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Efficient Color Transfer Method based on Colormap Clustering for Night Vision Applications

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***Abstract*—Recent night-vision cameras provide multiband images with complementary information which is useful to enable operations at night and in adverse weather conditions. The grayscale fused image is unnatural in appearance and therefore it is difficult to design a reliable intelligent system based on this results. In this paper, efficient natural color transfer method based on colormap clustering is proposed for Night Vision applications. The proposed algorithm is a novel and efficient framework to colorize the night vision imagery utilizing colormap clustering and cluster recognition based on color similarity. The target color look up table is derived from the set of natural color image database for a specific environment. Proposed method is applied on datasets of different environment and compared with standard color transfer method using objective evaluation parameters to evaluate efficacy of color transfer algorithm. The simulation results show that proposed method enhances the natural color appearance in the resultant image and provides consistent results for various datasets.**

***Index Terms*—Color transfer, night vision, colormap clustering, color similarity.**

I. Introduction

Modern night vision camera systems are used for military and law enforcement applications to design intelligent surveillance systems for security. These systems are designed to provide enhanced image with better perceptual quality in adverse environmental conditions. The most common night-time imagery systems capture images in two spectral bands, near infrared (NIR) and visual, thus providing complementary information of the observed scene which enables the observer to perceive more complete picture of the scene with a larger degree of situational awareness. A fused image combines all the salient information from the source images which is more suitable for human/machine perception. The rapid development in the technology of night vision (NV) systems has led to a growing interest in the natural color display of night vision imagery [1]. As human visual system is more sensitive to color information, efficient color transfer methods are required to enhance color image which has several benefits over gray image. The color transfer methods improve feature contrast, allowing better scene recognition and object detection which is useful in surveillance, reconnaissance, and security applications.

There are various approaches available in literature. Toet [2] proposed a global statistics matching algorithm for color transfer from single natural color target image. Yang et al in [3] have proposed region-based approach for color transfer in night vision image sequences. A local-coloring method utilizing image analysis and fusion was introduced by Zheng and Essock in [4], which render the NV image segment-by-segment by taking advantage of image segmentation, pattern recognition, histogram matching and image fusion. Recently, Toet [5] proposed a fast color mapping method in which the mapping optimizes the match between the multi-band image and the reference natural image, and yields a night vision image with a natural daytime color appearance. Gang and Huang [6] presented multi-scale color image fusion using contourlet transform and expectation maximization (EM) where the color transfer is implemented in YUV color space.

It is also observed from recent literature, the color transfer methods employ a classified database of natural scene images [4], [7], instead of using a single natural color target image [2] for colorizing night vision imagery. This approach provides more natural and realistic coloration as compared to a single target image [4]. In order to take an advantage of above approaches, in this paper we propose novel and efficient framework for colorizing night vision images using colormap clustering, cluster recognition based on color similarity and image fusion using non-subsampled contourlet transform. The paper is organized as follows: the proposed method is described in section 2, simulation results and comparative assessment are described in section 3 which is followed by the conclusion.

II. Proposed Method

In the proposed color transfer method color based clustering is applied on color map in $l\alpha\beta$ color space and cluster based color transfer is performed from multiple natural color images using color similarity metric. The block diagram of the proposed color transfer method is shown in Fig. 1 and image fusion method is shown in Fig. 2. The subsequent subsections of this section describe the detailed explanation of the major steps of proposed method.

A. False Color Fusion and Color Enhancement

The false color fusion can translate the gray information into easily distinguishable color information. Combining bands in color space therefore provides a method to increase the

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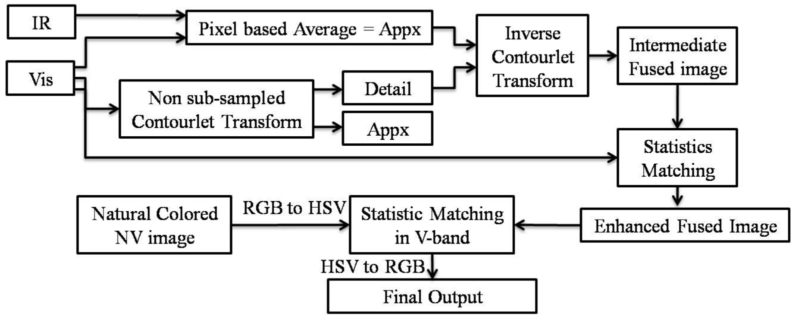

Fig. 2. Block diagram of the image fusion algorithm of the proposed method

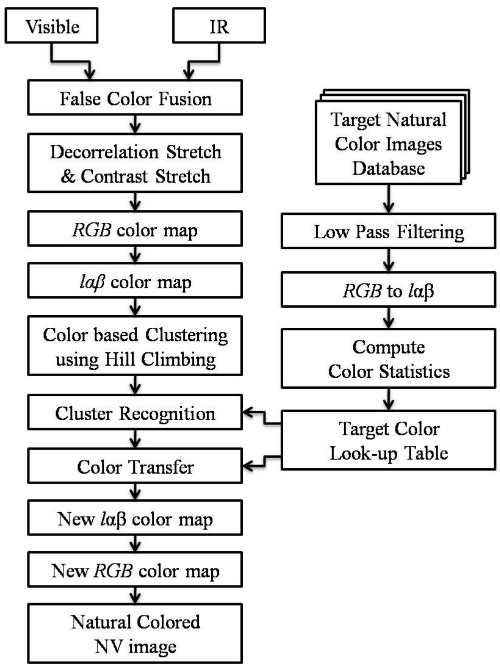

Fig. 1. Block diagram of the color transfer algorithm of the proposed method

dynamic range of a sensor system. In the proposed method the false color fusion is performed in RGB color space. The false color fused RGB image can be represented by the following equations:

$$R(m,n) = \frac{1}{2}(Vis(m,n) + IR(m,n)) \tag{1}$$

$$G(m,n) = IR(m,n) \tag{2}$$

$$B(m,n) = |Vis(m,n) - IR(m,n)| \tag{3}$$

The false color fused image so formed has intensity variations similar to visible and IR source images. In order to achieve better seperation in color based clustering we perform decorrelation stretch [8] for color enhancement and linear contrast stretch for intensity enhancement. Decorrelation stretch as described in increases color seperation across highly correlated channels while keeping the band variance same. It is followed by a linear contrast stretch on individual RGB channels. The enhanced false color image so obtained has more color variation and better contrast which significantly facilitates the subsequent clustering process.

B. Color based Clustering using Hill Climbing

The enhanced false color fused image is converted to an indexed image where each pixel contains a single index which refers to a RGB value in a color lookup table or colormap. The RGB colormap is then transformed into $l\alpha\beta$ color space to generate the $l\alpha\beta$ colormap of the same size. Performing the color space transform decorrelates the three color components (i.e. l, α and β) so that manipulations such as statistic matching on each color component can be performed independently.

Color based clustering is performed on the $l\alpha\beta$ colormap using the hill climbing algorithm. A color based image segmentation method using hill climbing algorithm proposed by Ohashi et al [9] is utilized for colormap clustering in the proposed method. The number of clusters required for proper classification of colormap are automatically determined by the hill climbing algorithm. The entries of the colormap are then associated with the local maxima detected by the algorithm, to generate several coherent clusters in the $l\alpha\beta$ colormap.

C. Cluster Recognition

For the purpose of color transfer, a natural color target image database having similar content images of the same environment as that of night vision operation (such as forest, sea or aerial environment) is considered from which a target color look-up table is built under supervision. This approach for color transfer based on target color look-up table derived from multiple natural color images gives consistent color rendering and more natural appearance [4]. In the proposed method, the natural image database consists of 3 different sets corresponding to 2 different environments - forest and sea. For the simulation purpose, 20 natural color images are considered for each environment.

The target color look-up table is created as follows. Each image from the natural color target image database is smoothed by low pass filter and transformed into $l\alpha\beta$ color space and first order statistics, mean μ and standard deviation

σ, are computed for each band. The target color look-up table contains total six statistics features for every natural color target image in the database, $\mu^l_{n,t}$, $\mu^\alpha_{n,t}$, $\mu^\beta_{n,t}$, $\sigma^l_{n,t}$, $\sigma^\alpha_{n,t}$ and $\sigma^\beta_{n,t}$, where subscripts t represents "target" and subscript n represents n^{th} image of the database. Similarly, each cluster in the $l\alpha\beta$ colormap of false color NV image is characterized by first order statistics in each band, $\mu^l_{k,s}$, $\mu^\alpha_{k,s}$, $\mu^\beta_{k,s}$, $\sigma^l_{k,s}$, $\sigma^\alpha_{k,s}$ and $\sigma^\beta_{k,s}$, where subscript s represents "source" and subscript k represents k^{th} cluster of the colormap.

A nearest neighbour criteria is used for automatic association of a cluster of colormap with a unique natural color image in the target color look-up table. The similarity metric $Q_w(k,n)$ [4] is used as the measure to find the distance in $l\alpha\beta$ space between k^{th} cluster of colormap and n^{th} natural color target image in the look-up table. The similarity metric is defined in the $l\alpha\beta$ color space as following:

$$Q_w(k,n) = \sum_{i=\{l,\alpha,\beta\}} [w_i \cdot Q_i(k,n)] \tag{4}$$

where w_i is the weight for each color component. $Q_i(k,n)$ is defined as:

$$Q_i(k,n) = \frac{2\mu_k\mu_n}{\mu_k^2+\mu_n^2} \cdot \frac{2\sigma_k\sigma_n}{\sigma_k^2+\sigma_n^2} \tag{5}$$

where μ_k and σ_k are the mean and standard deviation of k^{th} cluster in a particular color component of the source colormap of false color NV image. Similarly μ_n and σ_n are the mean and standard deviation of a particular color band of n^{th} natural color target image in the target color look-up table. It is evident from above equations that higher the value of similarity metric, larger their color similarity. Thus the purpose of cluster recognition is to decide with which natural color image a particular cluster should be rendered.

D. Color Transfer

Color transfer is performed cluster-by-cluster by the standard statistics matching method proposed by Toet [2]. Each index in $l\alpha\beta$ colormap is first checked as to which cluster does it belong and then the statistics of natural color target image associated with that cluster is transferred to the $l\alpha\beta$ values of the index in colormap. Thus a new $l\alpha\beta$ colormap is obtained. The equations for color transfer on each index in the colormap are defined as follows:

$$\bar{l}_{k,s} = \frac{\sigma^l_{n,t}}{\sigma^l_{k,s}}(l_{k,s} - \mu^l_{k,s}) + \mu^l_{n,t} \tag{6}$$

$$\bar{\alpha}_{k,s} = \frac{\sigma^\alpha_{n,t}}{\sigma^\alpha_{k,s}}(\alpha_{k,s} - \mu^\alpha_{k,s}) + \mu^\alpha_{n,t} \tag{7}$$

$$\bar{\beta}_{k,s} = \frac{\sigma^\beta_{n,t}}{\sigma^\beta_{k,s}}(\beta_{k,s} - \mu^\beta_{k,s}) + \mu^\beta_{n,t} \tag{8}$$

where kth cluster is associated with nth natural image in the color look-up table, and s and t denote source and target respectively. The modified values for each index, $\bar{l}_{k,s}$,$\bar{\alpha}_{k,s}$ and $\bar{\beta}_{k,s}$, form the new $l\alpha\beta$ colormap. The complete $l\alpha\beta$ colormap is transformed to RGB color space to produce the new RGB colormap, which is then applied to the indexed false color image to generate the natural colored night vision image.

E. Grayscale Image Fusion

The grayscale image fusion is performed after color transfer process. In the proposed method the non-subsampled contourlet transform (NSCT) [10] is incorporated because it is multi-scale, redundant and shift-invariant representation which is better in contour detection than a discrete wavelet transform [6], [11]. An intermediate fused image I_{if} is generated by considering the average of approximation components. In order to improve the contrast, a linear map is applied on I_{if} to match the mean and variance with that of visible source image I_{vi}:

$$I_{ef} = \frac{\sigma_{vi}}{\sigma_{if}}(I_{if} - \mu_{if}) + \mu_{vi} \tag{9}$$

where I_{ef} is the enhanced fused image. Thereafter, RGB to HSV transform is applied to the natural colored NV image and again linear map is applied with the 'V' band of the natural colored NV image. Finally, I_{fuse} is substituted in the V-band of the natural colored NV image and HSV to RGB transform is performed to generate the final output.

III. Simulation Results

The proposed method has been simulated with Matlab7 on system with 2GHz Core 2 Duo processor with 1GB RAM machine. The average computational time to generate the colored NV image is 3-4 seconds and to obtain fused image is 6-7 seconds. Our dataset consists of three different night vision multiband source imagery which belong to two different environments [12].

The simulation results for the UNcamp dataset corresponding to Forest environment is depicted in Fig. 3. Among the three datasets, the UNcamp and Trees data sets belong to Forest environment and the Navy data set belongs to Sea environment for color transfer. We have selected certain parameters based on extensive experimentation. The size of the colormap of the enhanced false colored image is taken as 1024. The number of bins used in 3D $l\alpha\beta$ histogram clustering in hill climbing algorithm is [10 10 10]. In the similarity metric $Q_w(k,n)$ the weights assigned to each color component are w_i=[0.25 0.35 0.40] corresponding to l,α & β channels respectively.

The quality assessment of different image fusion schemes for night vision images is traditionally carried out by subjective evaluations [13], [14]. The subjective evaluation is influenced by individual human perception. Since multiple natural images are used for color transfer, non-reference based objective evaluation parameters; entropy and colorfulness metric, are considered for evaluating proposed method. Entropy is used to measure the information content of an image. The entropy of natural colored night vision image is computed for each band in RGB color space and average of the entropy of the three bands is considered for evaluation. The other important parameter, Colorfulness Metric is an efficient metric for calculating

TABLE I
COMPARISON ON THE BASIS OF ENTROPY

Data Set	Statistics Matching [2]	Proposed method
UNcamp	6.6375	**6.8523**
Trees	6.0535	**6.8221**
Navy	6.8916	**7.0377**

TABLE II
COMPARISON ON THE BASIS OF COLORFULNESS METRIC

Data Set	Statistics Matching [2]	Proposed method
UNcamp	0.1852	**0.3547**
Trees	0.2846	**0.3156**
Navy	0.2240	**0.3139**

colorfulness of images and it is described in [15]. Larger the color variations in the image, higher is the colorfulness metric.

The proposed algorithm is compared with the standard statistics matching method proposed by Toet [2]. A suitable reference natural color target image 3(h) having similar scene content is considered for color transfer for implementing Toet's method. The simulation results of proposed algorithm is shown in Fig. 3(f). It is observed that proposed method provides more natural appearance compared to Toet's method [2] shown in Fig. 3(g). It is also evident from the objective evaluation parameters depicted in TABLE I and TABLE II. It is also observed from TABLE I and TABLE II that the proposed method consistently provide significantly better value of colorfulness metric and entropy compared to Toet's method [2].

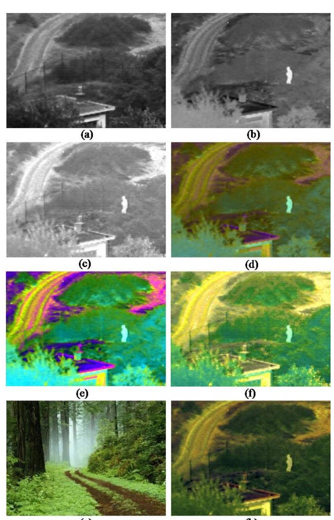

Fig. 3. Results for UNcamp data set (a) Visible source image, (b) IR source image, (c) Grayscale fusion image, (d) False color fusion image, (e) Enhanced false color fusion image, (f) Proposed method (g) Toet [2], (h) Reference natural color target image for Toet method [2]

IV. CONCLUSION

In this paper, we propose an efficient color transfer method from multiple target images using colormap clustering and cluster recognition based on color similarity. The proposed method utilizes decorrelation stretch for color enhancement which improves the efficiency of colormap clustering based on hill climbing algorithm. The simulation results of proposed method show that the color NV image has more natural and realistic appearance. The objective evaluation parameters are also better compared to standard statistics matching method. In future, the algorithm can be extended to obtain set of statistical properties of natural images of different environments which can be used for all operational environments.

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