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Fusion of Fuzzy Enhanced Overexposed and Underexposed Images

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Abstract

An image fusion algorithm based on DWT is used to combine fuzzy enhanced overexposed images and underexposed images. The proposed method provides fused image containing visual salient information present in both the input images along with significant contrast enhancement. The proposed algorithm is useful for a wide range of applications such as military applications, surveillance, medical diagnosis etc. The fused image obtained from DWT fusion of fuzzy enhanced images is visually better than those obtained from DWT fusion of: unenhanced images, gamma corrected images as well as histogram equalized images. Both subjective and objective assessment is performed to evaluate the performance of the proposed algorithm. The objective image quality measures: entropy and standard deviation, also shows that the proposed method performs better than the other method.

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Keywords: Fuzzy image enhancement; Gamma correction; Illuminated images; Image fusion; Discrete wavelet transform (DWT).

1. Introduction

Image fusion[1] is a process which correlates and combines two or more input images into a single image containing maximum possible information present in individual images. The objective of this process is to combine multiple images by reducing uncertainty, minimizing redundancy and maximizing information relevant to a particular application. The process of image fusion results in wider temporal, spatial and spectral coverage. Image fusion techniques are widely used in the fields of medical diagnostics, remote sensing, military applications, surveillance, etc. The process of image fusion is divided into three levels[2,3]: pixel – level, feature – level and decision – level, depending upon the stage at which fusion takes place. In pixel level (low level) image fusion, the fusion process works directly on the pixels of the input image and is preferred when the images to be fused are provided by the alike sensors. Pixel – level fusion algorithms works either in the spatial domain or in the transform domain. Feature level (mid level) image fusion works on features extracted from the input images and are very much image dependent. Decision level (high level) image fusion works at the highest level and combines the interpretations of different objects obtained from input images. Decision level algorithms are suitable when the input images to be fused are provided by very different sensors. The images to be fused may suffer from different image degradations[8]. Underexposed images may be affected by noise whereas over-exposed images may suffer from motion blur. The fusion process should be

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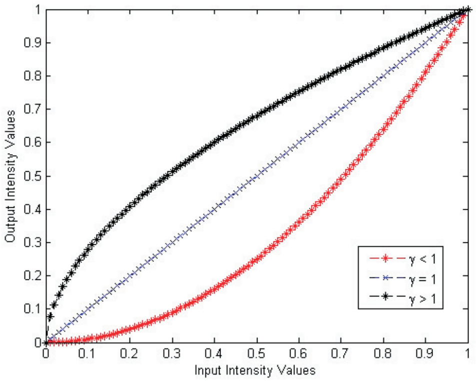


Fig. 1. Gamma correction curves.

such that it preserves the sharpness of edges from underexposed images and low noise characteristics of overexposed images. Thus, the proposed method uses fuzzy based image enhancement to improve the visibility of underexposed and over-exposed images and then uses discrete wavelet transform to fuse these enhanced images. The performance of the image fusion algorithm depends on the right intensity fusion of registered images. The rest of the paper is organized as follows: Section 2 and 3 discusses Gamma Correction (GC) algorithm and Histogram Equalization(HE), Section 4 presents detail of the proposed fusion method based on Fuzzy Enhancement(FE), Section 5 gives results and discussion and finally, conclusion is drawn in Section 6.

2. Gamma Correction

A non-linear transfer of signal exists between an electrical device and an optical device. This non-linearity causes serious distortions in the intensity of image, resulting with certain areas being too dark and with certain areas being bleached out.

To compensate for this non-linearity, an image processing algorithm called gamma correction is applied to the video signal to produce an image with fidelity. Thus, gamma is an important characteristic of all digital imaging systems which defines the relation between a pixels value and its actual luminance. Gamma correction is a non-linear transformation used to control the brightness and contrast of an image. It is used in image processing to compensate for non-linear relations in imaging sources, displays and printers. It not only changes the overall brightness of an image but also the ratio of red to blue to green. If images are not properly corrected, they are of poor quality and has reduced predictability of texture and colors. The gamma correction[4] function is a monotonic function producing output pixel intensity, $X(i, j)$ which is proportional to inverse of gamma power of input pixel intensity, $x(i, j)$ and is defined as

$$X(i, j) = 255 \times \left(\frac{x(i, j)}{255}\right)^{\frac{1}{\gamma}} \tag{1}$$

Figure 1 shows the gamma curves. It can be observed that the gamma corrected image is lighter than the original image for $\gamma < 1$ and is darker than the original image for $\gamma > 1$.

3. Histogram Equalization

Let $X = \{x_{ij}\}$ be a digital image of size $M \times N$ and r_j for $j = 1, 2, 3, \ldots, L$ be the L intensity level of the input image. Let $p(r_j)$ be the histogram associated with the intensity levels of input image which are approximations to the probability of occurrence of intensity level, r_j for $j = 1, 2, \ldots, L$ in a given image, i.e.

$$p(r_j) = \frac{n_j}{(M \times N)} \tag{2}$$

where n_j is the number of pixels with intensity level r_j and $M \times N$ are the total number of pixels in the given image. The cumulative distribution function of r_j, $cdf(r_j)$ is defined as,

$$cdf(r_j) = \sum_{i=0}^{j} p(r_i). \tag{3}$$

Also, $cdf(rL) = 1$.

Histogram Equalization[5] is a non-linear transformation and is based on cumulative sum of normalized histogram values. It maps the pixel intensity, rj of input image to the pixel intensity, sj in the output image resulting in an image with uniform distribution of intensities, higher contrast and increased dynamic range. Mathematically, the output pixel intensity is

$$s_j = T(r_j) = (L-1)\sum_{i=0}^{j} p(r_j) \tag{4}$$

4. The Proposed Method

Image Fusion is a process of combining the relevant information from two or more images into a single high quality fused image. The fused image retains the most desirable information of each individual input image.

Images to be fused may be captured under different illumination conditions[6]. Images which are captured under insufficient illumination (called as underexposed images) when fused with images captured with too much of light (called as overexposed images), results in loss of information.

Fuzzification and Intensification

An image I of size $M \times N$ and intensity level in the range $(0, L-1)$ can be considered as collection of fuzzy singletons in the fuzzy set notation,

$$\begin{aligned} I &= \cup\{\mu_X(x_{mn}) \\ m &= 1, 2 \ldots, M; \quad n = 1, 2 \ldots, N \end{aligned} \tag{5}$$

where $\mu_X(x_{mn})$ or μ_{mn}/x_{mn} represents the member – ship or grade of some property μ_{mn} of x_{mn}.

x_{mn} is the color intensity at (m, n)th pixel. For a color image, the membership functions are taken for the unions of all colors X, $X \in \{R, G, B\}$ or $X \in \{H, S, V\}$. For the transformation of the color X in the range (0, 255) to the fuzzy property plane in the interval (0,1), a membership function of the Gaussian type:

$$\mu_X(x_{mn}) = \exp\left[-\frac{(x_{\max} - x_{mn})^2}{2f_h^2}\right] \tag{6}$$

it involves a single fuzzifier, f_h[7]. Here, $x_{mn} \leq L-1$, is the maximum color value and L is the number of intensity values present in the image. The membership values are restricted to the range $[\alpha, 1]$ with $\alpha = \exp(-x_{\max}^2/2f_h^2)$. For computational efficiency, histogram of color X is considered for fuzzification. So, $\mu_X(k)$, represents the membership function of color X for intensity k, $k = 0, 1, 2 \ldots L-1$,

$$\mu_X(k) = \exp\left[-\frac{(x_{\max} - k)^2}{2f_h^2}\right] \tag{7}$$

This function is the same, with x_{mn} replaced by an index k, the intensity at the (m, n)th spatial location. It is observed that higher values of f_h are obtained for a brighter image.

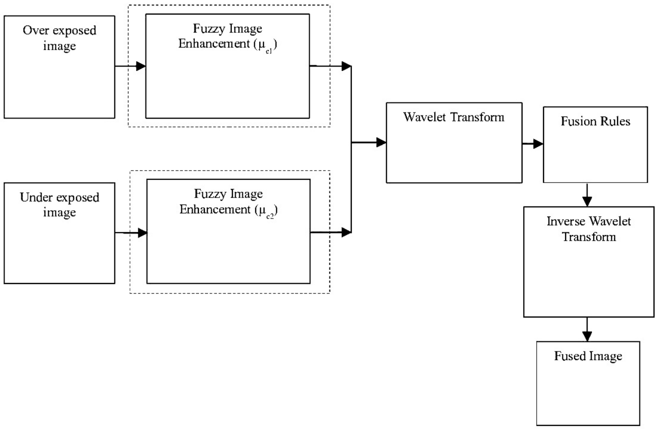


Fig. 2. Proposed flow diagram.

The membership values are transformed back to the spatial domain after the intensification operator is applied in the fuzzy domain. The inverse operation that converts fuzzy domain quantities to the spatial domain is given by:

$$k' = x_{\max} - \{-2\ln[\mu'_X(k)]f_h^2\}^{\frac{1}{2}} \tag{8}$$

where $\mu'_x(k)$ and k' are the modified membership function and intensity value respectively.

We restrict ourselves to image enhancement using a contrast intensification operator. It needs to be applied successively on an image for obtaining the desired enhancement. This is in the form of a sigmoid function given by:

$$\mu'_X(k) = \frac{1}{1 + e^{-t}(\mu_X(k) - 0.5)} \tag{9}$$

In the proposed technique, fuzzy intensification is suggested on the basis of optimization of fuzzy contrast and entropy globally. Optimizing f_h, t and the crossover point iteratively can accomplish the possible improvement.

A Gaussian membership function that transforms the saturation and intensity histograms of HSV color model into the fuzzy domain is discussed. The fuzzifier and intensification parameters are evaluated automatically for the input color image, by optimizing the contrast and entropy in the fuzzy domain. The method has been applied to various test images and found suitable for enhancement of low contrast and low intensity color images. It is observed that the 'index of fuzziness' and the 'entropy' decrease with enhancement. There is a further scope for improvement of an image, if the crossover point is treated as another parameter in addition to the proposed intensification parameter. This would make the new intensification operator more general as the enhancement can be made bereft of visual assessment.

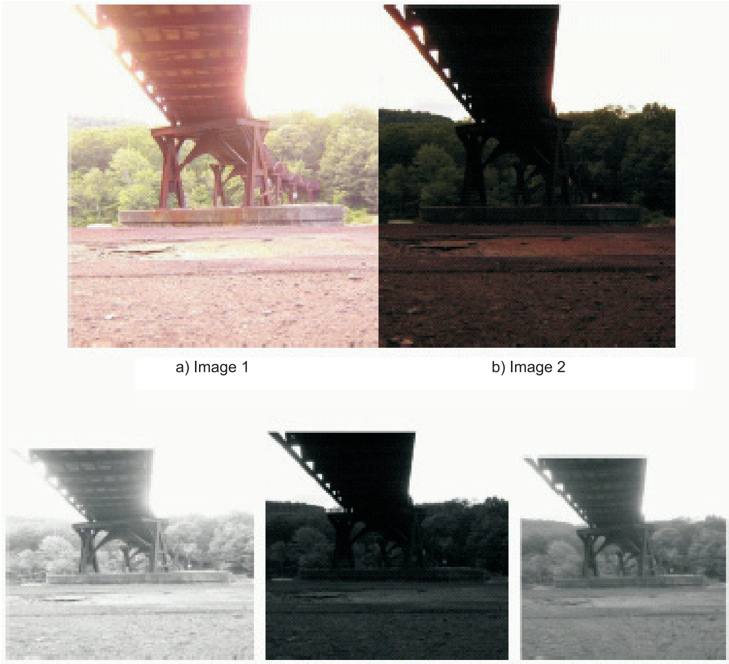
Image Fusion is a process of combining the relevant information from two or more images into a single high quality fused image. The fused image retains the most desirable information of each individual input image.

Thus, the proposed algorithm uses a technique based on fuzzy logic for enhancing the input images before their fusion. Figure 2 shows flow diagram for proposed algorithm. The proposed algorithm consists of two steps.

1. Both underexposed and overexposed images are separately enhanced using fuzzy image enhancement process based on Gaussian membership function of some radius 'r', through following steps:

   a. Both overexposed and underexposed images are divided into several blocks of size $m \times m$. For each block perform steps b) to e).
   b. Calculate normalized value of each input pixel intensity using

$$x_{\text{norm}}(i, j) = \frac{(x(i, j) - x_{\min})}{(x_{\max} - x_{\min})} \tag{10}$$



a) Overexposed b) Underexposed c) Fused

Fig. 3. DWT based fusion images.

a) Overexposed b) Underexposed c) Fused

Fig. 4. DWT with histogram based fusion images.

a) Overexposed b) Underexposed c) Fused d) Mean

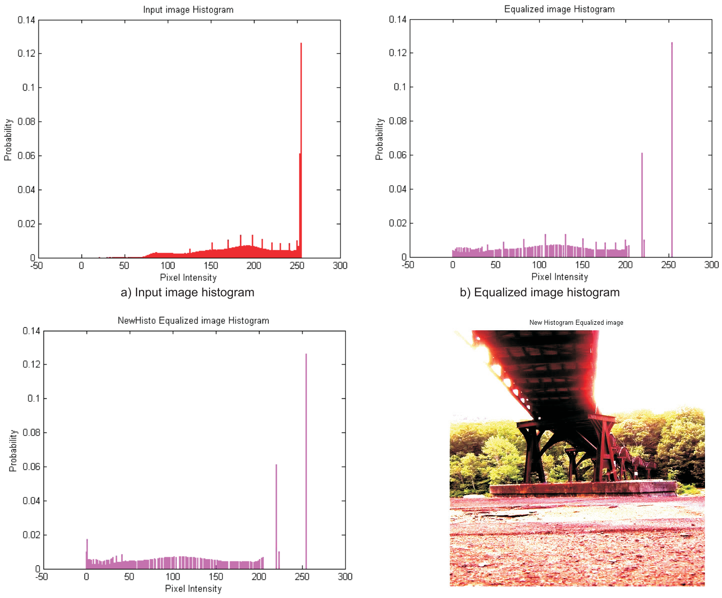
Fig. 5. DWT with fuzzy enhanced fusion (DWT + FE) images.

c. Calculate the crossover membership value of each block using

$$\mu_{\text{crossover}} = \frac{\left(1 + \frac{x_{\min}}{x_{\max}}\right)}{2\left(1 - \frac{x_{\min}}{x_{\max}}\right)} \tag{11}$$

Table 1. Comparison between performance parameters.

DWT based fusion		DWT with histogram based fusion		DWT enhanced fusion (DWT + FE) proposed	
Entropy Image 1	6.7856	Entropy Image 1	6.7856	Entropy Image 1	6.6854
Entropy Image 2	5.6534	Entropy Image 2	5.6534	Entropy Image 2	5.6519
Entropy Image Fused	6.4543	Entropy Image Fused	6.555	Entropy Image Fused	6.433
Std Deviation Image 1	52.0711	Std Deviation Image 1	52.0711	Std Deviation Image 1	48.7138
Std Deviation Image 2	88.4276	Std Deviation Image 2	88.4276	Std Deviation Image 2	86.6136
Std Deviation Fused	64.5457	Std Deviation Fused	76.4965	Std Deviation Fused	62.3614



a) Input image histogram b) Equalized image histogram

c) New histogram equalized histogram d) New Histogram Equalized Image

Fig. 6. Histogram equalized results (image 1 and image 2).

d. Fuzzify the image using the following steps
   If $0 < x_{\text{norm}(i,j)} < \mu_{\text{crossover}}$, then

$$f_{\text{img}}(i,j) = \frac{x_{\text{norm}}^{2r}(i,j)}{(1-\mu_{\text{crossover}})^{2(r-1)}} \tag{12}$$

else, $\mu_{\text{crossover}} - x_{\text{norm}} < 1$, and

$$f_{\text{img}}(i,j) = 1 - \frac{x_{\text{norm}}^{2r}(i,j)}{(1-\mu_{\text{crossover}})^{2(r-1)}} \tag{13}$$

e. The pixel intensity of defuzzified (enhanced) image is obtained using

$$x_{\text{enhanced}}(i,j) = f_{\text{img}}(i,j) \times (x_{\max} - x_{\min}) \tag{14}$$

f. Reconstruct the enhanced images using fuzzified blocks.

2. After enhancing the images, they are fused using Discrete Wavelet Transform for extracting various features of the images at different levels. DWT increases directional information and introduces no blocking artifacts thereby providing better perceptual image quality.

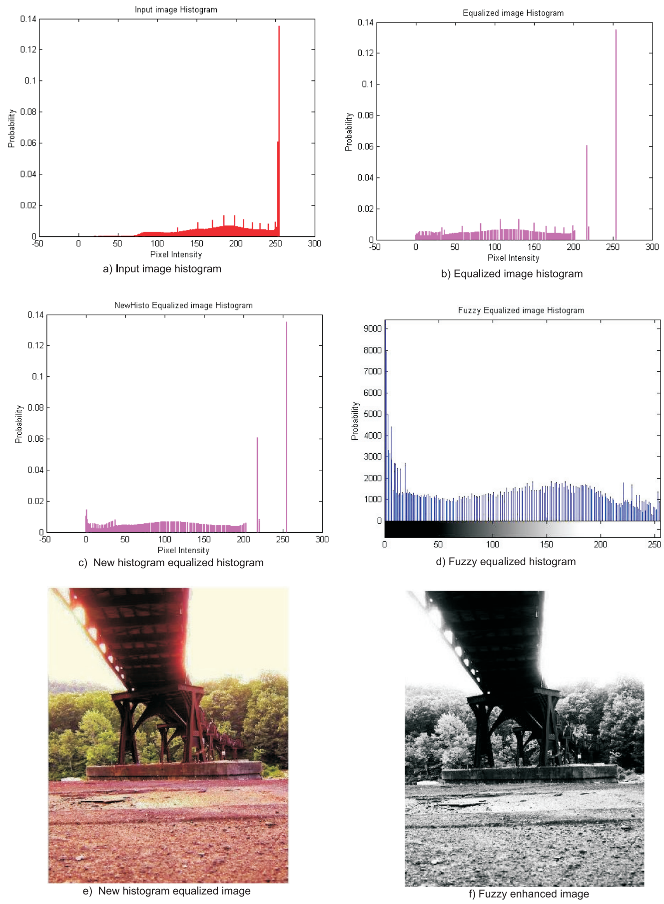


Fig. 7. Fuzzy enhanced histogram results (image 1 and image 2).

a) Obtain n-level symmetric wavelet decomposition of both images.
b) Apply fusion rule as

$$\text{fused}_{\text{coef}} = \begin{cases} I_{1\text{coef}} & \text{if } I_{1\text{coef}} > I_{2\text{coef}} \\ I_{2\text{coef}} & \text{otherwise} \end{cases} \tag{15}$$

where $I_{1\text{coef}}$ and $I_{2\text{coef}}$ are the DWT coefficients of overexposed and underexposed images respectively
c) Take the inverse DWT of fused image coefficients to obtain the final fused imag

5. Results and Discussions

The proposed algorithm has been experimentally used to enhance three sets of overexposed and underexposed images i.e is Tea Cup, Basket-Ball and Room images of size 256×256 and further to fuse them using DWT based image fusion .These images are obtained from[9–11]. Both subjective and objective image quality assessment are used to demonstrate the performance of the proposed algorithm. Also the results of the proposed algorithm are compared with those generated by DWT (without Enhancing), DWT + Gamma Enhancement and DWT + Histogram Equalization. Figures 3, 4 and 5 shows the subjective results indicating underexposed images, overexposed images and fused images. The fused image contains more clear details and is visually more pleasing. Entropy and standard deviation are used as measures for objective assessment. Entropy measures the information content of an image and is mathematically defined as:

$$E = -\sum_{l=0}^{L-1} P_l \log_2 P_l \tag{16}$$

where L is the number of gray level and P_l is the ratio between the number of pixels with gray values l and the total number of pixels. An image with high entropy have high information content. The standard deviation of an image is defined as:

$$\sigma = \left\{ \frac{1}{M \times N} \sum_{m=1}^{M} \sum_{n=1}^{N} (f(m,n) - \mu)^2 \right\}^{\frac{1}{2}} \tag{17}$$

where $f(m,n)$ is the pixel value of fused image and μ is the mean value of image. A high quality fused image has high value of standard deviation. It is observed from Table 1 that the proposed algorithm provides improved results of fusion when compared to other methods of enhancement used before DWT fusion. Figure 6 and 7 shows histograms plots for image set 1 and 2. It is clear that proposed method is better in qualitative and quantitative terms.

6. Conclusion

The need to improve the visual quality of image to be fused, which are captured under extreme illumination conditions led to the development of fusion of fuzzy enhanced overexposed and underexposed images. It can be achieved by fuzzy image enhancement process based on Gaussian membership function. DWT based fusion of these fuzzy enhanced images can be performed for further optimization. Fuzzy enhanced algorithm removes the noise, preserves the details as well as enhances the contrast of the image. DWT image fusion effectively combines salient features of fuzzy enhanced images.Although selection of fusion algorithm is problem dependent but this review results that spatial domain provide high spatial resolution. But spatial domain have image blurring problem. The Wavelet transforms is the very good technique for the image fusion provide a high quality spectral content. But a good fused image has both qualities so the combination of DWT & segmentation algorithm improves the performance as compared to use of individual DWT and PCA algorithm. Finally this review concludes that image fusion algorithm based on combination of DWT, fuzzy enhancement and PCA with morphological processing will improve the image fusion quality and may be the future trend of research regarding image fusion.

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