and six single pyramid transform. Research shows that effect of spherical transform fusion is better. Traditional fusion method of experiment result is shown in Figure 4. The fused image spatial resolution is higher, while maintaining the original low resolution multispectral image of the same hue and saturation.

D. NRL False Color Processing Method

Synthetic color method is based on pixel gray, different gray is endowed with different color value through the lookup LUT table. The method developed by Naval Research Laboratory consider: gray value was selected from the red LUT infrared, light gray value was selected from the blue LUT. Therefore, image is bright in the low light level and pixels are dark in infrared image, will show the bright blue. On the contrary in the low light level image of dark and bright pixels in infrared image, appear bright red. Pixels in the two images are bright white, in the two images are dark black. Formula as shown in follows, where IR represents the red image. Intensified Visible (IV) represents the visible light image.

\[ \begin{pmatrix} R_{IR} \\ G \\ B \end{pmatrix} = \begin{pmatrix} I_{IR} \\ IV \\ IV \end{pmatrix} \]  

The experimental results is shown in Figure 3, the Figure 5(a) visible light image, Figure 5 (b) is infrared image. It can be seen from the graph, infrared image of the gun is very eye-catching, eye easily noticed; but in the background details into visible light image information. Figure 5 (c) is the NRL algorithm to fusion results. We
can see from the image fusion, image of the gun show striking red, said the heat from an object in infrared image. Color fused image not only retains the detail information of visible images, but also retains the infrared image information. But before the fusion of infrared and visible light image without any treatment program, the fusion image is very low resolution and the color display is not very natural.

![Image of gun showing striking red heat](image)

Figure 5. (a) Visible light image, (b) Infrared image, (c) NRL algorithm to fusion.

NRL false color processing method is simple, it is convenient for hardware real-time operation, and not need any auxiliary cost. But the disadvantage is the color contrast is not natural, not distinct, the difference between target and background is not very good.

E. MIT Fusion Algorithm

The fusion structure of MIT is shown in Figure 6, the fusion process is divided into the following steps: first, image preprocessing, image using time average or median filter to remove noise, infrared image distortion correction lens inverting and optics in the computer, computation of this stage is very heavy, not suitable for real-time processing; second, each with a center - periphery separation network enhanced contrast gleam and infrared image, increase the high frequency information, at the same time adaptively standardized image, dynamic range compression image; third, the enhanced image after a center-periphery separation network, high resolution image into the center enhanced, low resolution infrared image into the surrounding are inhibited, thus forming a single antagonist color contrast image (+VIS-IR). The low-light-level and infrared gray fusion image; fourth, LLl image, infrared image enhancement and single antagonist color image into RGB channel enhancement, color the final fused image.

III. RESULT AND DISCUSSION

A. Visible Light and Infrared Image Fusion Based on Curvelet Method

As we know, the wavelet transform appeared in recent 20 years, it has been widely used in signal processing. Image fusion method based on wavelet transform is widely used. However, for the two-dimensional image processing, basis function of two-dimensional wavelet transform used is isotropic, local model transform coefficient maximum value can only reflect the wavelet coefficient is in position over the edge, and cannot express along the edge information. A series of processing methods such as image denoising, image fusion and image compression applications, are inevitably in the image edges and details position introduced partly fuzzy.

![Curvelet block diagram of spatial frequency](image)

Figure 7. Curvelet block diagram of spatial frequency.

Visible light image and infrared image fusion is an important part in multi-sensor image fusion. A major area of its application is the battlefield reconnaissance. As the reflection of visible light imaging sensor is only sensitive to the target scene, the thermal contrast with the target scene, so it is consistent with human’s vision such as direct and clear. It can arouse the through image stick out a mile to observe the enemy front terrain, front arrangement, weapons and equipment, military deployment. The infrared imaging sensor identify the target by detecting the thermal radiation difference between the target and background, thus it has the special ability to identify the camouflage, concealment to target situations or at night and in bad weather conditions to detect the target information. It can avoid the interference of external factors. Curvelet block diagram of spatial frequency is shown in Figure 7. Assume the existence of nonnegative real-valued W (R) and V (T), and satisfy the admissibility condition:

\[
\sum_{l=-\infty}^{\infty} W^2(2^l r) = 1, \forall r \in \left[\frac{3}{4}, \frac{3}{2}\right] \quad (12)
\]

\[
\sum_{l=-\infty}^{\infty} V^2(t-l) = 1, t \in (-1/2, 1/2) \quad (13)
\]
Uj(r, θ) = 2^{-3j/4}W(2^{-j/2}r)V^{21/2}2\pi (14)

Uj represent the wedge window coordinates. The frequency domain window Uj will smoothly into annular angle different, but the segmentation of complex in two-dimensional Cartesian coordinates. The diagram of discrete Curvelet frequency region of space block is shown in Figure 8.

$Uj(\omega) = Wj(\omega)Vj(\omega)$ (15)

$Wj(\omega) = \sqrt{\phi_{j+1}(\omega) - \phi_j(\omega)}$

$Vj(\omega) = V\left(\frac{2^{-j}\omega_2}{\omega_1}\right)$ (16)

$\phi_j(\omega_2, \omega_1) = \phi(2^{-j}\omega_1) - \phi(2^{-j}\omega_2)$ (17)

The diagram of discrete curvelet frequency region of space block is shown in Figure 8.

The mission of monitoring reconnaissance is not only to find, identify the target, but also determine the accurate position of the target's image requirements. Fusion of infrared and visible light image will help target infrared image indicative properties and visible light image clear scene. So the fusion of infrared and visible light image is very meaningful. In addition, visible light imaging sensor is sensitive to the changes of the target scene brightness, it can display the shape and texture details better, but it is constrained by the illumination condition. Infrared imaging sensor reflect infrared radiation characteristic of target and scene, it can the circadian dual-purpose, but it lacks of objective scene texture detail performance. Visible and infrared image can be extracted, and through certain algorithm combined the two images of the same scene visible and infrared images of the respective characteristics, when a fusion image is obtained, the hidden target detection can be used in military field.

Here, we proposed a new fusion algorithm for infrared and visible light. The algorithm flow chart is shown in Figure 9. This algorithm will be visible image and infrared image and its negative respectively were gray level fusion based on Curvelet transform. A gray scale image is obtained by simple linear combination. According to the human visual system, the gray fusion image to the RGB three channel display. This preserves the image details of source images is send to the maximum extent, improves the detectability of fusion image target, and makes the fusion result is close to natural color.

![Figure 9. The algorithm flow chart of fusion algorithm for infrared and visible light.](image)

B. Result of Color Fusion Image

Each source image is registered. In the gray fusion process, decomposition of Curvelet transform into two layers. The weighted average fusion rule for the coefficient of low frequency, high frequency coefficients used the mode value of the fusion rule. At the same time, for comparison, we also adopt the fusion experiments of NRL and TNO method based on. Evaluation of experimental simulates the NRL method which is presented for the United States Navy laboratory. It also used method based on Curvelet transform fusion in this paper, and fusion method based on recognition of natural color region. The following is a color image visible light and infrared image of the same scene through two methods which were employed to obtain the fusion. The results are shown in Figure 10.

Color fusion image is formed by the combination and the color mapping with human visual characteristics, not only can be used in different colors to highlight in infrared images of low ambient temperature and higher goals, but also preserve the visible detail rich, contrast enhancement important target in infrared image, the color image is close to the real, natural, to the human sense of visual comfort, at the same time, the contrast of the image better, target eye-catching, conducive to the observer to identify.

![Figure 10. The fusion results based on NRL method (a) and Curvelet method (b).](image)

C. Subjective Quality Evaluation of Image Fusion

Image fusion data representing mode algorithm pairs according to certain object more accurate description from different sources, different time, different media and different image, it can extract more accurate, reliable information from multiple images. The fusion effect
evaluation of fused image is to make correct analysis, measure of improvement in all aspects of the quality of image fusion. It’s not only the testing of the fusion effects, but also the system self-learning for future fusion process guidance, the result provides reliable basis for the subsequent processing steps. Fusion method of subjective image quality assessment method is the observer assess images rely on their own sense of image quality. The specific approach is composed of a group of observers, scoring for fusion images of different image fusion method, or fusion of specific target in the image identification, statistical recognition rate and time, then comprehensive comparison of the fusion image quality. The advantages of the subjective evaluation method are easier to realize, the result is reliable, while the disadvantages are affected by different observers, image types, applications and environmental conditions.

Subjective assessment can be divided into two types including absolute evaluation and relative evaluation. Absolute evaluation is made by the observer according to some evaluation of predetermined scale or your own experience, the evaluation of image quality judgment. In some cases, it also provides a set of standard image as reference, in order to help the observer to make the appropriate evaluation of image quality. The subjective evaluation of image scale tends to choose and make according to the applications. Table 1 gives five quality evaluation of image scale international regulations and prevent scale. According to the structure of knowledge and experience level of observer, the observer is divided into professional and non-professional personnel, the former uses five hinder scale, while the latter uses five level quality dimensions. In order to guarantee the subjective evaluation of image has significance in statistics, the observer participated in the evaluation should much enough. It should be noted that, if the image is the observer is very familiar with the content, then the observer is easy to find faults, and gives the lower score. While observer who is not familiar with the image content may give high scores, it can’t reflect the image quality accurately.

<table>
<thead>
<tr>
<th>Score</th>
<th>Quality scale</th>
<th>Prevent scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Very good</td>
<td>Can not see the image quality deterioration</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
<td>Can see the image quality is bad, but without prejudice</td>
</tr>
<tr>
<td>3</td>
<td>Common</td>
<td>Clear image quality deterioration</td>
</tr>
<tr>
<td>2</td>
<td>Bad</td>
<td>Watch slightly hinder</td>
</tr>
<tr>
<td>1</td>
<td>Very bad</td>
<td>Very serious impediments to watch</td>
</tr>
</tbody>
</table>

At present, the international on the color fusion image quality formed a variety of visual evaluation mainly adopt the subjective evaluation, due to a variety of visual tasks or visual objective system applied in different occasions. Detection is the most basic index of all applications; other indicators are closely related with the image details. Visual model based on the false color fusion method is proposed for Massachusetts Institute of Technology Lincoln Laboratory, in the synthesis of natural color of well known, that image fusion algorithm should take into consideration the nature. Color not only can enhance the target detection and recognition accuracy, but also shorten the time of judgment, the psychological impact, such as the fatigue of the user. Based on the above analysis, we analyze the target, details and color index which are the most basic, important and specific visual task irrelevant visual evaluation index.

D. Objective Quality Evaluation of Color Fusion Image

Image fusion from different sources, different time, different media, different image data representing mode algorithm pairs according to certain object more accurate description, it can extract any single image is more accurate, reliable information from multiple images. The fusion effect evaluation of fused image is to make correct analysis, measure of improvement in all aspects of the quality of image fusion, is to test the fusion effects, but also through the system self-learning for future fusion process guidance, provides reliable basis for the subsequent processing steps.

Figure 11. (a) Visible light image, (b) Infrared image, (c) Color fusion results based on NRL method, (d) The result of our method, (e) Color fusion results based on TNO method, (f) Infrared negative image.

With the continuous development of color fusion, objective evaluation of color image fusion quality will become an important research content. Diversity of subjective evaluation indexes and disunity is not conducive to the development of fusion algorithm, and give an objective evaluation difficult. To this end, we extract from the subjective evaluation of image quality index which are common and can be measured in physical. In the color fusion image subjective evaluation index, target is the most basic index of all applications; other indexes are closely related with the image details,
so we first consider the evaluation of color fusion image details. In order to effective color image fusion method that we proposed, several color fusion of visible and infrared image using Matlab simulation was carried out, the result was shown in Figure 11.

The ratio of maximum and minimum luminance image brightness is called contrast. Here we use the average gradient of the fused image to measure the fusion result details. The average gradient can be sensitive to reflect the ability of image expression on tiny details contrast, which can be used to image blur evaluation. A fuzzy image is near boundary and lines on both sides of the blurred image, namely gray change rate is small, and the rate of change of the size can be represented by gradient. In the image, the gray level changes in a certain direction, the rate is high. Therefore, we can evaluate image sharpness with average gradient value, also reflects the image contrast and texture feature in minute detail. In general, the average gradient is greater, the image clearer. So it can be used to evaluate the fusion image expression differences in ability in the tiny details.

IV. SUMMARY

Considering the fact that the fused color images false method was not natural, a novel region-based color mapping method is proposed to render the image fused multi-sensor images. Multi-sensor image fusion changed the traditional single channel backward method of displaying and processing. In this paper, the realization of several typical color image fusion algorithms were discussed, the principle and their respective advantages and disadvantages were analyzed. According to the different characteristics of visible image and infrared image, this paper proposes a color image fusion algorithm based on Curvelet transform, this algorithm will combine visible image, infrared image with its negative respectively fusion, and color mapping rules are in couple with the human visual characteristics. Experiments show that color fusion images obtained are richer in color, they contains more details and recognize easily.

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