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A Novel Architecture for Wavelet based Image Fusion

Susmitha Vekkot, and Pancham Shukla

Abstract**—**In this paper, we focus on the fusion of images from different sources using multiresolution wavelet transforms. Based on reviews of popular image fusion techniques used in data analysis, different pixel and energy based methods are experimented. A novel architecture with a hybrid algorithm is proposed which applies pixel based maximum selection rule to low frequency approximations and filter mask based fusion to high frequency details of wavelet decomposition. The key feature of hybrid architecture is the combination of advantages of pixel and region based fusion in a single image which can help the development of sophisticated algorithms enhancing the edges and structural details. A Graphical User Interface is developed for image fusion to make the research outcomes available to the end user. To utilize GUI capabilities for medical, industrial and commercial activities without MATLAB installation, a standalone executable application is also developed using Matlab Compiler Runtime.

Keywords**—**Filter mask, GUI, hybrid architecture, image fusion, Matlab Compiler Runtime, wavelet transform.

I. Introduction

WITH rapid advancements in technology, it is now possible to obtain information from multisource images. However, all the physical and geometrical information required for detailed assessment might not be available by analysing the images separately. In multisensory images, there is often a trade-off between spatial and spectral resolutions resulting in information loss [1]. Image fusion combines perfectly registered images from multiple sources to produce a high quality fused image with spatial and spectral information. It integrates complementary information from various modalities based on specific rules to give a better visual picture of a scenario, suitable for processing. An image can be represented either by its original spatial representation or in frequency domain. By Heisenberg's uncertainty, information cannot be compact in both spatial and frequency domains simultaneously [2]. It motivates the use of wavelet transform which provides a multiresolution solution based on time-scale analysis. Each subband is processed at a different resolution, capturing localized time-frequency data of image to provide unique directional information useful for image representation and feature extraction across different scales [3]. Several approaches have been proposed for wavelet based image fusion which are either pixel [4], [5] or region [6], [7] based. In order to represent salient features more clearly and enrich the information content in multisensory fusion, region based methods involving segmentation and energy based fusion were introduced [8], [9].

Other fusion methods are based on saliency measurement, local gradient and edge fusion [1], [7], [10]. Pixel based algorithms concentrate on increasing image contrast whereas region based algorithms provide edge enhancement and feature extraction. A few attempts have been made [11], [12] to combine these algorithms in a single fused image. The integration of image fusion algorithms offers immense potential for future research as each rule emphasizes on different characteristics of the source image. This paper proposes a novel hybrid architecture (algorithm) for wavelet based image fusion combining the principles of pixel and region based rules. To utilize the capabilities of image fusion at end user level, a Graphical User Interface is developed. There are several situations in which we would want to use applications developed in MATLAB for commercial and research activities. A standalone executable has been developed for the targeted image fusion application using Matlab Compiler Runtime library.

The rest of the paper is organised as follows. The next section gives the relevant theory and algorithms associated with wavelet transform fusion. Section III details the new hybrid architecture proposed in this paper. In section IV, the results obtained by applying wavelet based algorithms to test images are analysed in detail. Section V illustrates the GUI developed for image fusion applications. The paper is concluded in section VI.

II. Wavelet Based Image Fusion

A. Wavelet Theory

Wavelets are finite duration oscillatory functions with zero average value. The irregularity and good localization properties make them better basis for analysis of signals with discontinuities. Wavelets can be described by using two functions viz. the scaling function f (t), also known as 'father wavelet' and the wavelet function or 'mother wavelet'. 'Mother' wavelet ψ (t) undergoes translation and scaling operations to give self similar wavelet families as in (1).

$$\psi_{a,b}(t)=\frac{1}{\sqrt{a}}\psi(\frac{t-b}{a}),(a,b\varepsilon R),a>0 \quad (1)$$

where a is the scale parameter and b the translation parameter.

Susmitha Vekkot and Pancham Shukla are with Department of Computing, London Metropolitan University-North Campus, Holloway Road, London, N7 8DB, England (e-mail:susmirenju@gmail.com, p.shukla@londonmet.ac.uk).

Practical implementation of wavelet transforms requires discretisation of its translation and scale parameters by taking,

$$a = a_0^j, b = m a_0^j b_0 \quad j, m \varepsilon Z \tag{2}$$

Thus, the wavelet family can be defined as:

$$\psi_{j,m}(t) = a_0^{-j/2} \psi(a_0^{-j} t - m b_0) \;\; j, m \varepsilon Z \tag{3}$$

If discretisation is on a dyadic grid with $a_0 = 2$ and $b_0 = 1$ it is called standard DWT [13]. Wavelet transformation involves constant Q filtering and subsequent Nyquist sampling as given by Fig. 1 [9]. Orthogonal, regular filter bank when iterated infinitely gives orthogonal wavelet bases [14]. The scaling function is treated as a low pass filter and the mother wavelet as high pass filter in DWT implementation.

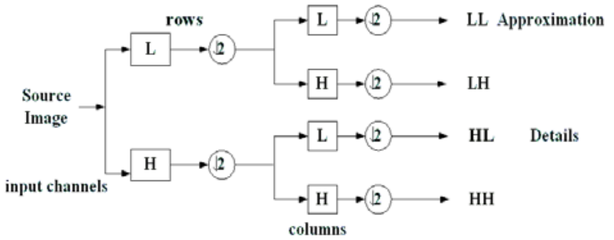


Fig. 1 Two-dimensional subband coding algorithm for DWT: The source image is decomposed in rows and columns by low-pass (L) and high-pass (H) filtering and subsequent downsampling at each level to get approximation (LL) and detail (LH, HL and HH) coefficients. Scaling function is associated with smooth filters or low pass filters and wavelet function with high-pass filtering

B. *Fusion Algorithms*

The advent of multiresolution wavelet transforms gave rise to wide developments in image fusion research. Several methods were proposed for various applications utilizing the directionality, orthogonality and compactness of wavelets [4], [5], [6]. Fusion process should conserve all important analysis information in the image and should not introduce any artefacts or inconsistencies while suppressing the undesirable characteristics like noise and other irrelevant details [1], [5].

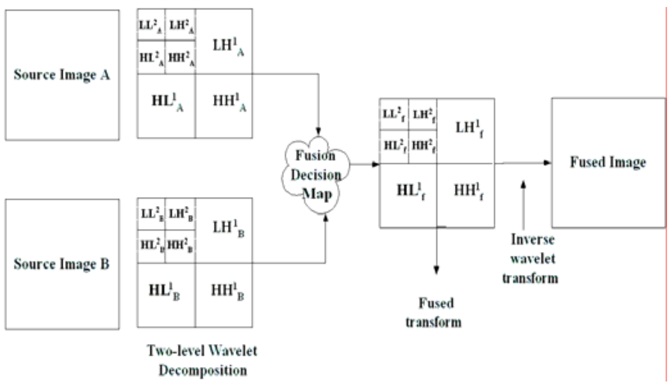


Fig. 2 Wavelet based image fusion: The source images A and B are decomposed into discrete wavelet decomposition coefficients: LL (approximations), LH, HL and HH (details) at each level before fusion rules are applied. The decision map is formulated based on the fusion rules. The resulting fused transform is reconstructed to fused image by inverse wavelet transformation

Fusion can be performed on pixel, feature or decision level [16]. The complexity of pixel based algorithms is lesser than other methods. They are used in applications where both pixel spacings and spectral properties of source images are same or similar [17]. The advent of region based image fusion can be attributed to the inefficiencies faced by pixel algorithms in cases where the salient features in images are larger than one pixel. Region based rules are more complicated than simple pixel algorithms and used when pixel spacings of images are different. Decomposition coefficients are segmented into small regions and activity measure along each region is computed. Coefficients with maximum activity level are preserved, retaining the salient features. Popular methods include computation of variances of small regions [6] in the image or energy based salience measurement [8], [9].

III. Hybrid Architecture

This paper proposes a hybrid fusion method which integrates both pixel and region based rules in a single fused image. Pixel based rules operate on individual pixels in the image, but does not take into account some important details like edges, boundaries and salient features larger than a single pixel. Region based fusion may reduce the contrast in some images and does not always succeed in effectively removing ringing artifacts and noise in source images. The inadequacies of these two types of fusion rules point to the importance of developing a hybrid algorithm based architecture combining the advantages of both. Hybrid architecture in Fig. 3 uses different rules for fusing low and high frequency subimages of wavelet decomposition.

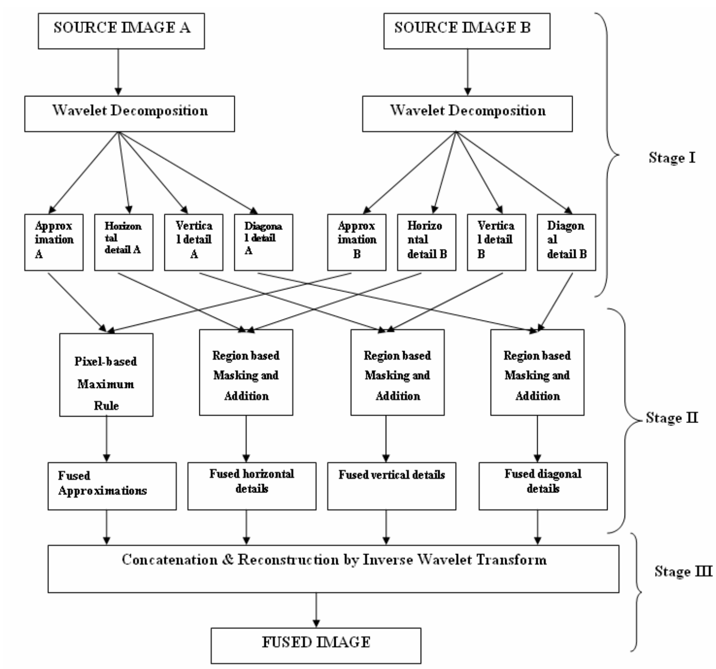


Fig. 3 Mask based image fusion: Test images are decomposed using discrete wavelet transform. The approximations are subjected to pixel based maximum selection rule. A 3X3 square mask and odd order rectangular averaging mask (5X7) are each applied to detail images. The new sets of coefficients from each source image are added to get

new approximations and details. Final fused coefficient matrix is obtained by concatenation of new approximations and details

A pixel based maximum selection algorithm is used for approximations while square and averaging filter masks are applied to detail coefficients. High pass square filter mask helps in enhancing the salient features and edges. Averaging filter mask removes noise by taking the mean of the gray values of the window surrounding the centre pixel.

Algorithm:

The algorithm for hybrid fusion rule can be divided into three different stages with reference to Fig. 3.

Stage I

1) Read the two source images A and B to be fused.
2) Perform independent wavelet decomposition of the two images until level L to get approximation (LL^L) and detail (LH^l, HL^l, HH^l) coefficients for $l = 1, 2, ..., L.$

Stage II

1) Select pixel based algorithm for approximations (LL^L) which involves fusion based on taking the maximum valued pixels from approximations of source images A and B.

$$LL_f^L = \max imum(LL_A^L(i,j), LL_B^L(i,j)) \tag{4}$$

Here, LL_f^L is the fused and LL_A^L and LL_B^L are the input approximations, i and j represent the pixel positions of the subimages.

2) A binary decision map is formulated based on the maximum valued pixels between the approximations. The decision rule D_f for fusion of approximation coefficients in the two source images A and B is thus given by (5).

$$\begin{aligned} D_f(i,j) &= 1, d_A(i,j) > d_B(i,j) \\ &= 0, otherwise \end{aligned} \tag{5}$$

3) A small window of size 3X3 or 5X7 is selected from the detail subbands based on whether the type of filter mask used is square or rectangular.
4) Perform region level fusion of details by applying 3X3 square and 5X7 averaging filter mask to detail coefficients. The resultant coefficients are added from each subband.

$$LH_f^l = mask(LH_A^l) + mask(LH_B^l)$$

$$HL_f^l = mask(HL_A^l) + mask(HL_B^l)$$

$$HH_f^l = mask(HH_A^L) + mask(HH_B^L)$$

LH_f^l , LH_A^l, LH_B^l are vertical high frequencies,

HL_f^l , HL_A^l , HL_B^l are horizontal high frequencies,

HH_f^l, HH_A^L, HH_B^L are diagonal high frequencies [15] of the fused and input detail subbands respectively.

Stage III

1) We obtain the final fused transform LL_f^L corresponding to approximations through pixel rules and the vertical, horizontal and diagonal details LH_f^l, HL_f^l, HH_f^l by mask based fusion where $l = 1, 2, ..., L.$
2) The new coefficient matrix is obtained by concatenating fused approximations and details.
3) Fused image is reconstructed using inverse wavelet transform and displayed.

IV. Experiments, Results and Discussion

TABLE I
THE SOURCE IMAGES USED FOR FUSION EXPERIMENTS

Source image type	Source Images	File format	Size
Scans	CT Scan MRI Scan	TIFF	256X256
Clocks	Large clock focused Small clock focused	TIFF	256X256
Cameraman	Background blur Foreground blur	TIFF	256X256
Girl	Face blur Background blur	TIFF	256X256
Lenna	Left blur Right blur	TIFF	512X512

Objective performance evaluation is done by taking Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) as given by (6) and (7) respectively.

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[S(i,j) - F(i,j)]^2}{MXN} \tag{6}$$

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right) \tag{7}$$

where S is the source image and F is the fused image. Table II consolidates the results obtained.

Fig. 4 shows that the hybrid fusion rule gives least values for MSE and the highest value of PSNR for all test cases. The 5X7 averaging filter mask gives a better performance with less noise when compared to a square mask, in all test cases as evident from Table II.

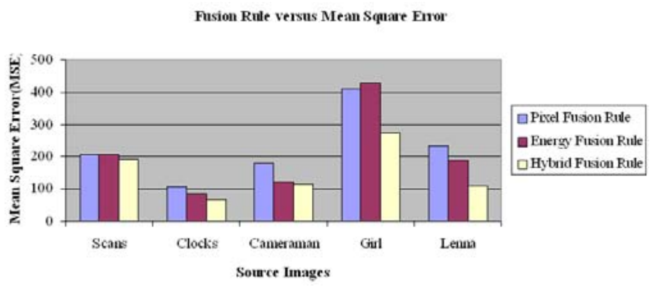
The optimum choice of filter mask gives maximum benefits from this fusion rule. Depending on the application, low pass or high pass filters can be used as masks and it provides the flexibility of using the same algorithm with different masks for fusion.

Fig. 5 and 6 give the results obtained by applying pixel, energy and the new hybrid algorithm to test images.

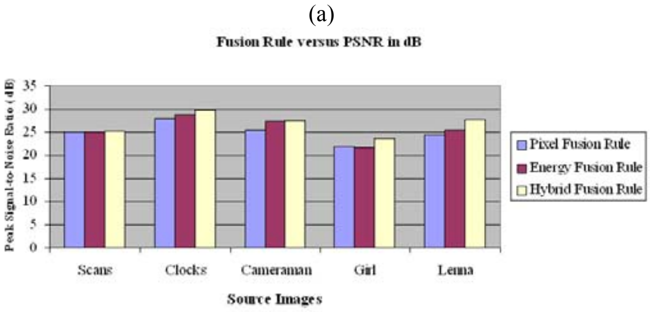
TABLE II
COMPARISON BETWEEN PIXEL, REGION AND HYBRID FUSION RULE BASED ON MSE AND PSNR

Source images	Fusion Rule	MSE	PSNR in decibels
CT/MRI Scan	Pixel	207.56	24.96
	Energy	206.22	25.03
	Hybrid	190.95	25.32
Clocks	Pixel	106.27	27.87
	Energy	85.92	28.79
	Hybrid	67.97	29.81
Cameraman	Pixel	180.57	25.56
	Energy	120.28	27.33
	Hybrid	114.29	27.55
Girl	Pixel	411.15	21.99
	Energy	428.84	21.81
	Hybrid	275.73	23.73
Lenna	Pixel	233.62	24.45
	Energy	188.52	25.38
	Hybrid	109.05	27.75

The pixel [4], energy [8] and hybrid algorithms were experimented.



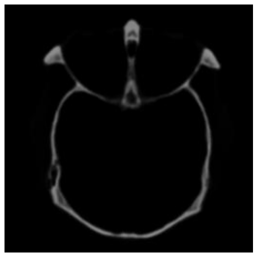
(a)



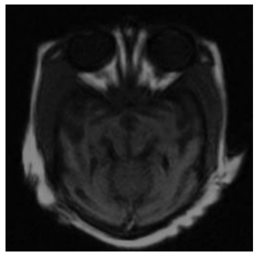
(b)

Fig. 4 Comparison between fusion algorithms based on objective strategies: (a)Using MSE(b)Using PSNR. In all test cases the highest value for PSNR and least MSE are obtained for hybrid fusion algorithm

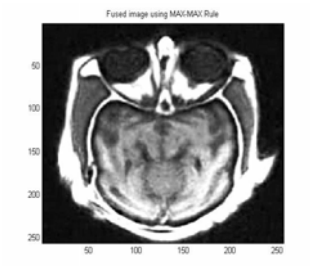
Results obtained by using hybrid fusion rule show that the filter mask removes noise and other artifacts in the image and preserves boundary information and structural details without introducing any other inconsistencies to the image. The high contrast fused image using pixel based rules may not always give a clear detection of boundaries while the energy based rule compromises on image contrast.



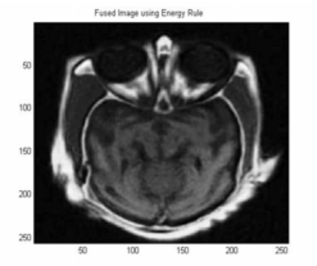
(a)



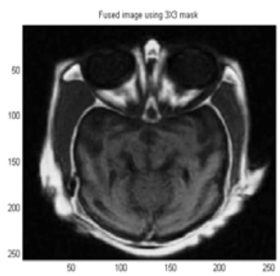
(b)



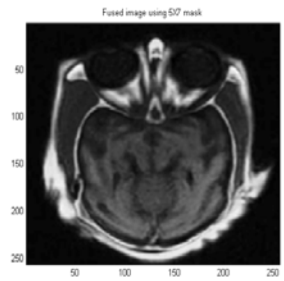
(c)



(d)



(e)

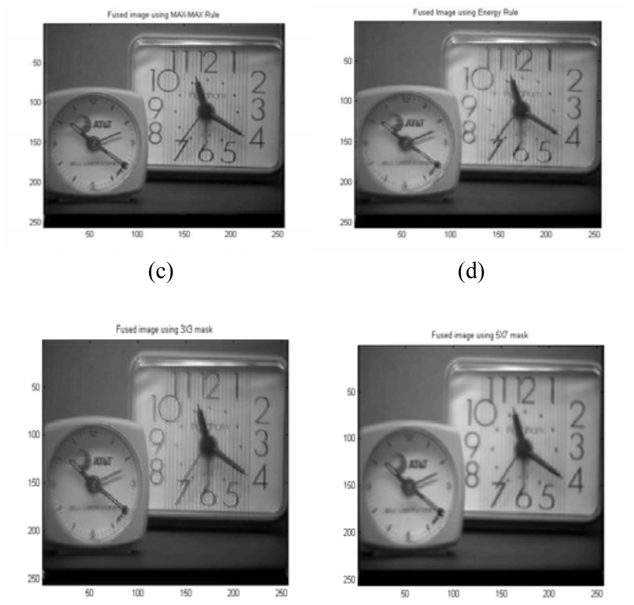


(f)

Fig. 5 (a)Source image 1:CT Scan(b)Source image 2:MRI Scan. (a) and (b) are fused using pixel based maximum selection rule to give the fused image in (c), energy based rule to give the fused image in (d) while (e) and (f) give the fused images for hybrid rule using 3X3 square and 5X7 averaging filter masks respectively.(Source images are courtesy of Rockinger, O. [19])

(a)

(b)



(c) (d)

(e) (f)

Fig. 6 (a)Source image1:Focus on large clock(b)Source image 2:Focus on small clock. (a) and (b) are fused using pixel based maximum selection rule to give the fused image in (c), energy based rule to give the fused image in (d) while (e) and (f) give the fused images for hybrid rule using 3X3 square and 5X7 averaging filter masks respectively.(Source images are courtesy of Rockinger, O. [19])

V. Graphical User Interface for Image Fusion

A Graphical User Interface (GUI) is a platform for application testing and analysis which consists of user interface controls like push buttons, edit boxes, radio buttons, menus and a variety of objects for graphics programming [18]. MATLAB has advanced capabilities and graphical interface tools for real-time application development. Image fusion requires graphical tools for better image perception and performance evaluation of the fusion rules used. A GUI helps user to interact with the tool and use it for various applications without requiring prior knowledge about the manner in which the commands or algorithms work. Various fusion rules discussed in this paper have been implemented using the user interface developed for image fusion application. The GUI can be extended to all types of images and fusion rules.

Several situations require applications developed in MATLAB to be utilized for industrial, medical and scientific activities. To make the capabilities of image fusion GUI available for systems where MATLAB software has not been installed, a standalone executable application has also been developed using the Matlab Compiler Runtime (MCR) library which is available as a freeware. To create a standalone executable, the compiler is configured and selected before creating the executable files. MCR is a compiler library responsible for generating the necessary files required for the creation of executable file. Fig. 7 gives the schematic of the GUI developed in this paper.

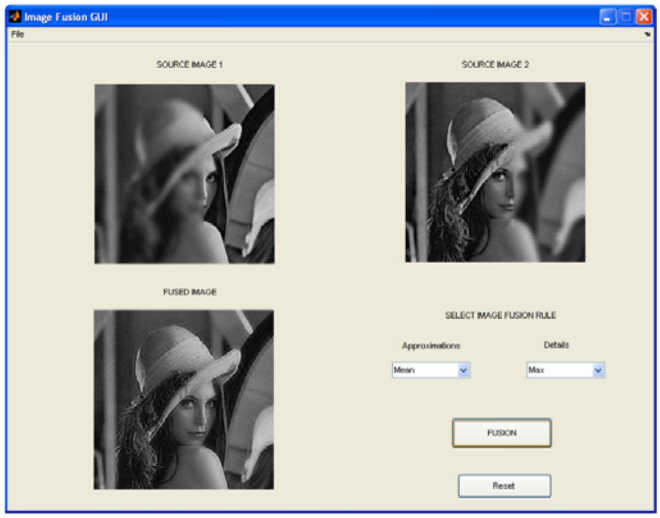


Fig. 7 Graphical User Interface developed for image fusion application. Source image 1 is Lenna image with Gaussian blur on left half and source image 2 has Gaussian blur on right half. The Mean-Max rule is selected which results in a fused image with both halves clear

VI. Conclusion

The work done in this paper forms the basis for further research in wavelet based fusion and other methods which integrate the fusion algorithms in a single image. The novel hybrid architecture presented here gives promising results in all test cases and can be further extended to all types of images by using different averaging, high-pass and low-pass filter masks. The variations in performance of fusion rules for different test images show that the choice of an optimum fusion rule depends mainly on the type of images to be fused, degradation models used to introduce noise in source images and the application. Studies about the type of source image noises will pave way for developing intelligent image fusion techniques capable of choosing the best rule depending on the type of degradation models used in images.

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