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ENHANCED SPARSE SYSTEM FOR MULTI-CHANNEL MANAGEMENT USING REDUCED MONOTONE GEOMETRIC ALGEBRA

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ABSTRACT

Sparse representations are mainly used in colour image processing. However, existing sparse models are used only in scalar methods to demonstrate colour image pixels. In these models, loss is very high compared to structured monotone geometric algebra. If we use vector matrix in multichannel management it gives more computational complexity. In our proposed system for novel enhanced sparse system for colour image that bears multi channel management based on monotone geometric algebra. Firstly, a novel theory of monotone vector geometric algebra (MVGA) is provided, including monotone vector matrix sparse basis and the reduced geometric operations. Secondly, taking advantage of the MVGA theory, the model represents colour image with multi-channel as a matrix vector with the spatial and spectral information in MVGA space. Thirdly, the dictionary learning algorithm is provided using the K-MVGA-based multi value decomposition (K-MVGAMVD) (Generalized K-means clustering for MVGAMVD) method. The comparison results demonstrate that the proposed model can remove the data redundancy and reduce the computational complexity, and can mean while effectively preserve the inherent colour structures. The result suggests its potential as a heterogeneous and efficient tool in various applications of colour image analysis.

KEYWORDS
dictionary learning, multi-channel image, reduced monotone geometric algebra, sparse representation.

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I. INTRODUCTION

Sparse representations of colour image based on dictionary learning have currently been an energetic area for its potential of providing extremely high performance for various applications [1, 2, 3, 4]. In this model, a multi-colour image can be well-represented as a sparse non linear combination of attributes from properly chosen over-complete dictionary instead of being separated into Independent attributes [4, 5]. The excellence of dictionary determines the performance of the sparse coding, which can be chosen as a pre-defined set of bases, such as monotone geometric transformations, wavelets [6], curvelets [7], contourlets [8], short-time Fourier kernels [9], Laplacian pyramid [10], or unions of bases. Conventional monotone models regard each colour image pixel as a scalar and process the pixel in an independent way, which fails to use the inter-relationship among the RGB colour channels, potentially resulting in some colour distortions and blurring effects always appearing in reconstruction results [11, 12]. Although the scalar product is modified to enforce average colours, which improves the efficiency of the illustration for denoising [11], in-painting [12] classification [13] and object detection [14], some unproductive results still persist. For development, Mairal et al. [15] proposed a concatenate model by performing simple concatenation of the RGB values to a single vector and training on those directly to alleviate the hue distortion problem. Unfortunately, the lack of explicit constraints on the correlations among colour channels inexorably leads to some unproductive results. Another scheme is using independent colour channels rather than RGB channels. Monotone-based methods have shown the efficiency in dealing with colour images. Recently, monotones have been introduced to represent multi-channel RGB structures for vector sparse representations of colour images [3] in which have shown improved performance for reconstruction [3] in proposed a vector sparse representation model for colour images using monotone vector matrix analysis, which conducts the sparse basis selection in monotone vector space to successfully avoid the hue bias issue. However, the monotone-based methods are known to suffer from high computational complexity due to non- commutative multiplication. To improve the method, reduced monotone vector matrix (RMVM) with commutative multiplication is introduced to reduce computational complexity. A new monotone vector- valued sparse representation model for colour images using RMVM. In general, the existing sparse models treat each colour image pixel either as a scalar, which loses some colour structures, or as a monotone vector matrix with high computational complexity. In this paper, we implement a monotone vector based sparse representation model for reduced geometric algebra in multi-channel image management. In particular, a novel theory of monotone based reduced geometric algebra (MRGA) is provided with commutative multiplication rules. Taking advantage of the MRGA theory, the model represents each colour image as a multi vector with the spatial and spectral information in MRGA space, where the basic operational rules, properties and MVD analysis of colour image are defined. We use multi vector operations among the colour atoms of the learned MRGA-based dictionary and the sparse MRGA-based coefficients to reconstruct colour image blocks. Then, the corresponding dictionary learning method namely K- MVGAMVD (Generalized K-means clustering for Multi Value Decomposition using MVGA), is provided. The MVGA-OMP (orthogonal matching pursuit in MVGA form) method is used to compute the sparse coefficients. Thus, it achieves the removal of the redundancy among colour channels, the inherent colour structures preserved, and low computational complexity. The rest of this paper is organized as follows. Section II describes the implementation and algorithm of proposed method for novel MVGA- based sparse representation model. The MVGA-based dictionary training algorithm is represented in Section III. In Section IV, the reconstruction and denoising experiments are implemented to show the effectiveness and rationality of this algorithm. Finally, Section V concludes the paper.

II. IMPLEMENTATION OF MONOTONE VECTOR BASED REDUCED GEOMETRIC ALGEBRA

The multiplication of GA is not commutative, which leads to the high algorithm complexity. As an improvement, we provide a novel monotone based vector reduced geometric algebra theory with commutative properties.

The monotone vector based Reduced Geometric Algebra (MVGA) is defined as follows:

$Y_i = 1/2\, m\, (1 + e_i e_{n+i}) \in G_n,\ i = 1, 2,$

According to the geometric product of γ_i and γ_j

$$\gamma_i^2 = \gamma_i \gamma_j \overset{\Delta}{=} \mu \begin{cases} \gamma_{i+1}, & i = 1, 2, \ldots, n-1 \\ \gamma_1, & i = n \end{cases} \qquad (1)$$

MVGA is generated by the collection of

$k = \mu\,\{a_1\gamma_1 + a_2\gamma_2 + a_{12}\gamma_{12},\ a_1, a_2, a_{12}\} \in P$

GA, here the multiplication operation is provided as follows.

$\forall k, l \in \Gamma_2 R$, suppose $k = \mu\{a_1\gamma_1 + a_2\gamma_2 + a_3\gamma_{12}\}$ and $Rl = \mu\{b_1\gamma_1 + b_2\gamma_2 + b_3\gamma_{12}\}$,

then the multiplication

$k\,l = \mu(a_1\gamma_1 + a_2\gamma_2 + a_3\gamma_{12})(b_1\gamma_1 + b_2\gamma_2 + b_3\gamma_{12})$

$= \mu\{(a_1b_3 + a_2b_2 + a_3b_1)\gamma_1 + (a_1b_1 + a_2b_3 + a_3b_2)\gamma_2 + (a_1b_2 + a_2b_1 + a_3b_3)\gamma_{12}\}$

Therefore, the muti-dimensional MVGA overcomes the data redundancy embodied in the previous sparse representation for colour image based on monotone vector.

The norm of the elements in G 2R is defined as

$k = \mu\, a\,'\gamma 1 + \mu b\,'\gamma 2 + \mu\, c\,'\gamma 12$ (2)

$k\, k = \mu\{(a\gamma 1 + b\gamma 2 + c\gamma 12)\,(a\,'\gamma 1 + b\,'\gamma 2 + c\,'\gamma 12)\}$ (3)

$= \mu\{\,(ca\,'+ bb\,'+ ac\,')\,\gamma 1 + (aa\,'+ cb\,'+ bc\,')\,\gamma 2 + (ba\,'+ ab\,'+ cc\,')\,\gamma 12\}$ (4)

Solving the above equations yields the values of the individual attributes but not all the elements of G 2R are conjugate.

Suppose a MVGA multi vector is given as $\mathbf{Km}\,(M) = \mu\, A(C) + \mu B(C)\gamma 2 = \mu\mathbf{K}1(C)\,\beta 1 + \mu\,\mathbf{K}\,2(C)\,\beta 2$

Thus, K1(C) and K 2(C) are two equivalent complex matrices. The MVD of the RGA multivector (MVGAMVD) is performed by the complex MVD of the equivalent complex matrices.

Consequently, the original RGA multivector is reconstructed by the sum of outer products

$\mathbf{Km}\,'(M) = \mu\{\mathbf{U}(M)\lceil \sum(M)\rceil\lceil \mathbf{V}(M)\rceil = \sum u(iM)\delta\,(iM)\lceil v(iM)\}$ *(5)*

where $\mathbf{K}\,'(\mathbf{M})$ is the reconstruction of $K(\mathbf{M})$.

The complexity of MVGASVD is much lower than the monotone vector based application because more real multiplications are needed to calculate the product of two monotone vectors. Thus, the use of MVGAMVD for colour image processing is more efficient than using monotone vectors. Given a colour image **I** , its MVGA form is

$Im\,(x, y) = I\, mR\,(x, y)\gamma 1 + IG\, m(x, y)\gamma 2 + I\, B\, m(x, y)\gamma 12(\,G\, 2R\,)$ respectively, and the colour image pixel $I\,(x, y)$ is re- presented in the form of a reduced geometric algebraic multi-vector. Each pixel of the image gives a data structure that is MVGA. To take the inter-relationship among the MVGB channels into consideration, a monotone vector based sparse representation model (MVGA-SR) for colour image based on reduced geometric algebra is presented in this paper.

The patch **f** in the RGA form is given as: $\mathbf{f} = \mathbf{Dg}$

Each pixel of the image gives a data structure that is MVGA. Then, we can obtain the following equation as the generalized form of colour image representation model.

$\mathbf{f} = \mathbf{Dg} \Leftrightarrow \mathbf{f}\,\mathrm{R}\,\gamma 1 + \mathbf{f}\mathrm{G}\,\gamma 2 + \mathbf{f}\,\mathrm{B}\,\gamma 12$

$= (\,\mathbf{D}\mathrm{R}\,\gamma 1 + \mathbf{D}\mathrm{G}\,\gamma 2 + \mathbf{D}\,\mathrm{B}\,\gamma 12\,)(\,\mathbf{g}1\gamma 1 + \mathbf{g}\,2\gamma 2 + \mathbf{g}\,3\gamma 12\,)$

$= (\mathbf{D}\mathrm{R}\,\mathbf{g}\,3 + \mathbf{D}\mathrm{G}\,\mathbf{g}\,2 + \mathbf{D}\,\mathrm{B}\,\mathbf{g}1\,)\,\gamma 1 + (\,\mathbf{D}\,\mathrm{R}\,\mathbf{g}1 + \mathbf{D}\mathrm{G}\,\mathbf{g}\,3 + \mathbf{D}\,\mathrm{B}\,\mathbf{g}\,2\,)\,\gamma 2 + (\,\mathbf{D}\mathrm{R}\,\mathbf{g}\,2 + \mathbf{D}\mathrm{G}\,\mathbf{g}1 + \mathbf{D}\,\mathrm{B}\,\mathbf{g}\,3\,)\,\gamma 12$ (6)

The advantages of mono tone based reduced geometric algebra (MVGA) - based sparse representation model over traditional sparse models for colour image can be summarized as follows: First, both the orthogonal property and the correlation among multiple channels are jointly preserved in the coefficient matrix. Each colour channel is linearly correlated with the MVGA dictionary, which is superior to traditional models in which atoms are selected from three independent channel dictionaries in the multi –channel interrelationship for colour patches can be preserved by properly training the MVGA-based dictionary D. Then the explicit vector relationship among channel dictionaries, which has been proven to b useful in colour constancy, is described by g1, g2 and g3. Finally, since the MVGA is commu- tative, the complexity of the algorithm is effectively reduced during the dictionary training stage, and the data redundancy is reduced accordingly.

III. MVGA BASED DICTIONARY LEARNING

When both the dictionary and the coefficients are unknown variables, the MVGA-based dictionary training process can be deemed as an extension of the model. Then, this process can be defined as G = arg min G F − DG2,

This dictionary algorithm called MVGA-DL is designed, a sparse coefficient matrix G needs to be obtained during the sparse coding stage, in which a fixed dictionary D is already given. In general, there exist a variety of methods that can be used to solve this sparse coding problem. Among them, methods such as matching pursuit (MP), basis pursuit (BP) and orthogonal matching pursuit (OMP) are the most common ones. Inspired by the high efficiency of OMP algorithm, the reduced monotone vector based geometric algebra-based orthogonal matching pursuit. Obviously, MVGA-OMP for MVGA multi vector is an extension of traditional OMP for the real data. Generally, the increase of the iteration number A leads to the consequent reduction of the reconstruction residual. And since the sparse coding phase aims to obtain the value of reconstruction residual as small as possible, and the sparsity of coefficient vector as large as possible, we set an upper bound of A to balance them. Let A be a monotone algebra and let Asa be the order unit (real) vector space of all self-adjoint elements of A. Let be a directed set and let (aλ : λ ∈) be a net in Asa. The net is increasing if λ ≤ μ implies aλ ≤ aμ. We say the net has least upper bound a when its range {aλ : λ ∈ } has a least upper bound a in Asa. We shall write aλ ↑ a. Similarly, the net (bλ : λ ∈) is decreasing if λ ≤ implies bλ ≥ bμ, and it has a greatest lower bound b if its range {bλ : λ ∈ } has the greatest lower bound b in Asa. We shall write bλ ↓ b. Clearly, a net (aμ : μ ∈ M) satisfies aμ ↑ a in Asa if, and only if, −aμ ↓ −a in Asa. Then we have the following:

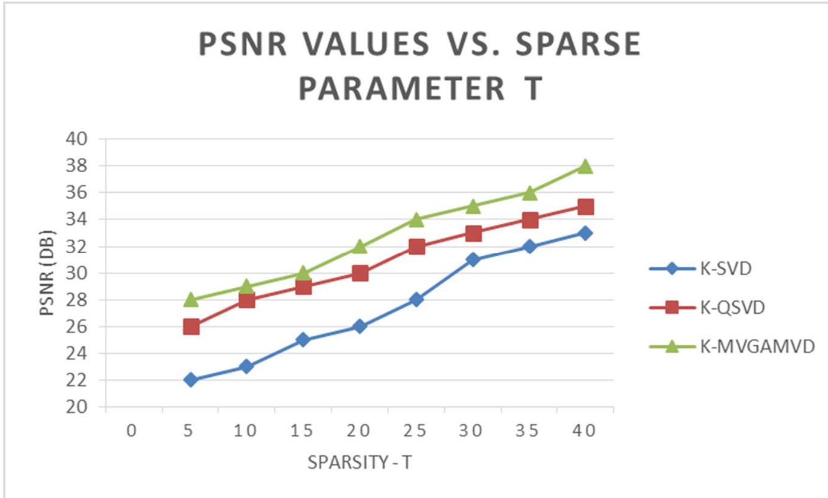
1. When (aλ : λ ∈) is an increasing net with aλ ↑ a and (bλ : λ ∈) is an increasing net with bλ ↑ b, then (aλ + bλ) is an increasing net with aλ + bλ ↑ a + b. Similarly, when (cγ : γ ∈) is a decreasing net with cγ ↓ c and (dγ : γ ∈) is a decreas-ing net with dγ ↓ d in Asa, (cγ + dγ : γ ∈) is a decreasing net such that cγ + dγ ↓ c + d in Asa.
2. When (aλ : λ ∈) is an increasing net with aλ ↑ a in Asa, then, for any z ∈ A, (zaλ z∗ : λ ∈) is also an increasing net satisfying zaλ z∗ ↑ zaz∗ in Asa.

To further analyze the efficiency of the MVGA-based joint sparse representation model, the time complexity of K- MVGAMVD will be compared to K-SVD (the traditional monochrome sparse model) and K-QSVD (quaternion- based sparse model). Because K-MVGAMVD makes use of the same framework of traditional K-SVD and quaternion form K-QSVD, its convergence is also similar to them. In each iteration, these three methods all consist of sparse coding phase and dictionary updating phase. In sparse coding phase, we use MVGA-OMP to obtain sparse codes while keeping the dictionary fixed. The MVGA-OMP is also a greedy algorithm like OMP, which means the construction residual will decrease when the number of nonzero coefficients we select keep growing. That is to say, the reconstruction residual reduces regarding the number of iteration. In dictionary learning phase, we optimize dictionary as K-MVD does while keeping the sparse codes fixed. The energy of the previous residual error matrix is reduced while each atom updating. In order to advance the above two dictionaries. The proposed MVGA- based sparse model takes full advantage of the MVGA (only three base elements □□1, □□2, □□12 are used for colour image), no extra component is produced. Thus, the MVGA overcomes the data redundancy experienced by the previous quaternion in colour image modeling.

IV. EXPERIENTAL ANALYSIS

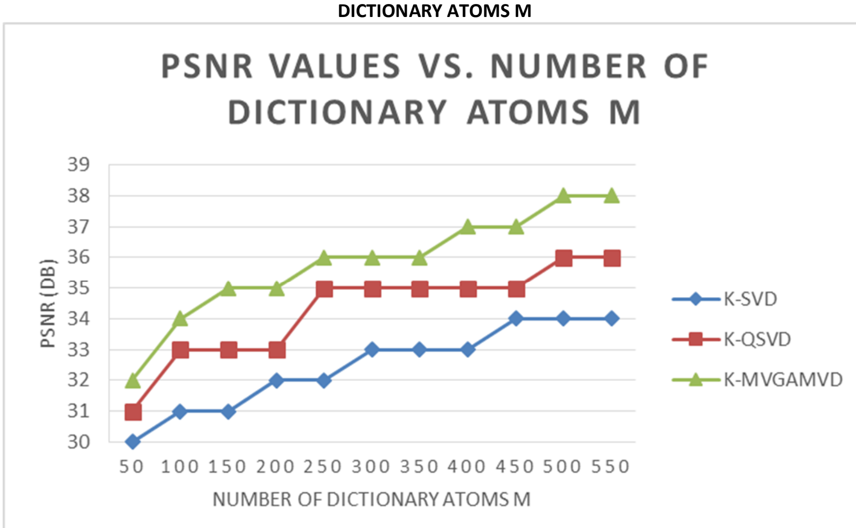
We first evaluate the proposed K-MVGAMVD based sparse model through colour image reconstruction experiments at different sparsity, comparing with K-SVD and quaternion-based sparse models. Based on the data sets above, the dictionaries using K-SVD, K-QSVD and K-MVGAMVD are trained respectively on the same training samples. A reasonable computational complexity can be maintained by choosing an appropriate number of dictionary atoms, which is not particularly large or small. In the sparse coding stage, we set the sparsity parameter T in OMP/QOMP/MVGA-OMP for the three sparse models, where T means the maximum value of nonzero coefficients allowed for representing each image block.

FIGURE 1: COMPARISON OF K-MVGAMVD, K-QSVD AND K-SVD BASED SPARSE MODEL FOR COLOUR IMAGE RECONSTRUCTION - PSNR VALUES VS. SPARSE PARAMETER T



The first reconstruction experiment is implemented to verify the superior performance of our K-MVGAMVD based sparse model through the PSNR (dB) values over different sparse parameter T for the three sparse models. And the number of the atoms of the three dictionary have been all fixed to be M 256. The relationship between reconstructed PSNR and sparse sparsity parameter T and the PSNR values of the proposed MVGA-based and quaternion-based sparse models are almost similar or a little higher. And they can present exactly higher PSNR values comparing to the traditional sparse model using K-SVD method under the same sparse parameter. When the number of atoms used increases, the superiority becomes even more distinct. Besides, the number of dictionary atoms is also an important indicator to evaluate the performance of reconstruction, and normally, has been fixed to be M 256. Since we suspect quaternions and our RGA better capture the correlations of colour channels, we now test the K-SVD, K-QSVD and our K-MVGAMVD algorithms with variety of atoms to see if these correlations can lead to a lower-redundancy for the dictionary. The comparison graphical analysis of K-MVGAMVD, K-QSVD and K-SVD based sparse model for colour image reconstruction - PSNR values vs. sparse parameter T is shown in Figure 1. Similarly, the comparison graphical analysis of K-MVGAMVD、K-QSVD and K-SVD sparse model for colour image reconstruction - PSNR values vs. the number of dictionary atoms M are shown in Figure 2.

FIGURE 2: COMPARISON OF K-MVGAMVD, K-QSVD AND K-SVD SPARSE MODEL FOR COLOUR IMAGE RECONSTRUCTION - PSNR VALUES Vs. THE NUMBER OF DICTIONARY ATOMS M



In this experiment, we test the reconstruction results of the three methods using dictionaries with the same number of atoms. The number of the atoms is set as 64, 128, 256, and 512. Clearly, in Figure 2, compared with the K-SVD based model, the K-QSVD and our K-MVGAMVD based models show great improvement in terms of the reconstruction PSNR values. And the increasing number of dictionary atoms greatly improves the results. This improvement can be more effective in the adaptive dictionary method. Generally, our K-MVGAMVD based model shows similar or a little higher PSNR values compared with the K-QSVD based model. We can clearly see that, owing to the commutative multiplication operation of MVGA, our proposed K-MVGAMVD algorithm achieves far less computational complexity compared to the K-QSVD algorithm. Therefore, we can conclude that, compared with the existing sparse models, our proposed joint representation model based on MVGA can greatly improve the performance of colour image processing while reducing the time complexity and removing the data redundancy.

V. CONCLUSION

In this paper, a novel sparse representation model for multi vector -channel image based on monotone vector geometric algebra is proposed, which formulates the colour image as a multi vector matrix with the spatial and spectral information in MVGA space. Our proposed K-MVGAMVD based model is shown better at retaining certain texture and colour information in the image for the retention of the correlation between multiple RGB channels. The experiments of reconstruction and noise removal natural colour images demonstrate our proposed model can preserve inherent colour structures completely, remove the data redundancy and reduce the computational complexity. Currently, our model focuses on modelling the multi vector-channel correlation which can be regarded as a sequence of channels for image information. We would like to extend to the case covering multiple images in video. On the other hand, we want to investigate the multi vector sparse representation of multispectral images based on geometric algebra. It is expected that the proposed MVGA model will be a heterogeneous and efficient tool in various applications of image analysis.

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