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Applying Image Fusion Techniques for Detection of Acute Intra-Cerebral Hemorrhage

تطبيق تقنيات دمج الصور لاكتشاف النزيف الداخلى الدماغى الحاد

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الخلاصة: دمج الصور هو عملية يتم بواسطتها اتحاد صورتين أو أكثر للحصول على صورة واحدة مع الحفاظ على أهم السمات الموجودة فى كل من الصور الأصلية, وذلك يهدف إلى تكامل البيانات لتحفيز المعلومات الظاهرة فى الصور وكذلك زيادة وثوق التفسير. والدمج الناجح للصور الناشئة عن مصادر أو وسائل مختلفة ذو أهمية قصوى فى العديد من التطبيقات مثل الصور الطبية، والتصوير الميكروسكوبى، والاستشعار عن بعد، والرؤية بالحاسب، والروبوت. وفى هذا البحث تم تنفيذ أربعة تقنيات لدمج الصور وتطبيقها على صور لأشعة مقطعية وكذلك صور رنين مغناطيسى، وهذه التقنيات هى " هرميات لابلاس" و "تحويل المويجات" و "تقنية ذات كفاءة حساب عالية على مستوى النقطة" و "تقنية متعددة التركيز معتمدة على التردد الفراغى". وقد تم تقييم نتائج الدمج طبقا لثلاثة مقاييس للكفاءة وهى "الإنتروبيا" و "الإنتروبيا المتقاطع" و "التردد الفراغى". وتم تطبيق تقنيات دمج الصور لتسهيل اكتشاف حالات النزيف الداخلى الدماغى الحاد، وذلك عن طريق دمج صور الأشعة المقطعية مع صور الرنين المغناطيسى المأخوذة عند نفس المستوى، وأدت الصور المدمجة إلى دقة اكتشاف أعلى من التى يتم الحصول عليها باستخدام صور الرنين المغناطيسى أو صور الأشعة المقطعية كل على حده.

Abstract: -Image fusion is the process by which two or more images are combined into a single image retaining the important features from each of the original images. It aims at the integration of complementary data to enhance the information apparent in the images as well as to increase the reliability of the interpretation. The successful fusion of images acquired from different modalities or instruments is of great importance in many applications such as medical imaging, microscopic imaging, remote sensing, computer vision, and robotics. In the present work, four different image fusion techniques were implemented and applied to Computed Tomography (CT) and Magnetic Resonance imaging (MRI). These are the Laplacian Pyramid, the Wavelet Transform, the Computationally Efficient Pixel-level Image Fusion (CEMIF) method, and the Spatial Frequency Multi-Focus Technique (SFMFT). Fusion results were evaluated according to three measures of performance; the entropy, the cross entropy and the spatial frequency. Image fusion techniques were applied to facilitate detection of acute intra-cerebral hemorrhage by fusing MRI and CT images at the same level. The fused images had led to higher detection accuracy than using either CT or MR images.

Key-Words:- Image fusion, Laplacian pyramid, CEMIF, spatial frequency, CT, MRI, intra-cerebral hemorrhage

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1 Introduction

Computed Tomography (CT) is a specialized X-ray imaging technique. It may be performed "plain" or after the injection of a "Contrast Agent". CT creates the image by using an array of individual small X-Ray sensors and a computer. By spinning the X-Ray source and the sensor/detectors around the patient, data is collected from multiple angles. A computer then processes this information to create an image on the video screen. These images are called "sections" or "cuts" because they appear to resemble cross-sections of the body. This technique eliminates the problem of conventional X-rays, where all the shadows overlap [1].

Magnetic Resonance Imaging (MRI) is a diagnostic technique that uses nuclear magnetic resonance to produce cross-sectional images of organs and other internal body structures. The patient lies inside a large, hollow cylinder containing a strong electromagnet; which causes the nuclei of certain atoms in the body (especially those of hydrogen) to align magnetically. The patient is then subjected to radio waves, which cause the aligned nuclei to flip. When the radio waves are withdrawn, the nuclei return to their original positions, emitting radio waves that are then detected by a receiver and translated into a two-dimensional picture by computer [2].

CT image offers high resolution in the visualization of bone structures, but its soft tissue contrast is poor. Conversely, MR imaging offers high contrast for the visualization of the soft tissue morphology, but it produces weak signal intensity in bone. Due to their complementary information, it is desired that both X-ray computed tomography (CT) and magnetic resonance imaging (MRI) are integrated [3]. To spatially relate the two datasets, image fusion techniques are employed. Fused images are valuable in clinical diagnosis, in planning surgery, and in the image guided surgical interventions.

Non-contrast computed tomography (CT) is the standard brain imaging study for the initial evaluation of patients, with acute stroke symptoms. Magnetic resonance imaging (MRI) has been proposed as an alternative to CT in the emergency stroke setting [13]. However, the accuracy of MRI relative to CT for the detection of hyper-acute intra-cerebral hemorrhage has not been demonstrated [13]. The present work aims at selecting the optimal method for fusion of MRI and CT images. The fused image gives higher detection accuracy than either MRI or CT images.

In Section 2, brief background about four image fusion techniques is introduced. Section 3 presents the results of applying these techniques to MRI and CT images. The conclusions are presented in Section 4.

2 Image Fusion Techniques

In the present work, four different fusion approaches have been used. These are the Laplacian Pyramid, the Wavelet Transform, the Computationally Efficient Pixel-level Image Fusion (CEMIF) method and the Spatial Frequency Multi-Focus Technique (SFMFT). The first two methods were selected for being the most representative approaches. The last two were selected to show comparisons with alternative approaches found in the literature.

2.1 Laplacian Pyramid

The Laplacian Pyramid representation was introduced by Burt and Adelson [4]. It is easy to implement and computationally efficient. The Laplacian Pyramid transform is specifically designed for capturing image details over multiple scales. Each band-pass level is sampled at precisely its Nyquist frequency making it less sensitive to noise. All these properties make the Laplacian pyramid transform a well-suited representation for the fusion task. Laplacian Pyramid implements a pattern selective approach to image fusion, so that the composite image is constructed not a pixel at a time, but a feature at a time. Given the image sequence $\{I_1, I_2, ..., I_n\}$, the entire fusion algorithm is outlined by the following steps:

1. Generate a Laplacian pyramid L_i for each of the images I_i.

2. Merge the pyramids L_i by taking the maximum at each pixel of the pyramid, obtaining the Laplacian pyramid representation L of the fusion result.

3. Reconstruct the fusion result I from its Laplacian pyramid representation.

4. Normalize the dynamic range of the result so that it resides within the range of [0, 1].

2.2 Wavelet Transform

An alternative to fusion using pyramid based multi-resolution representations is fusion in the wavelet transform domain. The multiresolution wavelet representation is argued to be superior in several respects to that obtained with pyramidal methods [5]:

1. Spatial orientation is introduced in the wavelet decomposition process, unlike pyramidal representations which do not include directional information.

2. The wavelet transform can be tailored to extract highly salient textures/edges while suppressing noise through the choice of the mother wavelet and high- and low-pass filters.

3. The different scales in the wavelet decomposition have a higher degree of independence than those in the pyramidal representations, which are correlated with each other.

The wavelet transform decomposes the image into low-high, high-low, and high-high spatial frequency bands at different scales and the low-low band at the coarsest scale. The L-L band contains the average image information whereas the other bands contain directional information due to spatial orientation. Higher absolute values of wavelet coefficients in the high bands correspond to salient features such as edges or lines. Since larger absolute transform coefficients correspond to sharper brightness changes, a good integration rule is to select, at every point in the transform domain, the coefficients whose absolute values are higher [6], [7].

2.3 CEMIF

This fusion system is based on an adaptive, multi-resolution approach with a reduced number of levels. The goal of this technique is to reduce the computational complexity of multi-resolution systems, such as the Laplacian pyramid and Wavelet transform, while preserving the robustness and high image quality of multi-resolution fusion. The spectral decomposition employed in this system represents a simplified version of the conventional Gaussian-Laplacian pyramid approach [8].

Multi-scale structure is simplified into two levels of scale only, the background and the foreground levels. The former contains the DC component and the surrounding base-band and represents large scale features. The latter contains the high frequency information, which means small scale features. Signal fusion is performed at both levels independently. Background signals, obtained as the direct product of the average filtering, are combined using an arithmetic fusion approach. Foreground signals produced as the difference between the original and background signals are fused using a simple pixel-level feature selection technique. Finally, the resulting, fused, foreground and background signals are summed to produce the fused image.

2.4 SFMFT

It is simply a pixel level image fusion algorithm based on the spatial frequency. Spatial frequency measures the overall activity level in an image. It was demonstrated that it could be used to reflect the clarity of an image [9]. To calculate spatial frequency, consider an image of size $M \times N$, where M equals to the number of rows and N the number of columns. The row and column frequencies of the image are given respectively by:

$$RF=\sqrt{\frac{1}{MN}\sum_{m=0,n=1}^{M-1,N-1}\left[F(m,n)-F(m,n-1)\right]^2} \quad (1)$$

and

$$CF=\sqrt{\frac{1}{MN}\sum_{n=0,m=1}^{N-1,M-1}\left[F(m,n)-F(m-1,n)\right]^2} \quad (2)$$

Where $F(m,n)$ represents the intensity of the pixel at row m and column n. The total spatial frequency of the image blocks is given as:

$$SF=\sqrt{(RF)^2+(CF)^2} \quad (3)$$

When the image gets blurred, the spatial frequency diminishes accordingly [10]. As a result it was demonstrated that the spatial frequency can be used to reflect the clarity of an image. The spatial frequency fusion algorithm consists of the following steps:

1. Decompose the source images A and B into blocks of size MxN. Denote the i^{th} blocks of A and B by A_i and B_i respectively.
2. Compute the spatial frequency for each block, and denote the spatial frequencies of A_i and B_i by SF_i^A and SF_i^B respectively.
3. Compare the spatial frequencies of two corresponding blocks A_i and B_i, and construct the i^{th} block F_i for the fused image as:

$$F_i=\begin{cases} A_i & SF_i^A > SF_i^B + TH \\ B_i & SF_i^A < SF_i^B - TH \\ (A_i+B_i)/2 & otherwise \end{cases} \quad (4)$$

Where TH is a user defined threshold

3 Results

In order to perform image fusion, an initial registration step was performed to align image pairs. Maximization of mutual information was the selected algorithm for all image registration applications.

In the literature, almost all image fusion evaluations are done qualitatively because of the user perception factor [11]. However, there are some quantitative criteria that can be used. Some of them need an ideal composite image (RMSE, mutual information, differential entropy), while some others do not (standard deviation, entropy, cross entropy, spatial frequency [12]. In the present work, the second group of measures was applied.

The standard deviation is defined as the square root of the variance. It reflects the spread in the data. Therefore, a high contrast image will have a high variance, and a low contrast image will have a low variance. Due to the dependence of this measure on illumination, it was excluded as a performance criterion for real applications.

The entropy measures the information content in an image. The cross-entropy measures the similarity in information content between the source and the fused images. Spatial frequency measures the overall activity level in an image [9]. These three criteria were used to evaluate the four fusion techniques.

3.1 Detection of Intra-cerebral Hemorrhage

A prospective, multi-center study was performed at 2 stroke centers (UCLA Medical Center and Suburban Hospital, Bethesda, Md), between October 2000 and February 2003. Patients presenting with focal stroke symptoms within 6 hours of onset underwent brain MRI followed by non-contrast CT [13].

Fusion of MRI and CT images can be helpful to detecting intra-cerebral hemorrhage. Twenty 420 x 560 image pairs were taken as a test set [13]. They were divided into three categories. In case A, the hemorrhage was visualized on MRI, but not on CT. Case B represents regions that were interpreted as acute hemorrhage on CT but were interpreted as chronic hemorrhage on MRI. Case C represents regions that were interpreted as acute hemorrhage on both CT and MRI.

CT-MRI image fusion can increase the accuracy of detection of intra cerebral hemorrhage. This was achieved by applying fusion techniques on three cases.

Figure 1 shows an example of input CT and MRI images for case A. Figure 2 shows the results of fusing the two images to detect intra-cerebral hemorrhage. Table 1 presents the quantitative measures of performance for each algorithm. The average values for input entropy and input spatial frequency were 4.806 and 24.9174 respectively.

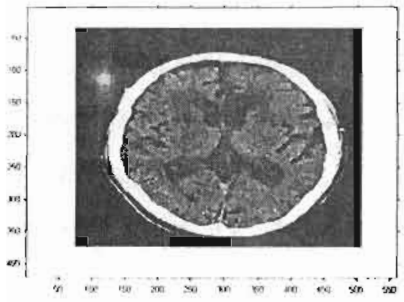
Figure 3 shows an example of input CT and MR images for case B. Figure 4 shows the results of fusing the two images to detect intra-cerebral hemorrhage. Table 2 presents the quantitative measures of performance for each algorithm. The average values for input entropy and input spatial frequency were 4.4576 and 24.1322 respectively.

Figure 5 shows an example of input CT and MRI images for case C. Figure 6 shows the results of fusing the two images to detect intra-cerebral hemorrhage. Table 3 presents the quantitative measures of performance for each algorithm. The average values for input entropy and input spatial frequency were 4.5523 and 24.4156.

For all cases, it is noted that all fusion techniques have led to a fused image that is qualitatively better than the original ones.

Using quantitative measures, Wavelet fusion has given the highest entropy while the CEMIF technique has the least value for entropy.

CT image



MR image

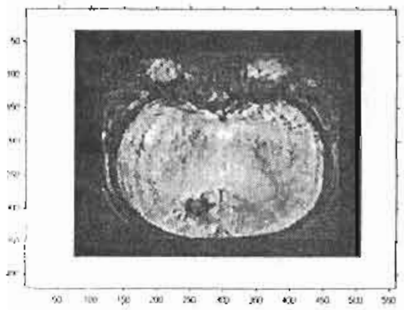
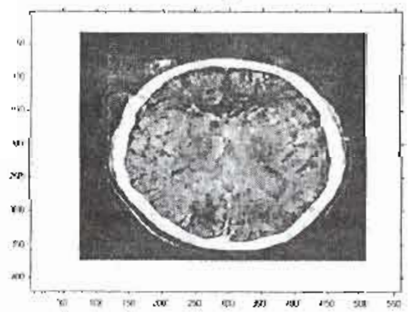
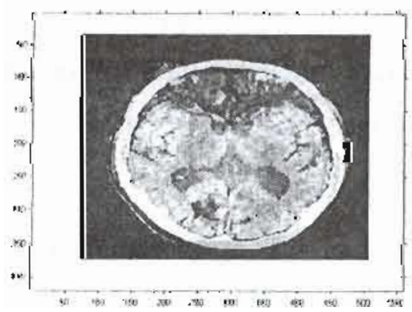


Fig. 1 The input CT and MR images (case A)

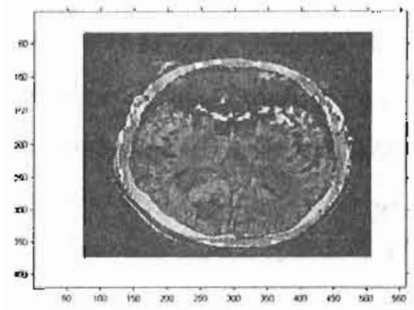
Fusion using Wavelet



Fusion using CEMIF



Fusion using SFMFT



Fusion using Laplacian Pyramids

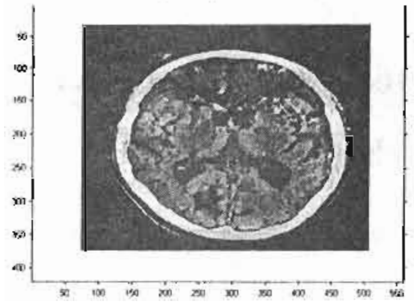
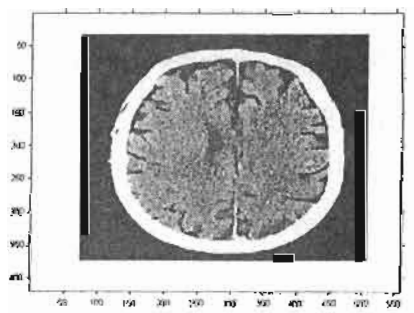
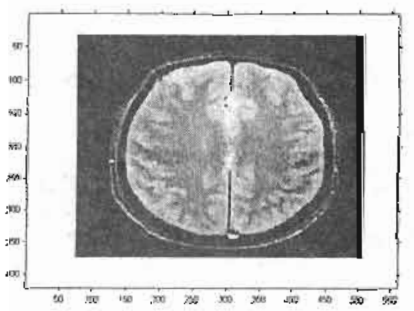


Fig. 2 Fusion Results (Case A)



MR image



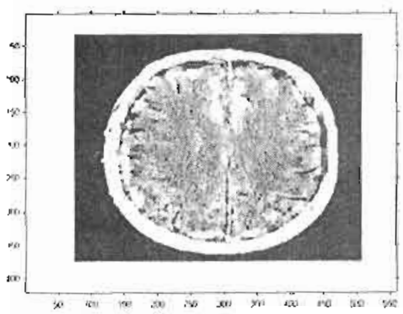
CT image

Fig. 3 The input CT and MR images (Case B)

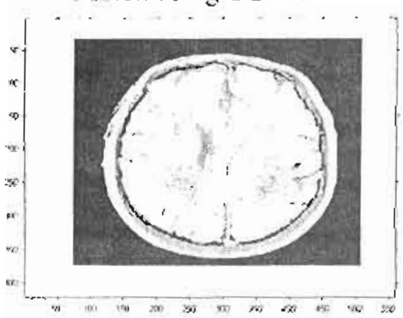
Table 1 Mean values of performance measures (Case A)

Measure / Algorithm	Entropy	C.E.	S.F.
Laplacian	4.7330	-0.0461	25.6062
Wavelet	5.0091	0.0891	25.8398
CEMIF	4.3756	-0.1386	25.5534
SFMFT	4.8720	0.0675	24.8295

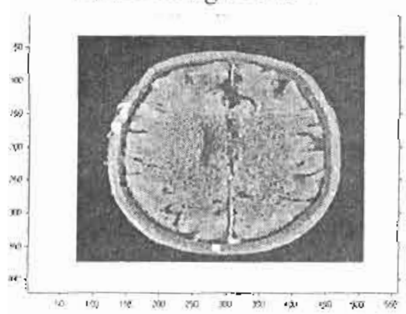
Fusion using Wavelet



Fusion using CEMIF



Fusion using SFMFT



Fusion using Laplacian Pyramids

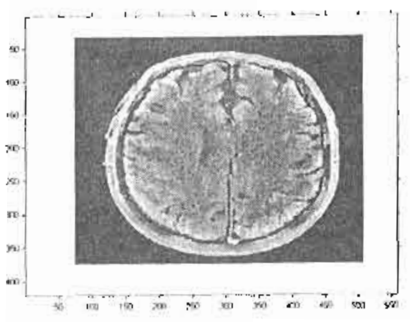
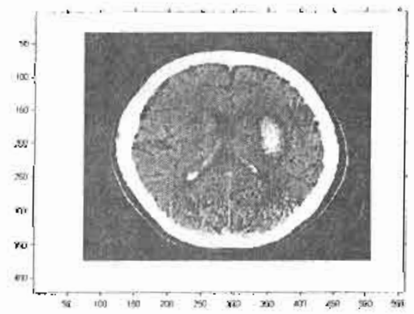


Fig. 4 Fusion Results (Case B)

Table 2 Mean values of performance measures (Case B)

Measure / Algorithm	Entropy	C.E.	S.F.
Laplacian	4.5087	-0.0135	25.6546
Wavelet	4.5674	0.0556	25.8966
CEMIF	4.1682	-0.0183	26.0346
SFMFT	4.4431	0.0157	23.7540

CT image



MR image

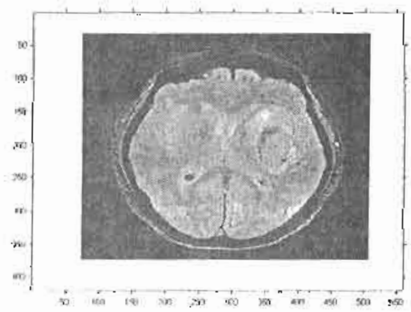
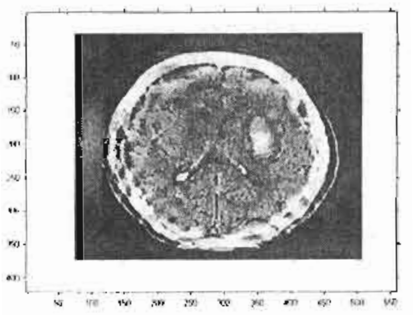
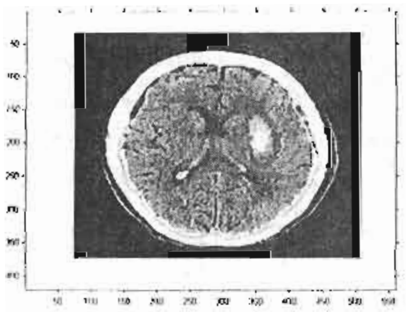


Fig. 5 The input CT and MR images (case C)

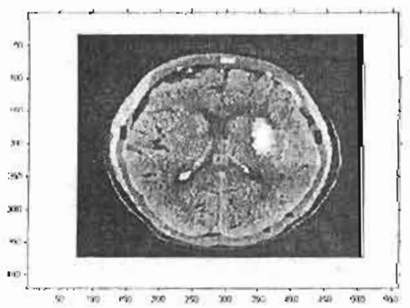
Fusion using Wavelet



Fusion using CEMIF



Fusion using SFMFT



Fusion using Laplacian Pyramids

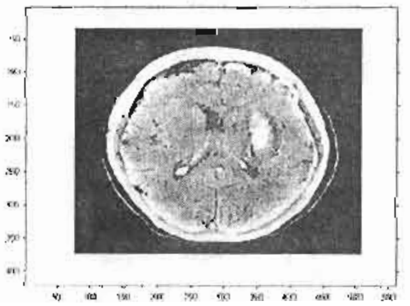


Fig. 6 Fusion Results (Case C)

Table 3 Mean values of performance measures (Case C)

Measure / Algorithm	Entropy	C.E.	S.F.
Laplacian	4.338	-0.0938	26.1
Wavelet	4.9674	0.1247	25.667
CEMIF	4.5142	-0.0101	26.862
SFMFT	4.9598	0.1818	24.346

4 Conclusions

Four image fusion algorithms have been applied to multimodality medical images. They are based on the Laplacian pyramid, the CEMIF, the Wavelet transform, and the SFMFT. Three meaningful performance evaluation metric based on entropy, cross entropy, and spatial frequency were used to assess the effectiveness of different image fusion algorithms.

Image fusion techniques were utilized to facilitate detection of acute intra-cerebral hemorrhage by fusing MRI and CT images at the same level. Results have shown that Wavelet method is more suitable than other techniques for fusing medical images. In addition, the fused CT-MRI image contains more information than the source images. As a conclusion, fusion of CT and MR images leads to higher diagnosis accuracy. Thus, image fusion can be considered as an assistant diagnostic tool especially when CT and MR scans give different results.

References

[1] Computed Tomography (CT) From Wikipedia, *free encyclopedia, technical report, available at:* http://en.wikipedia.org/wiki/Computed_axial_tomography

[2] Joseph P. Hornak, "The Basics of MRI," *technical report, Center for Imaging Science, Rochester Institute of Technology,* NY 14623-5604, 1996

[3] I. P. I. Pappas, M. Styner, P. Malik, L. Remonda, and M. Caversaccio, "Automatic Method to Assess Local CT-MR Imaging Registration Accuracy on Images of the Head." *AJNR: 26(1), pp. 137-144, January 2005*

[4] P. J. Burt., "The Pyramid as Structure for Efficient Computation." In Multiresolution *Image Processing and Analysis, pp. 6-35. Springer Verlag, 1984.*

[5] J. J. Lewis, R. J. O'Callaghan, S. G. Nikolov, D. R. Bull, C. N. Canagarajah, "Region-Based Image Fusion Using Complex Wavelets," *report, The Centre for Communications Research, University of Bristol, 2004*

[6] M. I. Smith, J. P. Heather, "Review of Image Fusion Technology in 2005," *Proceedings of the SPIE, Volume 5782, pp. 29-45, 2005*

[7] Z. S. Long, "Image Fusion Using Wavelet Transform," *Symposium on Geospatial Theory, Processing and Applications, Ottawa 2002*

[8] V. Petrović, C. Xydeas, "Computationally Efficient Pixel-level Image Fusion," *report, Manchester Avionics Research Center (MARC), University of Manchester, 2000, available at:* http://imaging.utk.edu/~priya/GAweb/petrovic.doc

[9] Y. Wang and B. Lohmann, "Multisensor Image Fusion: Concept, Method, and Applications," *Univ. Bremen, Bremen, Germany, Tech. Rep., 2000.*

[10] L. R. Liang, C. G. Looney, "Image Fusion with Spatial Frequency," *Computer Science Department, University of Nevada, USA, 2002*

[11] F. Laliberté, L. Gagnon, and Y. Sheng, "Registration and Fusion of Retinal Images – An Evaluation Study," *IEEE Transactions on Medical Imaging, Vol. 22, No. 5, MAY 2003.*

[12] Z. Wang, D. Ziou, C. Armenakis, D. Li, and Q. Li, "A Comparative Analysis of Image Fusion Methods," *IEEE Transactions on Geoscience and Remote Sensing, Vol. 43, NO. 6, JUNE 2005*

[13] C. S. Kidwell et al., "Comparison of MRI and CT for Detection of Acute Intracerebral Hemorrhage," *JAMA, Vol. 292, No 15, pp. 1823-1830, 2004.*