IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Performance Analysis of Optimized Image Fusion Algorithm for WSN using Raspberry Pi

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Abstract*—In recent years, the accessibility of low price hardware units like CMOS cameras and tiny microphones has contributed Wireless Multimedia Sensor Networks (WMSNs) in various applications. However, the effectiveness of sensor devices for real time image based applications are strictly inhibited by energy, bandwidth, storage space and processing capability. Therefore, to transmit the details of all the captured images with less energy and bandwidth consumption, a technique called image fusion is utilized. Most of the existing image fusion algorithms which are proved and recommended for WMSN are based upon their software simulated results only. Also, those types of algorithms are confined to few fields and not suitable for all WMSN based applications. Therefore, it is essential to develop an efficient image fusion algorithm which should be examined through software and hardware simulation and also satisfy all the requirements of WMSN. In this research, a simple image fusion technique which combines the optimized histogram based multi-thresholding and double density wavelet is considered for fusing the noisy image sets. Then, the effectiveness of the proposed image fusion is analysed and evaluated through the MATLAB software and Raspberry Pi hardware simulation.

***Keywords*— Double Density Wavelets; Image Denoising; Image Fusion; Multi-Thresholding; Optimization.**

I. Introduction

In a wireless image sensor network, each camera enabled nodes can capture the images from a limited physical area of the environment depending upon the type of applications [1]. The captured images may be noisy, incomplete, and more redundant. Hence, the transmission of those images to the sink/base station for further process could be difficult.

Therefore, instead of sending the entire captured images, it is better to transmit the meaningful representation of a scene from each image i.e transforming the complementary information of different sensor images in to a single image. This can be achieved by image fusion. In general, image fusion techniques are basically classified as spatial based techniques and transform based techniques [2]. Some of the multi-scale transforms used in transform based image fusion are pyramid transforms, fast discrete curvelet transform, wavelet transforms, complex wavelet transform and non-sub sampled contourlet transform [3-6]. From that, wavelet transform is considered to be one of the most commonly used image fusion method due to its excellent localization property with respect to time and frequency domain. However, wavelets are lack in shift-invariance property and cannot represent the image edges perfectly.

To surmount this, dual tree complex wavelet transform is developed and utilized for image fusion [7]. Though, the above mentioned different image fusion categories have a number of perceived advantages and limitations. But, most of the image fusion approach is not suitable to fulfill all the requirements of the WSN. Recently, the fusion algorithm using Histogram based Multi-Thresholding (HMT) with Improved Harmony Search with Perturbution Strategy (IHSPS) approach [8] produces better fusion results over wavelet based fusion methods for different image sets such as multi-sensor, multi-focus and medical image sets. It mainly deals with optimized fusion method to fuse the WSN based images without noise. But, the presence of noise during image acquisition reduces the quality of an input image and its subsequent fusion output in case of practical situations. Therefore, in this paper, the research work is extended by combining the HMT and IHSPS based image fusion technique with double density wavelet based image denoising to improve the performance of the fusion of noisy image sets precisely. Moreover, this paper discusses about the efficiency of the developed image fusion model for various noise levels.

II. Existing Hardware Platforms

In general, conducting hardware based experiments for wireless multimedia sensors are naturally complex, especially consume more time to construct and implement the hardware set up which is hard to follow or repeat by other researchers [9-10]. For these reasons, the choice of researchers is always software based simulation to analyse the image based WSN. But, the conduction of simulation analysis and its results are not promising due to a noticeable degradation in scientific standards [11]. Hence, for a network like WSN, it is important that the image processing algorithms developed for WSN has to be analysed with proper hardware experimental set up. For such experiments, the cost of simulation testbeds setup and their maintenance should be less as much as possible.

Now a day, several commercial hardware products are developed to program the function like WSN device. But, vary in terms of processing time, type of communication and energy requirement. For example, the Stargate [12] and the Imote2 [13] processing platforms can offer networking connectivity using IEEE 802.11b and 802.15.4. However, the above mentioned platforms require separate camera interface to capture the required information. The CMUcam3 which is specifically designed for this purpose is used as a camera interface. The major advantage of using CMUcam3 is that it can capture and process the images together [14]. Later, the mote is designed in such a way to permit interfacing more than two cameras with different resolutions. However, the selection of motes mainly depends upon simplicity, size of the hardware, and life time of the node. To satisfy the above conditions, the nodes need to be familiar with a stable operational environment, where the processing and communication metrics are fixed. The essential feature of any WSN node is that it should have low energy consumption. In order to have reduced energy consumption, the main processor of the WSN node must have the clock speed at low frequency range to convince the requirements of image based WSN.

There are some recent works concentrated on implementation in the hardware platform with low energy consumption. Li-Minn Ang, et al. [15] has presented different FPGA based architectures suitable for multimedia WSN. It is designed by using a low frequency 16-bit RISC microprocessor. The advantage of this processor is that, it includes image processing functions. Further, Sun et al. [16] have developed a processor using DSP chip for real time applications. Generally, the selection of DSP chip for hardware implementation is mainly depends upon the processing speed. In this case, fixed point DSP-C6201 is chosen to reduce the memory cost and also the coding time. Then, Fakhari et al [17] has introduced a DCT processor using Xilinx virtex5 FPGA with high throughput. Later, K.Dang et.al [18] has introduced a mi-live platform based image segmentation to detect the plant diseases. However, these techniques are more complex for computing simple image coding algorithms. To overcome the above mentioned problems, the latest technology called Raspberry Pi is used to provide increased flexibility with low power consumption and better performance compared to that of microprocessors and ASICs [19]. Also, this technology is considered in many practical applications. Zhaozhuo Xu,et.al [20] have utilized the low power Raspberry Pi to monitor the rain fall in the remote areas. Similarly, Sheikh Ferdoush et.al [21] and Michal Kochian,et.al [22] have incorporated the Raspberry Pi for environmental monitoring and traffic monitoring.

It is evident from the critical review of literature survey that, most of the existing image coding algorithms developed for WSN are mainly concentrated on maintaining the image quality and not considered about the computation time which is related with energy consumption.

III. Proposed Optimized Image Fusion Technique for Different Noisy Image Sets

To alleviate the energy consumption problem as mentioned before, this section illustrates the working principle of the proposed optimized image fusion algorithm using histogram based multi level thresholding with optimization and double density dual tree based wavelets. Due to the disadvantages of handling wavelets for image fusion, this work mainly concentrates on the histogram based multi-thresholding based image fusion. To enhance the quality of the image and reduce the overall computation time of processing the proposed algorithm significantly, the local search based optimization called IHSPS is appended with the proposed histogram based multi-thresholding.

The overall working model of the proposed optimized image fusion for noisy image sets is shown in Figure 1. The major parts used for constructing the proposed image fusion are: wavelet based image denoising and HMT with IHSPS based optimization. Each part is explained in detail in the following subsections.

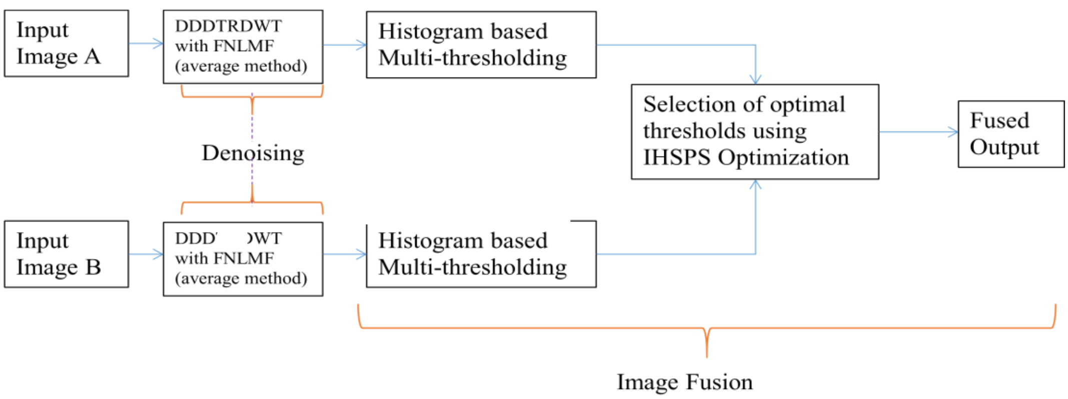

Figure 1: Block Diagram of Proposed Optimized Image Fusion Method using the combination of DDDTRDWT with FNLMF and HMT with IHSPS

A. *Wavelet based Image Denoising*

In the first part, the noisy input images are given as input to the denoising block to reduce the impact of the practical noise called AWGN noise. The better denoised image is obtained with the help of wavelet named Double Density Dual Tree Real Discrete Wavelet Transform (DDDTRDWT) [8] and the denoising filter called Fast Non Local Means Filter (FNLMF). The basic work flow of the DDDTRDWT with FNLMF based denoising algorithm is described by using the following steps:

- A two level decomposition using DDDTRDWT is applied on input noisy image sets.

- After decomposing the images, the optimal threshold value of each subband is measured by using Bivariate Thresholding (BT).
- All high frequency subbands less than that of the optimal threshold value are set to zero. Otherwise, retain in the same value
- Finally, Inverse DDDTRDWT is applied on the wavelet coefficients to obtain the denoised output image.
- The effectiveness of the newly developed algorithm is improved by appending the FNLMF [23] to reduce the noise level by reducing the redundancy.

B. *Optimized Histogram based Multi-Thresholding for Image Fusion*

The second part is used to reduce the pixel values of the denoised images by using histogram based multi-thresholding. The major advantage of utilizing the histogram based multi-thresholding is, it enhances the image features and compresses the images with less loss of information. The following steps describe the working principle of the proposed optimization with histogram based multi-thresholding technique.

Step 1: consider the denoised image *I* of size M*N.

$$H = \{h_0, h_1, \ldots\ldots h_{L-1}\} \quad (2)$$

Step 4: Then, the *n* number of thresholds (T) are considered as,

$$T = \{T_1, T_2, .., T_n\} \quad //0 \le T_1 < T_2 < \ldots < L-1 \quad (3)$$

With the aim of finding the better threshold values, the Shannon entropy is utilized. The entropies of each group of gray levels are,

$$H_1 = -\sum_{i=0}^{T_1} \frac{p_i}{P_1} \ln \frac{p_i}{P_1}, \; H_2 = -\sum_{i=T_1+1}^{T_2} \frac{p_i}{P_2} \ln \frac{p_i}{P_2}, \ldots\ldots,$$

$$H_{n+1} = -\sum_{i=T_{n+1}}^{L-1} \frac{p_i}{P_n} \ln \frac{p_i}{P_n} \quad (4)$$

where, the probability of occurrence (*p*) can be calculated by using,

$$p_1 = \sum_{i=0}^{T_1} h_i, \; p_2 = \sum_{i=T_1+1}^{T_2} h_i, \ldots\ldots\ldots, \; p_{n+1} = \sum_{i=T_{n+1}}^{L-1} h_i \quad (5)$$

Step 5: The total entropy is calculated as,

$$H(T) = H_1 + H_2 + \ldots\ldots\ldots + H_{n+1} \quad (6)$$

Step6: For effective thresholding, the best optimal thresholds T* can be obtained by maximizing the total entropy using the optimization technique namely IHSPS

$$T^* = \max\{H(T)\} \quad (7)$$

Step2 : Then, the gray levels (L) of each denoised image is calculated for the probability of occurrence of gray level *k*

$$h_k = n_k / (M*N) \; ; \; k \in \{0,1,2,\ldots.L-1\} \quad (1)$$

where, n_k is nothing but a number of pixels in each gray level of the input image

Step 3: After that, the normalized histogram (H) of the denoised image is used to separate the image into different classes.

Once the image is thresholded by using HMT with IHSPS optimization technique, it is fed into the fusion block. In the fusion section, the best image features are selected for fusing purpose by considering the optimal threshold value from each input image. Then, by applying the maximum selection rule, the best threshold values are combined to produce the fused output image.

IV. Hardware Implementation for the Proposed Method

The detailed work flow of image fusion algorithm using Raspberry Pi is portrayed in the following Figure 2. Here, the input image is stored and processed automatically by using the Raspberry pi with the help of image coding algorithms which are written in the memory card. The coding of the proposed image fusion algorithm which is described in the previous section is fed into the Raspberry Pi.

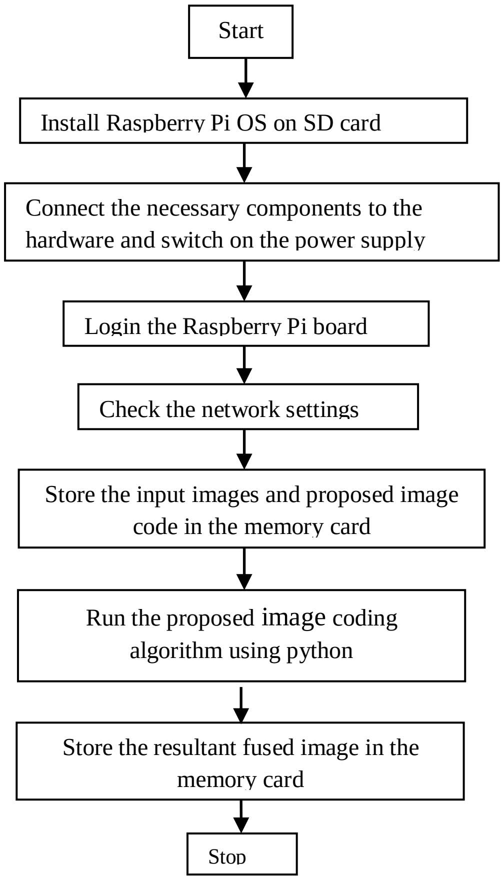

Figure 2: Hardware Implementation of the Proposed Image Fusion

Each block from the above flowchart demonstrates the activation of Raspberry Pi and collection and process of input images from a camera sensor. After applying the fusion process, the resultant image is stored in a memory card and transmitted to the wireless medium like Zigbee through the gateway.

V. Results and Discussion

The latest version of Raspbian wheezy with python 2.7.3 is used for hardware implementation. Once the images are stored in the memory card, the rest of the process will be done automatically without user intervention. Similarly, software simulations are carried out with the help of MATLAB R2014a programming environment.

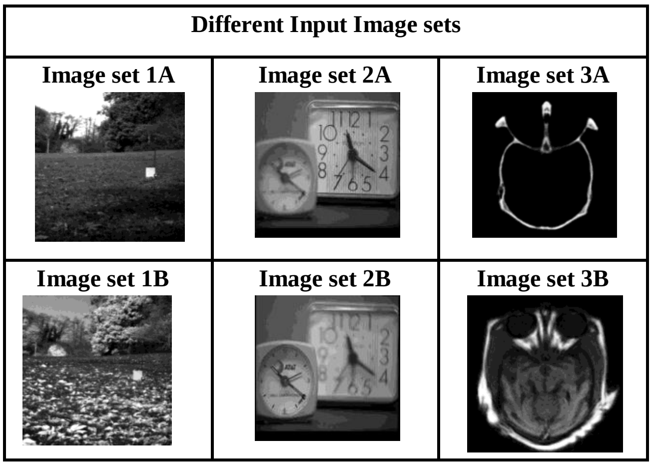

Figure 3: Input Image sets

In this section, both quantitative and qualitative analysis of the proposed hardware and software based image fusion model is demonstrated. To analyse the efficiency of the proposed fusion algorithm for real time applications, the input images are artificially corrupted by different levels of AWGN noise. In this work, noise levels taken in to consideration are 20db and 40db. For demonstration purpose, the input image sets from Berkley dataset [24] is considered for simulation as shown in Figure 3. The parameter values listed for simulation of the optimized image fusion algorithm and hybrid of FNLMF and DDDTRDWT through testbeds are assigned as shown in the following Table.1 and 2. The number of thresholds chosen for multi-thresholding is 32.

Table 1
Parameter value selection of IHSPS

Parameters	**Values**
Harmony Memory Size (HMS)	150
Pitch Adjustment Rate (PAR)	0.85
Harmony Memory Consideration Rate (HMCR)	0.9
BandWidth distance (BW)	[0,1]
Perturbation Parameter (P)	0.35
Constant σ	0.6
Constant ω	0.2

Table 2
Parameters of FNLMF

Parameters	Value
Patch Radius (f)	10
Searching range (t)	2

A. *Quantitative Analysis*

The standard performance metrics used in the existing image fusion algorithms [21] are considered in this research work to analyse the efficiency of the proposed overall optimized image fusion using Matlab and Raspberry pi hardware. The performance comparison of hardware (Hw) and software (Sw) simulation of the proposed overall optimised image fusion model by considering different image sets along with various noise levels 20db and 40db respectively is showcased in Table 3.

It is depicted through the quantitative analysis that the image quality of the hardware based proposed optimized image coding algorithm is better compared to that of the software simulation. In this research work, the hardware Raspberry Pi consume approximately 32mJ on an average for performing the overall proposed optimized image coding algorithm which include image denoising, optimized multi-thresholding and image fusion.

Table 3: Performance Comparison of the Hardware (Hw) and Software (Sw) Results of the Proposed Optimized Image Fusion Model for Different Image Sets

Input Image Set	**Noise Level (σ)**	**PSNR(db)**		**API**		**MI**		$Q^{AB/F}$		**Computation Time(sec)**	
		Sw	**Hw**	**Sw**	**Hw**	**Sw**	**Hw**	**Sw**	**Hw**	**Sw**	**Hw**
Image set 1	20	31.80	32.24	85.67	85.76	2.212	2.97	0.729	0.74	2.89	3.26
	40	28.26	28.54	84.11	84.15	1.868	1.88	0.548	0.550	3.25	3.52
Image set 2	20	33.62	34.89	92.46	92.58	6.978	7.12	0.695	0.761	2.58	2.804
	40	28.94	29.10	90.89	91.24	5.98	6.065	0.532	0.599	3.04	3.52
Image set 3	20	30.32	30.84	48.58	48.58	2.92	3.215	0.587	0.685	1.98	2.248
	40	28.26	29.02	47.41	47.59	1.88	1.951	0.480	0.504	2.37	2.62

Table 4
Average Energy Consumption of the Proposed Optimized Image Fusion Model using Raspberry Pi for Different Image Sets

Input sets	Energy (mJ)
Image set 1	36.11
Image set 2	33.56
Image set 3	26.72

It is clear from the table 3 and 4 that, the quantitative metrics such as PSNR, MI, $Q^{AB/F}$ and API of the proposed optimized image fusion using hardware is better for all type of image sets than that of the software simulated optimized image fusion model. Though, the proposed coding algorithm using hardware consumes higher computation time than that of the software simulation as shown in Table 3. The energy required to process the proposed coding model is moderate and acceptable for WSN based applications as shown in Table 4.

VI. Conclusions

To improve the performance of the image based applications for WSN, an attempt has been made in this research work by developing the image fusion algorithm namely hybrid of histogram based multi-threshold optimized image fusion algorithm and DDDTRDWT with FNLMF based denoising algorithm for noisy image sets. From the quantitative and qualitative analysis of the MATLAB software and hardware Raspberry pi simulation, it is clearly understood that the proposed overall optimized image fusion algorithm achieves better results for noise levels 20db and 40db respectively. It is also observed through the quantitative comparison of the hardware and software based results that the proposed optimized image fusion model is suitable for WSN based multi-sensor and multi-focus images.

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