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Fusion method for infrared and visible images based on improved quantum theory model

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ABSTRACT

Quantum theory model (QTM) owns a superior characteristic to turn a complex problem into the form of the linear combination of several much simpler components. Therefore, a novel fusion method based on improved quantum theory model (IQTM) is proposed in this paper, aiming at dealing with the fusion problem of infrared and visible images. Firstly, the traditional QTM is modified to be a better version called IQTM. Compared with the traditional QTM, IQTM has three qubit states responsible for reflecting much more information of the represented pixel in the image. Then, the pixels of the source images are transformed into the qubit state representation, and the corresponding quantum results can be obtained according to the basic principle of quantum theory. Finally, the quantum results are transformed into the final fused image. Experimental results show that the proposed method has remarked superiorities over other current typical ones in terms of both fusion performance and computational efficiency.

1. Introduction

As known to us, there is considerable complementary and redundant information in the images from different imaging sensors with the same scene. For example, the visible image places great emphasis on the reflection of the entire background information. However, the information amount of the visible image relies on the lighting condition to a great extent. Thus, we may scarcely see anything from it under poor light conditions. Unlike visible images, infrared ones are greatly sensitive to thermal sources, so the information of thermal objects can still be captured regardless of the lighting conditions. It is a useful property which is beneficial for noticing the objects such as humans and idled motors hiding in the shelters. Due to the facts mentioned above, it is necessary to extract their respective advantages and fuse them into a single one to enhance the amount of the useful information. So far, the fusion of infrared and visible images has increasingly become a hot topic in the field of image processing, and the corresponding research results has also been widely utilized in the civilian and military applications.

Recently, a great many of fusion methods [1–13] for infrared and visible images have been proposed. According to the processing modes towards the source image, the main approaches can be categorized into two categories including transform domain (TD) ones and non-transform domain (NTD) ones. The core idea of TD is to capture and extract the information of the edge and details of the source images as much as possible via geometric analysis. Commonly, the whole process of TD methods consists of three steps. Firstly, the source images are decomposed into several sub-images with different scales and directions. Then, certain fusion rules are adopted to complete the fusion course of the corresponding sub-images. Finally, the final fused image can be restored by using inverse TD models. During the early stage of the image processing research, TD methods indeed enhanced the fusion performance. However, along with the advancement of research and method, several of its inherent drawbacks begin to appear. For example, the problem with discrete wavelet transform (DWT) is that it is merely adept at capturing point-wise singularities, but cannot be sensitive to other types of features such as lines. Therefore, DWT often causes artifacts in the final fused image. In order to overcome the drawbacks of DWT, the contourlet transform (CT) theory [2] is proposed, but CT does not have the property of shift-invariance, so the final result based on CT has the Gibbs phenomena. Compared with DWT and CT, non-subsampled contourlet transform (NSCT) [4,10] and non-subsampled shearlet transform (NSST) [9] are characterized by much better fusion performance, but the higher requirements of the computational resources prove to be their major limitations to the real-time applications.

The current NTD methods mainly involve the theories of pulse coupled neural networks (PCNN) [14–16], non-negative matrix factorization (NMF) and quantum theory model (QTM). As a third

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generation of artificial neural networks, PCNN has been already widely used in the field of image fusion. However, the inherent complex mechanism and too many existing parameters requiring setting in PCNN always restrict its performance. NMF must meet the requirement that the original non-negative matrix can be rewritten as the product of two non-negative matrixes. Unlike PCNN, NMF [6] is a purely mathematical model which is able to eliminate the subject influences on the final result as much as possible. Unfortunately, the parameters in NMF are commonly initialized at random so that the performances of NMF-based methods often vary a lot. QTM [17–19] is a recently developed theory in the area of information processing. A remarked distinction between QTM and other methods lies in that QTM is able to turn a complex problem into several simpler components which can be comprehended or done easily. However, QTM has been rarely involved in the field of image fusion. Under the above background, it is necessary and meaningful to investigate the potential of QTM on the image fusion issue especially the fusion of infrared and visible images which is with increasing importance. Meanwhile, a novel fusion method for infrared and visible images based on improved quantum theory model (IQTM) is proposed. During this paper, the traditional QTM is modified to be IQTM with three qubit states responsible for reflecting much more information of the represented pixel in the image. Then, the pixels of the source images are transformed into the qubit state representation, and the corresponding quantum results can be obtained according to the basic principle of quantum theory. Finally, the quantum results are transformed into the final fused image. To evaluate the proposed method with several current popular fusion methods, simulation experiments are conducted in terms of both fusion performance and computational efficiency. The salient contributions of this paper can be summarized as follows.

- The classic QTM is improved to be modified edition called IQTM, which has not been studied yet both at home and abroad.
- This paper presents a novel fusion method based on IQTM for visible and infrared images.
- Both qualitative and quantitative comparisons with some state-of-art and conventional methods have been performed on several pairs of datasets, and the superiorities of the proposed method are obviously verified in this paper.
- Furthermore, the proposed method has been also extended for other categories of source images.

The rest of this paper is organized as follows. In Section 2, a brief introduction to the QTM is presented. Section 3 concretely describes the structure of IQTM and the proposed fusion algorithm for infrared and visible images in detail. Experimental results and performance analysis are presented and discussed in Section 4. Concluding remarks and future work are given in Section 5.

2. Preliminaries

Unlike the traditional concept of bit, qubit is the abbreviation of the dual-state quantum system which includes two distinct states denoted by 0 and 1, respectively. Commonly, a qubit is used to represent the two different probabilities of one quantum system, and the corresponding mathematical expression can be written as

$$|\varphi> = c_0|0> + c_1|1> \tag{1}$$

Obviously, the quantum system φ can be expressed as the linear combination of two basic states namely zero and one. The probability amplitude of state 0 and state 1 are denoted as c_0 and c_1 whose values must be satisfy the following requirement.

$$c_0^2 + c_1^2 = 1 \tag{2}$$

Therefore, the quantum system φ will converge to the state 0 with the probability c_0^2. Similarly, the state 1 will be achieved at the probability c_1^2.

According to Eqs. (1) and (2), for the quantum system φ with m qubits, the pth qubit can be expressed as follows.

$$|\varphi^p> = c_0^p|0> + c_1^p|1> \tag{3}$$

As a result, the quantum system φ can be written as the tensor product of the m qubits, whose mathematical expression is given as follows.

$$\begin{aligned}|\varphi> &= |\varphi^1> \otimes |\varphi^2> \otimes \ldots \otimes |\varphi^p \ldots \otimes |\varphi^m \\ &= \left(c_0^1|0> + c_1^1|1>\right) \otimes \left(c_0^2|0> + c_1^2|1>\right) \otimes \ldots \otimes \left(c_0^p|0> \right. \\ &\quad \left. + c_1^p|1>\right) \ldots \otimes \left(c_0^m|0> + c_1^m|1>\right) \\ &= \left(c_0^1 c_0^2 \ldots c_0^m\right)|00\ldots0> + \left(c_0^1 c_0^2 \ldots c_1^m\right)|00\ldots1> + \ldots \\ &\quad + \left(c_1^1 c_1^2 \ldots c_1^m\right)|11\ldots1>\end{aligned} \tag{4}$$

It is noteworthy that the quadratic sum of the coefficients mentioned in Eq. (4) still equals to one. Moreover, the number of the basic vectors in the quantum system φ is 2^m.

In the quantum theory, each pixel in the image is necessarily in the form of the qubit state, so its original gray value have to be normalized into the range [0, 1]. Let a gray image denoted by A with the size of $m \times n$, the qubit state of the pixel p in A can be represented as follows.

$$|p(x, y)> = \sin\alpha|0> + \cos\alpha|1> \qquad 0 \le x \le m, 0 \le y \le n \tag{5}$$

where $p(x, y)$ denotes the pixel p located at coordinates (x, y). sinα and cosα are the probabilities of 0 and 1, respectively, which satisfy the following trigonometrical function equation.

$$\sin^2\alpha + \cos^2\alpha = 1 \tag{6}$$

3. Proposed fusion method

This section consists of two parts. First, the IQTM is given in detail in Section 3.1. Second, concrete fusion algorithm is proposed in Section 3.2.

3.1. Improved quantum theory model

As mentioned above, we can find that only the extreme points namely 0 and 1 have been concerned when the traditional quantum theory are used to deal with the issue of image processing. As a result, on the one hand, the interval analyzed is somewhat coarse and much information may be omitted in the reassigning process of the gray value of the pixel. On the other hand, the absolute probability distribution on the value 0 or 1 is actually not large towards a common gray image. On the contrary, the gray values of most pixels commonly range from 0 to 1, so it is neither scientific nor objective to consider the extreme points alone.

In this paper, another qubit state 0.5 is added to the traditional quantum theory model to form an improved one called improved quantum theory model (IQTM) whose mathematical expression is given as follows.

$$|p(x, y)> = a|0> + b|1> + c|0.5> \qquad 0 \le x \le m, 0 \le y \le n \tag{7}$$

where a, b and c denote the probability amplitude of states 0, 1 and 0.5. They have to meet the following requirement.

$$a^2 + b^2 + c^2 = 1 \tag{8}$$