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Discrete Wavelet Transform and Event-triggered Particle Swarm Optimization Approach for Infrared Image Enhancement

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***Abstract*—** Infrared images suffer from low contrast and poor image quality mainly as a result of data collection and transmission. Conventional techniques used in infrared image enhancement have being reported with over enhancement and brightness distortion. This work proposes an infrared image enhancement technique based on discrete wavelet transform (DWT) and event-triggered particle swarm optimization (ETPSO). This technique will be implemented by first performing image preprocessing using Daubechies D4 filter, image transformation and enhancement based on discrete wavelet transform and finally brightness correction using event-triggered particle swarm optimization. The proposed algorithm was implemented on a dataset obtained from Dynamic Graphics Project laboratory database of infrared images and the output was put side by side with conventional approaches. A quantitative comparison shows that the proposed technique performs better with an average peak signal-to-noise ratio (PSNR) and discrete entropy (DE) values of 20.9 and 6.49 respectively.

***Keywords*—** Infrared Image Enhancement; Discrete Wavelet Transform; Particle Swarm Optimization

I. INTRODUCTION

Enhancing a digital image (visible or infrared image) that is corrupted by noise and other disturbance during its acquisition or transmission is a critical subject in the domain of computer vision and digital image processing [1]. Infrared images are extensively used in remote sensing, military detection, fault diagnosis, medical analysis, fire monitoring, and scientific research [2]. However, unlike visible images, infrared images experience major drawbacks such as; poor image contrast, blurred resolution, lack of color information, and visual disturbance caused by noise [3]. These drawbacks pose much difficulty when trying to recognise the target of interest from the background which is important for proper analysis, accurate interpretation and further image processing such as image restoration and feature extraction. To obtain better results, infrared images should be enhanced with effective algorithms to make it fit for various uses [4].

The primary factor that affects the property of infrared images is the presence of noise. It is well known that the signal-to-noise ratio, as well as the contrast of infrared images, is low [5]. These two inherent factors make the processing of infrared images challenging. The main causes of noise in infrared images are; atmospheric conditions, the infrared sensors and intrusion of the signal processing circuit. Based on the infrared sensor technology, the problem may be related to photoelectric conversion (in photo-detectors) or temperature variation noise (in thermal-detectors) and also the influence of the manufacturing process. This causes non-uniformity in the infrared detector, which is revealed by the different response of the image pixels. This non-uniformity if not adequately corrected, maybe the major cause of noise in infrared images. Also environmental and atmospheric conditions during capturing also constitute noise [6].

To achieve improved results during image interpretation and analysis, infrared images should be enhanced with effective techniques. This research proposes an infrared image enhancement technique based on discrete wavelet transform and event-triggered particle swarm optimization. This technique effectively enhances image detail and also addresses the drawback of brightness distortion.

II. RELATED WORKS

Conventional infrared image enhancement techniques can be grouped into two major categories. This is based on the method of intensity mapping [7]. They are; global intensity mapping and local intensity mapping. In the global intensity mapping technique, histogram equalization is the commonly adopted technique, which manipulates the occurrence probability histogram to differentiate the intensity levels with high probability from the neighbouring intensity levels[8]. But, over-enhancement of the background image has being reported with histogram equalization [9]. This is because the high probability intensity levels are usually the background pixels that fill most of the dynamic range and they are radically enhanced, while the low probability intensity levels are associated with small objects and are most times conceal or even lost[10]. Several advances have been made to resolve the issue of over-enhancement in histogram equalization. The plateau based techniques, such as plateau histogram equalization [11], double plateaus histogram equalization and adaptive double plateau histogram equalization [12] techniques based on histogram segmentation, introduced to threshold the probability of intensity levels of background and augment the low probability to maintain the details of images. Also, other techniques were developed as alternate solutions to address the over enhancement of histogram equalization, such as Brightness-preserving Bi-histogram equalization [13], Range Limited Bi-Histogram Equalization [14], Adaptive Histogram Partitioning [3]. Still, the modified histogram-based techniques do not adequately reduce the gap of probabilities between intensity levels, and the probabilities of objects-related intensity levels are still less or equivalent to the probabilities of background-related levels [15]. As a result, the outputs of the probability histogram equalization based techniques, the contrast between the image objects and the image background is not sufficiently enhanced, which is inadequate for infrared image applications.

III. METHODOLOGY

The proposed infrared image enhancement technique is established on frequency domain transformation and optimization. The frequency domain technique used is discrete wavelet transform; this decomposes the low frequency and high frequency constituents of test image, eliminates the inherent noise and reconstructs the image. The ETPSO enhances the image brightness by optimizing the objective function which is expressed in terms of the sum of intensity values, number of edge pixels and entropy value. The flowchart in Fig 1 shows the design methodology.

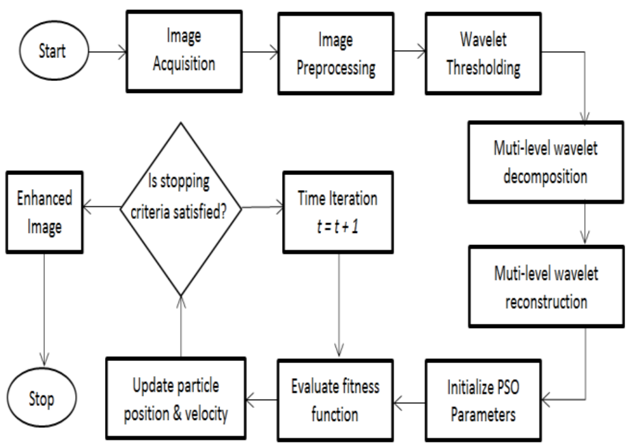


Figure 1: Design Methodology flow chart

The dataset used for the algorithm were acquired from Dynamic Graphics Project laboratory database of infrared images [16], to form a valid basis of comparison with infrared image enhancement using conventional approaches. After the dataset was acquired, the test images were pre-processed. The dataset contains eight test images namely; building, cabinet, car, computer, guardrail, leg, residence and room. These test images were pre-processed using Daubechies D4 filter

A. *Wavelet transformation*

The wavelet transformation is in three phases: a forward wavelet transform, a wavelet thresholding phase and an inverse wavelet transform in two levels. Based on the developed wavelet thresholding technique, the infrared image enhancement is carried out. Multi-level discrete wavelet transform is used for decomposing the original test image. At every level of the multi-level wavelet decomposition, four sub-images of approximation, horizontal, vertical and diagonal details. Fig. 2 show the multi-level decomposition of original test image (leg).

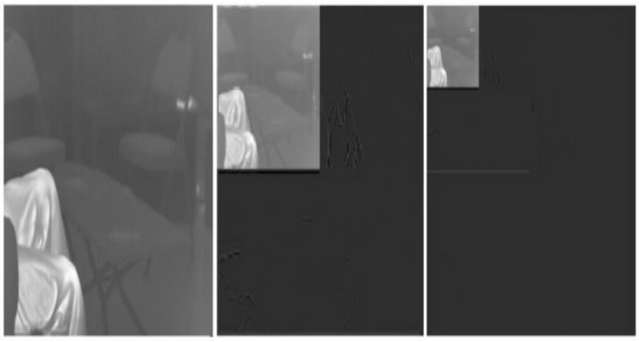


Figure 2: Multi-level decomposition of the original test image (leg)

Multi-level inverse wavelet transform is used for reconstruction of the image. It is implemented by taking the wavelet coefficients from a previous decomposition matrix and performing the inverse wavelet transform.

B. *Implementation of Event-Triggered Particle Swarm Optimization for Brightness Correction.*

Event triggering in particle swarm optimization is a technique employed to minimize the number of computations required to get an optimal solution [17]. It is defined as follows;

$$v_k^d(i+1) = wv(i) + \alpha(i) + \beta(i) \quad (1)$$

Where α(i) represents the cognitive term and β(i) the social terms. The cognitive term comprises of a constant c_1, a random variable r_1 gotten from a uniform random distribution over the interval [0, 1]) and the distance between the particle's present position and the local best position. This distance serves as a scaling factor that puts an upper limit on the maximum value of the cognitive term. The distance between the dth dimension of the global best and the particle's current position serves the same funtion for the social term. We express the particle's local distance (L_d) for its dth dimension as the absolute difference between the particle's current position and its local best position. The particle's global distance (G_d) is defined similarly as the absolute difference between the particle's current position and its global best position. This is expressed in equations 2 and 3 as follows;

$$L_d = |p_k^d - x_k^d| \quad (2)$$

$$G_d = |p_k^d - x_k^d| \quad (3)$$

If the value of the local distance is less than the given threshold, denoted by γ, then the cognitive term in equation (1) is zero, meaning that it is not part the update for that iteration. This is shown in Equation 4 as follows;

$$\alpha(i) = \begin{cases} c_1 r_1 (p_k^d - x_k^d(i)), |p_k^d - x_k^d| \geq y \\ 0, |p_k^d - x_k^d| < y \end{cases} \quad (4)$$

The concept here is that if the dth dimension of the particle is very near to the dth dimension of its local best, the impact of the cognitive term of in equation (4) will be negligible, and ignored can be ignored. The velocity of the particle for the dth dimension would still be updated based on its inertia weight term and the social term, β. Also, if the dth dimension of the particle is very close to the dth dimension of the global best of the swarm then the impact of the social term in the update of equation (5) would be negligible and can be ignored. That is;

$$\beta(i) = \begin{cases} c_1 r_1 (g_k^d - x_k^d(i)), |g_k^d - x_k^d| \geq y \\ 0, |g_k^d - x_k^d| < y \end{cases} \quad (5)$$

The cognitive and social terms of the optimization model for the dth dimension will not be computed if the particle's current position is within γ distance of its local best position and the swarm's global best position, respectively. The equation for particle velocity is given in equation 6 as follows;

$$x_k^d(i+1) = x_k^d(i) + v(i+1) \quad (6)$$

The event-triggered particle swarm optimization is implemented to optimize the brightness of the infrared images. This was carried out using the model for event-triggered PSO in equations 1 and 6 as well as the objective function defined in equation 7 as follows;

$$F(I_z) = \log(\log(E(I_z))) \frac{n\_edgels(I_z)}{MN} H(I_z) \quad (7)$$

$F(I_z)$ is the objective function, I_z denotes the original image. $E(I_z)$ is the sum of intensity of the edges, *n_edgels* is the number of edge pixels. *M* and *N* are the numbers of pixels in the horizontal and vertical direction of the image. Lastly, $H(I_z)$ measures the entropy of the image I_z.

The parameter settings for the optimization process is given in Table 1

Table 1: Parameter setting for the optimization

Meaning	Default value
Number of particles	24
Local entropy window	7
Maximum iteration	50
Minimum weight	0.4
Maximum weight	0.9
Learning factor	2.4
Learning factor	1.7
Local best position	0
Global best position	0

Based on the equation for ETPSO stated in equations 5 and 10 as well as the objective function in equation 11, the algorithm for the optimization process is defined in Algorithm 1 as follows;

Algorithm 1: Brightness Optimization Using ETPSO

Input: Test Infared image
Create N number particles
for each particle i = 1: N *do*
Initialize the position of each particle poition and particle velocity;
end for
for t = 1 : tmax *do*;
Compute local distance and global distance;
Compute the fitness function;
end for
for each particle i = 1 : N *do*
Update particle velocity;
Update particle position;
end for
end for
Output: Enhanced IR image.

C. Performance Evaluation

The performance of this research would be evaluated using Peak-Signal-to-Noise Ratio (PSNR) and Discrete Entropy (DE) as performance metrics. PSNR and DE are discussed in this subsection.

- *Peak Signal-to-Noise Ratio*

Peak signal-to-noise ratio is a metric for evaluating the quality of an enhanced image by computing the ratio of maximum signal power to maximum noise power. It is measured on a logarithmic scale in decibels (dB). Mean Square Error (MSE) which is the average of the squared difference of the intensities of the original and enhanced image is used to compute PSNR. The larger the PSNR value of an image the higher the image quality [18] . The equations for PSNR and MSE are stated in equations 8 and 9.

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE(O,I)}\right) \quad (8)$$

Where *Max* denotes the maximal gray level and MAX = 255 for 8-bit digital images; MSE (O, I) is the mean square error between the output O and input I, which is defined as:

$$MSE = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}(O_{(x,y)} - I_{(x,y)}) \quad (9)$$

Where M and N are the total numbers of rows and columns respectively and *x, y* are the pixel values across the rows and columns.

- *Discrete Entropy*

Discrete Entropy (DE) is a statistical index that characterizes the information amount contained in an enhanced image. It was employed to measure the degree of over-enhancement in our experiment. The DE of an image is expressed in Equation 10 as follows:

$$DE = \sum_{s=0}^{L-1} -P_s \log_2 P_s \quad (10)$$

Where s is image pixel, *L* is the total number of pixels and P_s is the probability of event *s.* A larger DE value means fewer gray levels are merged, leading to a clearer visual performance [19].

IV. RESULTS AND DISCUSSION

The developed technique was tested with a data set of eight images obtained from Dynamic Graphics Project laboratory database of infrared images [16]. The results of the original test images and the enhanced test images using adaptive histogram partitioning (AHP) and Particle swarm optimization (PSO) as well as the developed technique (DWT & ETPSO) is presented in Fig 3.

Illustrated in Fig 3 are the test images from the dataset before and after enhancement. Three enhancement outputs are placed alongside the proposed technique. The approach of decomposing the original image into its frequency components produced the horizontal, vertical, diagonal and approximation constituents of the image thereby making it possible to effectively remove the inherent noise present in the image and produce an enhanced output without over-enhancement. Also implementing event-triggered particle swarm optimization on the test image helped to optimize the image's brightness effectively. This was able address any sort of brightness distortion as show in Fig. 3a (v). The same result was obtained for all eight test images present in the dataset. The image details and features of building, cabinet, car, computer, guardrail, leg, residence and room were adequately enhanced without brightness distortion. For quantitative assessment the PSNR and DE values are presented in Tables 2 and 3.

Table 2: Comparison of PSNR values of test images

Test Images	BBHE	ADPHE	AHP & PSO	PROPOSED TECHNIQUE
Building	12.6611	16.8048	16.8685	18.5102
Cabinet	12.5129	12.0847	16.5403	18.4239
Car	13.4511	15.3592	16.9767	18.6048
Computer	11.4154	27.6319	21.4629	23.4305
Guardrail	13.2453	13.1659	16.7550	18.2091
Leg	14.2202	25.2335	24.6008	27.5500
Residence	12.0603	18.8433	18.5197	20.1963
Room	13.2009	12.5104	20.5891	22.7962

Based on the results presented in Table 2, infrared image enhancement based on the proposed technique has high PSNR values. The range of PSNR values obtained from the eight enhanced images is from a minimum value of 18.2091 for guardrail to a maximum value of 27.5500 for leg, also the dataset has an average PSNR value of 20.96. Given that the larger the PSNR value the higher the quality of the enhanced image leading to a clearer visual performance in the final output, the proposed technique outperforms conventional techniques such as BBHE, ADPHE and AHP in terms of PSNR.

Table 3: Comparison of DE values of test images

Test Images	BBHE	ADPHE	AHP & PSO	PROPOSED TECHNIQUE
Building	5.2030	5.1544	5.5059	6.5238
Cabinet	5.3335	5.6247	5.6769	6.7230
Car	5.6892	5.3767	5.7270	6.9979
Computer	4.1793	4.1892	4.4657	5.5885
Guardrail	5.5252	5.3767	6.0788	7.2166
Leg	5.4267	5.3053	5.4650	6.8558
Residence	4.6137	4.7578	4.7814	5.5042
Room	5.6513	5.4883	5.6247	6.5380


a) i. BBHE


ii. DPHE

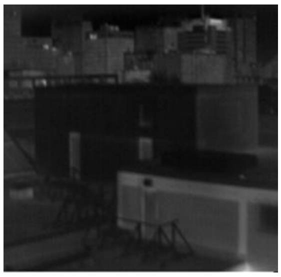

iii. AHP


iv. proposed


b) i. BBHE


ii. DPHE


iii. AHP

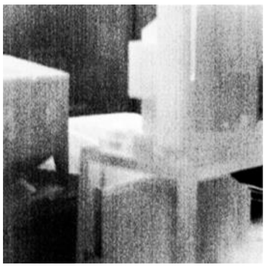

iv. proposed

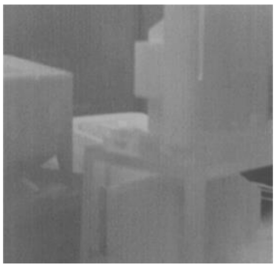

c) i. BBHE

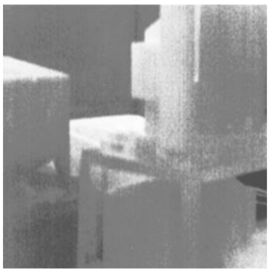

ii. DPHE

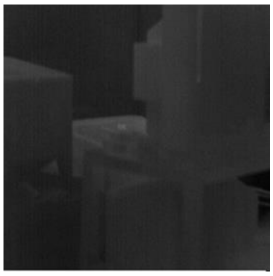

iii. AHP


iv. proposed


d) i. BBHE


ii. DPHE


iii. AHP


iv. proposed


e) i. BBHE


ii. DPHE


iii. AHP


iv. proposed

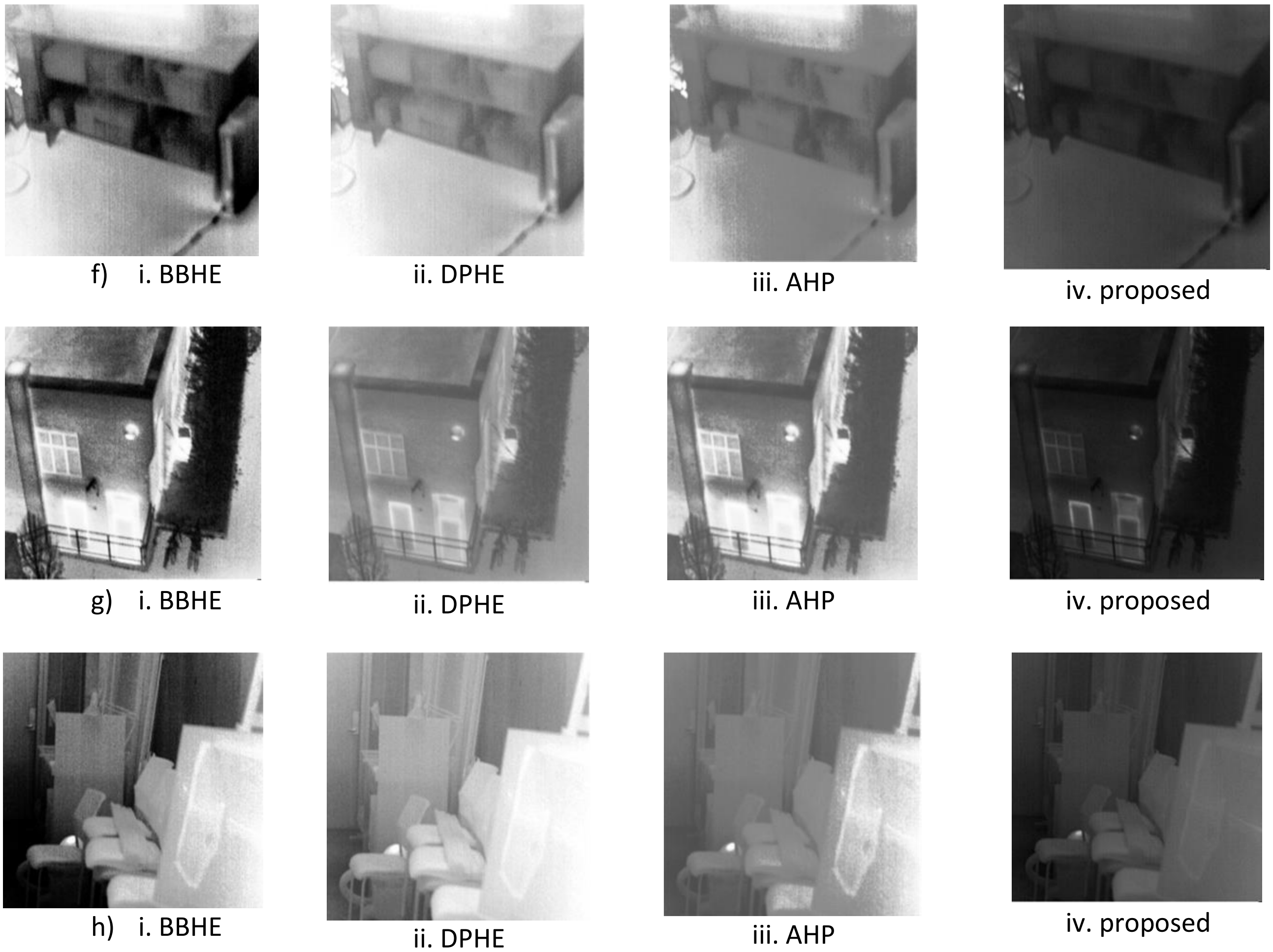


Figure 3: Original images, enhanced images using (ii) BBHE, (iii) ADPHE, (iv) AHP & PSO and (v) the propose technique.

From the results presented in Table 3, infrared image enhancement based on the proposed technique has high DE values. The range of DE values obtained from the eight enhanced images is from a minimum value of 5.5042 for residence to a maximum value of 7.2166 for guardrail, also the dataset has an average DE value of 6.49. A large DE value means fewer gray levels were merged leading to a better dynamic range; therefore the proposed technique outperforms conventional techniques such as BBHE, ADPHE and AHP in terms of DE.

V. CONCLUSION

To address the challenges of over enhancement and brightness distortion, the development of an infrared image enhancement technique based on DWT and ETPSO is presented in this paper. The algorithm was tested on a dataset obtained from Dynamic Graphics Project Laboratory database of infrared images for objective comparison with existing infrared image enhancement techniques. Based on the results obtained, the image details were effectively enhanced without brightness distortion. The results obtained from implementing the developed technique on the dataset shows an average value of 20.9 and 6.49 for PSNR and DE respectively. This shows better performance when compared with conventional techniques.

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