A New Sight for Direct Decorrelation Stretch Techniques

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ABSTRACT

Two decorrelation stretch techniques called Direct Decorrelation Stretch (DDS) and Intensity Conservation DDS (ICDDS) have been recommended for applications on highly correlated multispectral images. This work examines the approaches of DDS and ICDDS in more details and seeks to clarity some apparent misconceptions in saturation stretching. To describe the misconceptions, an IHS substitution (IHSS) technique is proposed. For saturation stretching or image fusion, the fact that the product of saturation value and intensity value equals to a constant value, the hue is unchanged and the saturation value of a pixel is inversely proportional to its intensity value. This fact is crucial to be considered in designing the algorithms.

Keywords: decorrelation stretch; multispectral images; saturation stretching; image fusion.

多光譜影像解相關伸展技術的一種新視野

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摘　　要

目前多光譜影像存在有各光譜間彼此高度相關的問題，為解決此問題遂有解相關伸展技術的提出，其中一種稱為直接的解相關伸展技術(Direct Decorrelation Stretch；DDS)，另一種則為影像強度保持解相關伸展技術 (Intensity Conservation DDS；ICDDS)。 本論文旨在更詳細檢視 DDS 和 ICDDS 方法在飽和度伸展過程中一般人未注意的一些明顯誤解。為了說明這些誤解，本文提出一個 IHS 代換技術(IHSS)是基於相同基礎上來檢視飽和度變化。事實上就飽和度伸展或影像融合來說，影像原色是不會改變的，飽和度值與影像強度值的乘積是一常數值，亦即飽和度值與影像強度值成反比關係。這個現象是很重要的，因此在設計演算法過程中應該要考慮到此因素。

關鍵詞：解相關伸展，多光譜影像，飽和度伸展，影像融合

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I. INTRODUCTION

Multispectral image bands are often highly correlated, i.e. they are visually and numerically similar to each other. Therefore, they often cannot be adequately displayed by independent contrast stretching in the displays of RGB bands. The colors in a RGB image, after a direct contrast stretch for those three bands, may still appear undersaturated. To overcome this problem, the decorrelation stretch techniques, called Direct Decorrelation Stretch (DDS), has been presented in [1] which is a form of decorrelation stretching that increases color saturation by reducing the achromatic component of the RGB image. Furhtermore, Intensity Conservation DDS (ICDDS) was also proposed which is similar to DDS, but may preserve the original RGB image intensity more than DDS [1]. These two techniques can be used to directly adjust the saturation component in the RGB space without any coordinate transformation. However, the formula for the DDS listed in (Liu and Moore 1996) has an apparent misconception and can not work well, because the saturation value of the original RGB image should be changed, but it has been preserved. For the method of ICDDS, despite of the fact that ICDDS is an efficient method for saturation stretching (Liu and Moore 1996), but since it is derived from DDS that has an apparent misconception, the resulted efficiency should be achieved by coincidence. The detailed description is shown in Section 3. In this work, we present a relatively detailed study indicating that the DDS technique is an intrinsic IHS substitution (IHSS) method. Also, through two RGB-IHS transformations, the problem of saturation stretch in DDS is addressed.

II. THE RGB-IHS CONVERSION MODELS

To understand the problem of saturation stretch in DDS, it is necessary to review two essential and important RGB-IHS conversion models [2]. The first RGB-IHS conversion system is a linear transformation:

$$\begin{bmatrix} I \\ v1 \\ v2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & 2\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \text{and}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I \\ v1 \\ v2 \end{bmatrix} \tag{1}$$

Variables $v1$ and $v2$ in Equation (1) can be considered as x and y axes in the Cartesian coordinate system while intensity I indicates the z axis. In this way, the hue (H) and saturation (S) can be represented by,

$$H = \tan^{-1}\left(\frac{v2}{v1}\right) \ \ and \ \ S = \sqrt{v1^2 + v2^2}\ . \tag{2}$$

The hue component is associated with the dominant wavelength of pure color and the saturation component refers to the relative amount of white light mixed with a hue and inversely proportional to the amount of white light added.

Alternately, we can rotate the RGB cube until the horizontal plane is parallel to the Maxwell triangle and the vertical axis lies on the gray line of the RGB cube. As such, a nonlinear RGB-IHS conversion system [3] can be represented by

$$I = (R + G + B)/3\,, \tag{3-1}$$

$$H = \begin{cases} \cos^{-1}(\tau), \ if \ \ G \geq R \\ 2\pi - \cos^{-1}(\tau), \ if \ \ G \leq R \end{cases},$$

$$\tau = \frac{(2B-G-R)/2}{\sqrt{(B-G)^2+(B-R)(G-R)}} \qquad (3\text{-}2)$$

and $$S = 1 - \frac{3\min(R,G,B)}{R+G+B}. \qquad (3\text{-}3)$$

The relation of Equations (1), (2) and (3) was derived by Ledley [4]. These two RGB-IHS conversion systems differ mainly in their representations of the saturation. In Equation (1) and Equation (2), pixels with identical $\sqrt{v1^2+v2^2}$ have the same saturation value which is independent of the intensity I. These pixel points form a saturation barrel in the IHS space. For the conversion system in Equation (3), pixels with identical $\sqrt{v1^2+v2^2}$ are located on the surface of a saturation cone with saturation values proportional to distinct intensities. This means that the saturation value is preserved using the conversion model in Equation (1), but the saturation value is related to the change of intensity values when using the conversion model in Equation (3).

III. A GENERALIZED IHS SUBSTITUTION (IHSS) TECHNIQUE

To describe the misconception in the DDS technique, herein, we introduce a unified image fusion technique called IHS substitution (IHSS) method. The IHSS method uses a RGB image in distinct bands and transforms them into an IHS space. The intensity component in the IHS space is then replaced by a gray-level image and transformed back into the original RGB space with previous H and S components. The merged image is a product that synergistically combines the best features from each of their components.

The IHSS method for each pixel can be accomplished by the following procedure:

Step1:

$$\begin{bmatrix} I \\ v1 \\ v2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & 2\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}, \qquad (4\text{-}1)$$

Step 2: I component is replaced by a gray-level image I';

Step3:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I' \\ v1 \\ v2 \end{bmatrix}. \qquad (4\text{-}2)$$

where R, G, B, I, $v1$, and $v2$ represent the corresponding values in the original RGB image, R', G', and B' are corresponding values of the fused image.

The direct implementation of the IHSS method in Equation (4) requires numerous multiplication and addition operations, making it computationally intensive. To develop a computationally efficient method without the coordinate transformation, Equation (4-2) can be rewritten as,

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} \text{I-(I-I}') \\ v1 \\ v2 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I-\delta \\ v1 \\ v2 \end{bmatrix} = \begin{bmatrix} R-\delta \\ G-\delta \\ B-\delta \end{bmatrix} \qquad (5)$$

where $\delta = I - I'$. Equation (5) states that the fused image, $[R', G', B']^T$, can be easily obtained from the original image, $[R, G, B]^T$, simply by subtraction operation only. Hence, the IHSS method can be implemented efficiently by this procedure.

To analyze IHSS behaviors, Equation (5) can be rewritten as

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} R-\delta \\ G-\delta \\ B-\delta \end{bmatrix} = \begin{bmatrix} I' \\ I' \\ I' \end{bmatrix} + \begin{bmatrix} -1/\sqrt{2} & 1/\sqrt{2} \\ -1/\sqrt{2} & -1/\sqrt{2} \\ \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} v1 \\ v2 \end{bmatrix} \quad (6)$$

From Equation (6), it is important to recognize that both H and S defined by Equation (2) are preserved during fusion, only the intensity component I has been replaced by I'.

To compare Equation (6) with DDS, the formula of the DDS in (Liu and Moore 1996) is rewritten as,

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} R-ka \\ G-ka \\ B-ka \end{bmatrix} = \begin{bmatrix} I' \\ I' \\ I' \end{bmatrix} + \begin{bmatrix} -1/\sqrt{2} & 1/\sqrt{2} \\ -1/\sqrt{2} & -1/\sqrt{2} \\ \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} v1 \\ v2 \end{bmatrix} \quad (7)$$

Herein, we let $\delta = ka$ for Equation (6), k is an achromatic factor and 0< k < 1, a denotes the minimum value among R, G, and B. Therefore, we know that the DDS formula in Equation (7) has not done any saturation stretch because the saturation and hue remain their original values as shown in Equation (6), only the intensity component I has been changed to I'. The only difference is that the resulted image is darker than the original image (due to $I' = I - \delta =$ I-ka). As such, the image is easily to be visually confused as saturation-stretched.

For the ICDDS case, the formula in (Liu and Moore 1996) can be rewritten into an IHS-like form as,

$$\begin{bmatrix} R'' \\ G'' \\ B'' \end{bmatrix} = l \cdot \begin{bmatrix} R-ka \\ G-ka \\ B-ka \end{bmatrix} = l \cdot \left(\begin{bmatrix} I' \\ I' \\ I' \end{bmatrix} + \begin{bmatrix} -1/\sqrt{2} & 1/\sqrt{2} \\ -1/\sqrt{2} & -1/\sqrt{2} \\ \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} v1 \\ v2 \end{bmatrix} \right)$$

$$= \begin{bmatrix} I \\ I \\ I \end{bmatrix} + \begin{bmatrix} -1/\sqrt{2} & 1/\sqrt{2} \\ -1/\sqrt{2} & -1/\sqrt{2} \\ \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} l \cdot v1 \\ l \cdot v2 \end{bmatrix} \quad (8)$$

where $l = \frac{I}{I'}$, and its value is always larger than 1 (due to $I' = I - ka$). From the definition in Equation (2), the hue and saturation of the resulted image can be given by

$$H'' = \tan^{-1}\left(\frac{l \cdot v2}{l \cdot v1}\right) = H \quad (9\text{-}1)$$

$$S'' = \sqrt{(l \cdot v1)^2 + (l \cdot v2)^2} = l \cdot \sqrt{v1^2 + v2^2} = l \cdot S \quad (9\text{-}2)$$

By referring to Equation (8) and Equation (9), they show that intensity value and hue value of the resulted image are the same as the original RGB image, but only the saturation value has been altered. Therefore, since the saturation value is changed in the resulted image, the ICDDS has achieved the goal of saturation stretch. However, by referring to Equation (6), the DDS has not done any saturation stretch, as mentioned previously.

IV. THE RELATIONSHIP BETWEEN iNTENSITY AND SATURATION IN RGB-IHS CONVERSION MODELS

To further analyze the behavior of saturation stretch, δ in Equation (5) can be substituted into Equation (3) and the notations defined before can be adopted. Following the process of image substitution in Equation (3-1), Equation (3-1) can be rewritten as,

$$\mathrm{I}' = ((\mathrm{R}\text{-}\delta) + (\mathrm{G}\text{-}\delta) + (\mathrm{B}\text{-}\delta))/3 = \mathrm{I}\text{-}\delta$$

τ in Equation (3-2) can be re-calculated and given by

$$\tau' = \frac{(2(\mathrm{B}-\delta) - (\mathrm{G}-\delta) - (\mathrm{R}-\delta))/2}{\sqrt{((\mathrm{B}-\delta)-(\mathrm{G}-\delta))^2 + ((\mathrm{B}-\delta)-(\mathrm{R}-\delta))((\mathrm{G}-\delta)-(\mathrm{R}-\delta))}}$$

$$= \frac{(2\mathrm{B}-\mathrm{G}-\mathrm{R})/2}{\sqrt{(\mathrm{B}-\mathrm{G})^2 + (\mathrm{B}-\mathrm{R})(\mathrm{G}-\mathrm{R})}} = \tau \qquad (10)$$

Equation (10) indicates that the hue H of the resulted image is unchanged by using Equation (3-2) for calculation, i.e., the hue value of the resulted image is the same as that of the original RGB image when I value is replaced by I′ value. In contrast, by using Equation (3-3), the saturation value of the original RGB image can be given by

$$\mathrm{S} = 1 - \frac{3a}{\mathrm{R}+\mathrm{G}+\mathrm{B}} = \frac{\mathrm{I}-a}{\mathrm{I}} \qquad (11\text{-}1)$$

where a denotes the minimum value of R, G, and B. By substituting δ and corresponding notations into Equation (8-1), the new saturation value for the resulted image becomes

$$\mathrm{S}' = 1 - \frac{3\min(\mathrm{R}-\delta, \mathrm{G}-\delta, \mathrm{B}-\delta)}{\mathrm{R}+\mathrm{G}+\mathrm{B}-3\delta}$$

$$= 1 - \frac{3(a-\delta)}{\mathrm{R}+\mathrm{G}+\mathrm{B}-3\delta} = \frac{\mathrm{I}-a}{\mathrm{I}'} \qquad (11\text{-}2)$$

An important relationship between Equation (11-1) and Equation (11-2) is that,

$$\frac{\mathrm{S}'}{\mathrm{S}} = \frac{\mathrm{I}}{\mathrm{I}'} \text{ or } \mathrm{I}\cdot\mathrm{S} = \mathrm{I}'\cdot\mathrm{S}' = \text{constant}. \qquad (12)$$

By observing Equation (10) and Equation (12), for an image before and after the process of saturation stretch, the product of saturation and intensity equals to a constant value and the hue value is unchanged. The saturation value of a pixel is inversely proportional to its intensity value. More precisely, the saturation value is expanded and stretched ($\mathrm{S}' > \mathrm{S}$) if I' value is less than I value, while the saturation value is compressed ($\mathrm{S}' < \mathrm{S}$) if I' value is larger than I value. For the saturation stretching, I value must be always larger than I' value to achieve the purpose of larger S' value than S value. Therefore, since $\delta = \mathrm{I} - \mathrm{I}'$, the value of δ is a crucial factor to the saturation stretch process.

By referring to the relationship of S and S' in Equation (12), the saturation stretching can be accomplished simply by shifting S to S' or multiplying a factor $l = \frac{\mathrm{I}}{\mathrm{I}'}$ into Equation (5). That is

$$\begin{bmatrix}\hat{\mathrm{R}}\\ \hat{\mathrm{G}}\\ \hat{\mathrm{B}}\end{bmatrix} = \begin{bmatrix}\mathrm{I}'\\ \mathrm{I}'\\ \mathrm{I}'\end{bmatrix} + l\cdot\begin{bmatrix}-1/\sqrt{2} & 1/\sqrt{2}\\ -1/\sqrt{2} & -1/\sqrt{2}\\ \sqrt{2} & 0\end{bmatrix}\begin{bmatrix}v1\\ v2\end{bmatrix}$$

$$= \begin{bmatrix}1 & -1/\sqrt{2} & 1/\sqrt{2}\\ 1 & -1/\sqrt{2} & -1/\sqrt{2}\\ 1 & \sqrt{2} & 0\end{bmatrix}\begin{bmatrix}l\cdot\mathrm{I}\text{-}(l\cdot\mathrm{I}-\mathrm{I}')\\ l\cdot v1\\ l\cdot v2\end{bmatrix}$$

$$= \begin{bmatrix}l\cdot\mathrm{R}\text{-}(1+l)(k\mathrm{a})\\ l\cdot\mathrm{G}\text{-}(1+l)(k\mathrm{a})\\ l\cdot\mathrm{B}\text{-}(1+l)(k\mathrm{a})\end{bmatrix} \qquad (13)$$

where $[\hat{\mathrm{R}}, \hat{\mathrm{G}}, \mathrm{B}]^{\mathrm{T}}$ is the resulted saturation-stretched image. After this process, a fused image is obtained by an unchanged hue, different intensity and the saturation S is compensated to S'. This is the original purpose of DDS, rather than the results implemented by Equation (6) or Equation (7). The DDS implemented in Equation (6) or Equation (7) has preserved but not changed the saturation value of the original RGB. That is, DDS has not done any saturation stretching.

To preserve the intensity and hue of the original image, but only the saturation is stretched; the compensation strategy for saturation value can be implemented as,

$$\begin{bmatrix} R'' \\ G'' \\ B'' \end{bmatrix} = l \cdot \left(\begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I' \\ v1 \\ v2 \end{bmatrix} \right)$$

$$= l \cdot \begin{bmatrix} I' \\ I' \\ I' \end{bmatrix} + l \cdot \begin{bmatrix} -1/\sqrt{2} & 1/\sqrt{2} \\ -1/\sqrt{2} & -1/\sqrt{2} \\ \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} v1 \\ v2 \end{bmatrix}$$

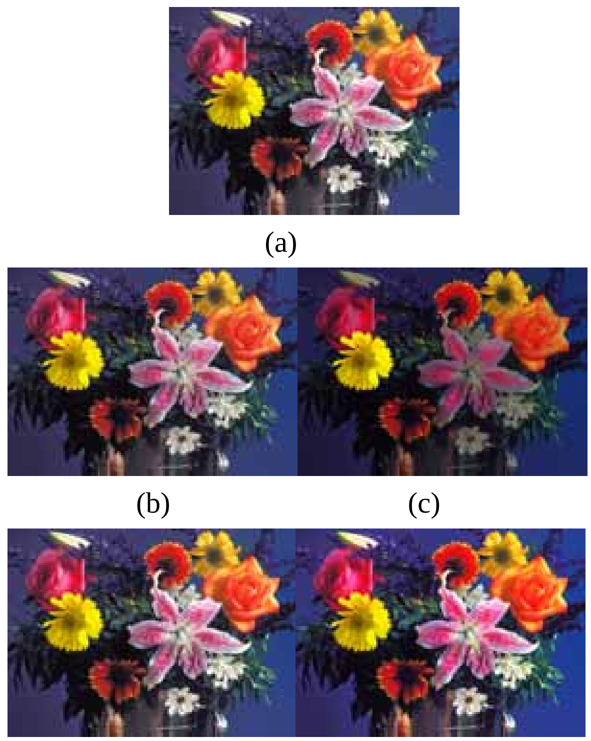
$$= \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I \\ l \cdot v1 \\ l \cdot v2 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} l \cdot I\text{-}(l\text{-}1) \cdot I \\ l \cdot v1 \\ l \cdot v2 \end{bmatrix}$$

$$= l \cdot \begin{bmatrix} R\text{-}ka \\ G\text{-}ka \\ B\text{-}ka \end{bmatrix} \tag{14}$$

The final result presented in Equation (14) is the same as ICDDS listed in (Liu and Moore 1996) and rewritten in Equation (8). This is to explain the fact mentioned in Section 1 that ICDDS is an efficient method for saturation stretching, but since it is derived from DDS, the efficiency should be achieved by coincidence.

Figure 1 is used as an example to illustrate the misconceptions in DDS and ICDDS. The original flower image is shown in Fig. 1(a). The DDS approach by Equation (7) with k=0.1 is displayed in Fig. 1(b) and k=0.5 is displayed in Fig. 1(c). Since the saturation refers to the relative amount of white light mixed with a hue, it is easy to see that the saturation of Fig. 1(b) is the same as that of Fig.1(c) from blue and green color while the intensity of Fig.1(c) is darker than that of Fig.1(b). Furthermore, ICDDS approach by Equation (8) with k=0.1 is exhibited in Fig. 1(d) and k=0.5 is exhibited in Fig. 1(f). Compared Fig. 1(a) with Fig. 1(d) and Fig. 1(f), those three images have the same intensity clearly but they don't have the same saturation value which can be found from the relative amount of white light mixed with blue and green color.



(a)

(b) (c)

(e) (f)

Fig. 1. Illustration of DDS and ICDDS, (a) The original image, (b) by Equation (7) k=0.1, (c) by Equation (7) k=0.5, (d) by Equation (8) k=0.1, (e) by Equation (8) k=0.5.

V. CONCLUSIONS

The major advantage of the DDS and ICDDS is that they can perform saturation stretching in the RGB space, without applying any coordinate transformation. However, despite of the fact that ICDDS is an efficient method, due the misconception of the authors proposed in (Liu and Moore 1996), it is easy to make the readers confused. The main purpose of this work is to clarify the misconception. This misconception has been explained in Section 3 and Section 4. In this work, an IHS substitution (IHSS) technique is proposed and through two RGB-IHS transformations, the problem of saturation stretching using DDS is described. Meanwhile, the misconception of DDS has been also occurred in the IHS-based image fusion methods. The key issue is the fact that the product of saturation value and intensity value equals to a constant value, the hue is unchanged and the saturation value of a pixel is inversely proportional to its intensity value. Considering the remote sensing image fusion, it is injection the high spatial resolution image information into the low spatial resolution multispectral imagery such that the resultant image preserves the high spatial resolution information without degrading the chromatic information. Note that the intensity of high spatial resolution image is almost different from that of low spatial resolution multispectral imagery. Therefore, when we design the algorithms for saturation stretching or image fusion, this is an important factor to be considered carefully.

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