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# Image Enhancement by Using Fuzzy Firefly Optimization and Fuzzy Perceptron Neural Network

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**Abstract**

The image enhancement methods play an important role in digital image processing. And by using a different *kinds* of image enhancement techniques, such as artificial intelligence techniques methods. The aim of this methods is to enhance the visual appearance of the digital image and to reduce image noise. In this paper, to enhance the corrupted image and de-noise image, we used swarm optimization algorithms such as a firefly algorithm (FA) and also used neural network such as the perceptron neural network algorithm (PNN). And then after we added the fuzzy membership function to these two algorithms, we obtained to a new method called a fuzzy firefly algorithm (FFA) and fuzzy perceptron neural network algorithm (FPNN). And was computed the performance and efficiency measures for all methods, such as RMSE and PSNR. And the FFA method was the best among the other methods used in this paper.

**Keywords**

image enhancement, firefly optimization, swarm intelligence, perceptron neural network, gray and colored images

## 1 Introduction

Image enhancement is method important to make the image clearer. And one of the important processing steps for image is image enhancement without of image information loss and also to improve quality of the image [1]. In image processing, distorted images or image noise is an important subject for many application fields, such as image matching, image transmission, remote sensing, target detection. And image quality degradation is caused by noise in the image, this is leading to distortion of valid pixels and image blurring. Therefore, also to noise reduction and to guaranteed pixel quality must use, effective and reliable approaches [1–4]. One branch of artificial intelligence is swarm intelligence, which simulates the natural behavior of fireflies, bees, fish, and ants [5, 6]. Swarm intelligence algorithms based on the basic principles of artificial intelligence (AI) and neural networks are mostly used in many fields such as image processing, identification, pattern recognition, classification, speech, and control systems [7–10]. The firefly algorithm depends on the intelligence of the swarm and has two important features, first: fireflies are characterized by automatic division and their ability to deal with multimedia, as fireflies depend on attractiveness, which is affected by distance. Subgroups can be formed from the division of the population automatically, and each new group of these divided groups has the ability to gather around the best local solution. The global solution can be obtained from among these multiple solutions. Second: fireflies have the ability to simultaneously find perfect elements through this division of fireflies, and their automatic ability to segment makes them division for enhancement problems [11, 12]. Artificial neural networks are used in image processing of all categories, such as images reconstruction and restoration, to remove any deviations from it, including noise, image enhancement, that is, to highlight some desired features. The image is inserted into the neural network and processed by the network to obtain an enhanced image free from distortions and noise that it is exposed to while obtaining the image from any source and surrounding conditions [13].

In this paper, we used swarm intelligence and neural network to enhance images and de-noise of images. Where the firefly optimization algorithm which is one of a meta heuristic method that represent swarm intelligence technique was used to enhance image by de-noise from the image. And also use supervised neural network represented by a single layer perceptron to enhance image. And by adding

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membership functions to each of firefly algorithm and perceptron neural network, we obtained a new two methods called fuzzy firefly algorithm and fuzzy perceptron neural network, these methods applied it on several color images corrupted to enhance it by de-noise from it.

The goals of image enhancement are noise reduction and noise elimination. The fitness function creates a balance between contrast and naturalness of an image and helps reduce distortion and noise in the image and access to the best global solution with firefly and access to the optimal solution in neural network solution.

## 2 Related work

Much research has been done in the field of image enhancement: G. Kaur and M. Kaur [14] presented image enhancement research using SVD to adjust low contrast enhancement approaches, as well as using swarm intelligence, such as particle swarm optimization (PSO) with a cuckoo search, ant colony optimization (ACO) algorithm to boost image enhancement accuracy, These methods obtained different percentages of PSNR which are SVD 37.3485, ACO 37.9968, PSO 37.4431, cuckoo search 45.9126. The image enhancement proposed by Pathak et al. [15] can be used to improve the digital image quality, it is really used to increase the compactness image quality that is too used to enhance the poor image quality into decent image or image, this section recommends a mix of global and local ways to improve the contrast of an image, global image enhancement, contrast enhances no image disparity internationally, this kind of global enhancement removes a noise of image, improvement of the image in global variance when there is high assessment. Bouaziz et al. [16] worked on the images, overcoming the limitations of traditional optimization methods, and to enhancement the fingerprint image comparison they proposed a method based on cuckoo search, the formula combines both a method for mapping the white level to increase contrast using cuckoo search, and the other goal is to be a great scale of the global fingerprint image, so the expected algorithm proved to be very effective in improving fingerprint image quality for more control. Iqbal et al. [17] employ an unsupervised color correction process to boost images of poor quality. Zhang et al. [18] applied the network algorithm to the adaptive image enhancement problem to identify processing parameters, based on an analysis of theory of image enhancement a BP neural network algorithm introduced the image filter design and the detailed image enhancement application procedure. Pitkänen [19] used CCN for enhanced images, the network architecture consists of several convolution and fully connected layers, this bilateral grid allows for local and edge-aware improvement, although effective in computational terms. Biswasa et al. [20] proposed a quality of microscopic images improved using a contrast and brightness enhancement strategy based on the cuckoo search (CS) and multi-scale retinex (MSR) methodes is (CS-MSR) and compared with ABC-MSR and PSO-MSR. PSO-MSR method obtained PSNR equal to 3.928 and RMSE equal to 45.961 and ABC-MSR obtained PSNR equal to 2.836 and RMSE equal to 44.027, and the CS-MSR method obtained PSNR equal to 2.749 and RMSE equal to 42.928. Elbir et al. [21] artificial bee colony (ABC) optimization and particle swarm optimization (PSO) methods was used to improve image quality using the histogram stretching methodology. The PSO is more efficient than the ABC in adapting to histogram stretching. ABC obtained of PSNR equal to 23.85 and PSO obtained PSNR equal to 27.62.

## 3 Firefly algorithm

The firefly FA method relies ideal behavior of the fireflies flash feature. In this algorithm, search agents mimic fireflies, which flash instances of light to attract their mating partner. The attractiveness observed by a firefly depends upon many factors such as the intensity of the light emitted, distance from the source firefly and absorption properties of the atmosphere. There are three ideal rules for a firefly algorithm FA as the following [22]:

1. The attraction in fireflies depends not on their gender, but on their brightness, and regardless of their gender, fireflies are attracted to each other.
2. Attractiveness of fireflies corresponds to the brightness of fireflies, and brightness decreases when distance between two fireflies increases.
3. Objective function that is determines the brightness of fireflies.

The other fireflies will be attracted to brighter flash firefly. Attractiveness depends on the intensity of the lighting. The intensity of light affects attractiveness, so if the distance from the light source increases, then intensity of light will decrease, and thus attractiveness will decrease. That is, inverse proportional between the attractiveness of the intense light and the distance *dis*.

$$L(dis) = L_o e^{-\gamma r^2} \tag{1}$$

$L$ represent the intensity of light, $L_o$ initial intensity of light, $\gamma$ coefficient of light absorption, $dis$ is the distance between fireflies. And it is possible to determine the attractiveness of a firefly, by relying on the proportional between the attractiveness of the firefly and the intensity of light that the neighboring fireflies see.

$$\beta = \beta_o e^{-\gamma dis^2} \tag{2}$$

The $\beta_o$ is the attractiveness at $dis = 0$, distance between the two fireflies is computed as follows:

$$dis_{ij} = p_i - p_j = \sqrt{\sum_{k=0}^{d} \left(p_{ik-p_{jk}}\right)^2}, \tag{3}$$

where $dis_{ij}$ denotes the distance between the two $i^{th}$ and $j^{th}$ fireflies. A firefly $i$ is attracted and moved toward another firefly $j$ that more attractive. As shown in Eq. (4):

$$p_i^{t+1} = p_i^t + \beta_o e^{-\gamma dis_{ij}^2}\left(p_j^t - p_i^t\right) + \alpha\varepsilon_i \tag{4}$$

$$\varepsilon_i = (\text{rand} - 0.5).$$

The current iteration number represented by $t$, $\gamma \in [0, \infty]$ denote to the absorption coefficient, $\alpha \in [0, 1]$ is randomization parameter. The first variable indicates the current position of firefly $i$, second variable represents attraction towards the more attractive and brighter firefly $j$, the firefly random walk is represented by last variable. The $\varepsilon_i$ is the random number between (0, 1). Algorithm 1 [22, 23] shows the pseudo code for firefly algorithm.

In this work, the firefly algorithm was used to perform image enhancement by using a midpoint filter as a fitness function to enhance each pixel within the specified window. The formula for the fitness function is as follows:

$$\text{fitFA} = \frac{IM_S - IM_L}{2}. \tag{5}$$

This fitness function helps to enhance the image and increase its accuracy due to its role in cleaning noise perfectly, as it represents the best solution for each pixel to be processed.

Fig. 1 shows the flowchart for the firefly algorithm (FA) [23, 24].

**Algorithm 1** Firefly algorithm pseudo code

```
Start
Define the Objective function f(p), p = (p_1, p_2, ..., p_d)^T
Create an initial population of k fireflies p_i, i = 1, 2, ..., k
Determine intensity light L_i at p_i by f(p_i) define the γ
coefficient of light absorption
While not reaching the number of iterations (t < Max_Gen)
    for i = 1:k
    for j = 1:k
Brightness of nearest fireflies are comparing,
    if (L_j > L_i)
move less bright firefly i towards brighter firefly j
    end if
Attractiveness differ by exp(−γr) and distance dis,
A new solutions evaluation & adjust the light of intensity
    end loop j
    end loop i
Arrange Fireflies and find best g* global current
End while loop
Stop
```

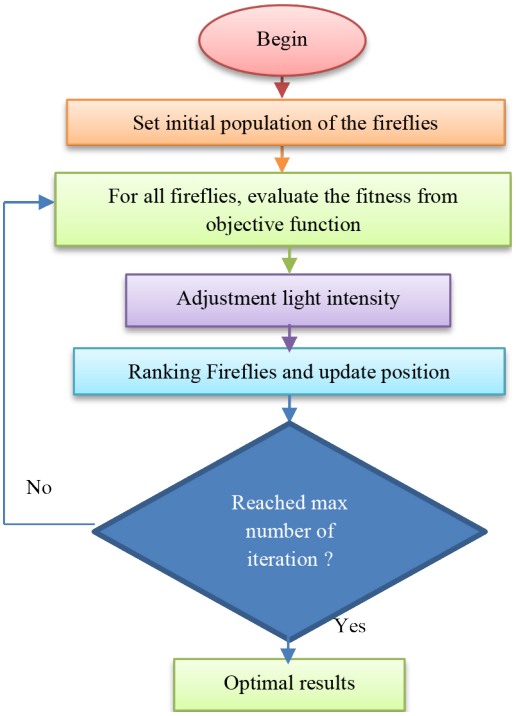


**Fig. 1** FA Flowchart

## 4 Proposed methods

When hybridizing swarm algorithm with fuzzy logic, then produced a proposed fuzzy swarm algorithm, such as, in this work we combined the fuzzy membership function with a firefly algorithm to produce a new method called a fuzzy firefly algorithm (FFA). And that's when the fuzzy membership function $S_i$ is added to equation of updating the movement of the firefly, the new equation is become as shown in Eq. (6):

$$p_i^{t+1} = p_i^t + S_i\beta_o e^{-\gamma dis_{ij}^2}\left(p_j^t - p_i^t\right) + \alpha\varepsilon_i. \tag{6}$$

Where $S_i$ is the fuzzy membership function given by

$$S_i = \left(\mu_{ik}\right)^m$$

$$\mu_{ik} = \frac{1}{\sum_{j=1}^{c}\left(\frac{D_{ik}}{D_{jk}}\right)^{\frac{2}{(m-1)}}}, \tag{7}$$

where $m$ denotes a real number >1 which is represented the fuzzy generator, $S_i$ is the fuzzy membership function depends on the $m$. And the range of membership function values between (0-1). To speed up the work of the firefly and improve its performance, here in this research it was hybridized with a fuzzy logic by adding the fuzzy membership function to the equation of updating the movement of the firefly that depends on attracting, which plays a large role in determining whether the firefly will go to the best solution.

In neural networks consist of a simple element (nodes) that operating in parallel. These elements are mimicking biological nervous systems. By the connections between elements the network function is determined, as in nature, and by adjusting the weights connections between nodes we can train the artificial neural network to execute a particular function. Here we used a perceptron neural network. The perceptron neural network consists of input layer that has a number of neurons at which receive the data from the outside world, and these neurons are linked with all neurons in the output layer by the connections called weights. The network is trained on this data, and the network weights are adjusted to reduce error and reach solution [25, 26].

The hybridization process of the neural network with fuzzy logic was done by adding the membership function to the equation for adjusting the weights, which plays a major role in the network balance process and obtaining the best solutions and the following equations explain this: Update weights that connected nodes between input layer and output layer as in Eqs. (8)–(10):

$$W_{\text{ij}}^{\text{new}} = W_{ij}^{\text{old}} + \Delta W_{ij} \tag{8}$$

$$\Delta W_{ij} = F_i(t)\partial * e_i * E_i \tag{9}$$

$$F_i = \left(\mu_{ik}\right)^m. \tag{10}$$

Where $F_i$ is the fuzzy membership function, $W_{ij}^{\text{old}}$ represent the old weight of the perceptron neural netwok, $\Delta W_{ij}$ refers to the change in the weights of the network, $\partial$ is the value of the learning rate, $e_i$ represent the input of the neural network. And $E_i$ denots the difference between actual output and target output.

In this paper, the fuzzy neural network was used to perform the image enhancement process by removing noise and removing corrupt from the images. This was done by taking a window of image data containing noise and entering it into the neural network and producing an enhanced pixel. A fuzzy supervised algorithm was used to enhance the images, as by adding a membership function to the neural network and producing a new method called fuzzy perceptron neural network, it enhanced the work performance and increased the image accuracy.

Where the target of perceptron network is the midpoint value of the specified window for the pixel to be treated from the noise. Whereas, the value of the target is calculated for each pixel by adopting the values of the midpoint filter. Thus, when implementing this method, the best results are obtained.

**5 Quality measures**

Efficiency measures between the input image and the resulting image are Root Mean-Square Error (RMSE), Peak-Signal to Noise Ratio (PSNR). Gray image efficiency measures RMSE and PSNR in Eq. (11) and Eq. (12) [27–29]:

$$\text{RMSE} = \sqrt{\frac{1}{N^2}\sum_{x=1}^{N}\sum_{y=1}^{N}\left[f(x,y) - f'(x,y)\right]^2}, \tag{11}$$

where $f(x, y)$ represent the orginal image, and $f'(x, y)$ denotes the enhane image;

$$\text{PSNR} = 10\log_{10}\frac{255\times 255}{\text{RMSE}^2}. \tag{12}$$

255 represent the largest value of the gray level in the image that processed.

And efficiency measures RMSE in color image as follows:

$$\text{RMSE}_{\text{H}} = \sqrt{\frac{1}{3}\left(\text{RMSE}_{\text{R}}^2 + \text{RMSE}_{\text{G}}^2 + \text{RMSE}_{\text{B}}^2\right)}, \tag{13}$$

this equation for $\text{RMSE}_{\text{R}}$, $\text{RMSE}_{\text{B}}$ and $\text{RMSE}_{\text{G}}$. And $\text{RMSE}_{\text{R}}$, $\text{RMSE}_{\text{B}}$ and $\text{RMSE}_{\text{G}}$ result the $\text{RMSE}_{\text{H}}$ for complete color image.

And efficiency measures PSNR in color image as follows: $\text{PSNR}_{\text{color}} = 10\log_{10}\left(\frac{255^2}{\text{MSE}_{\text{color}}}\right)\text{dB}$, where $\text{MSE}_{\text{color}} = \frac{1}{N}\left(x_{jk} - y_{jk}\right)^2$, this equation to each color (red, green, blue) for the image:

$$\text{PSNR} = \frac{\text{PSNR}_{\text{red}} + \text{PSNR}_{\text{green}} + \text{PSNR}_{\text{blue}}}{3}. \tag{14}$$

## 6 Experiment results

In this paper, we have used four methods which are firefly optimization algorithm (FA), perceptron neural network algorithm (PNN), and the new methods, fuzzy firefly algorithm (FFA), fuzzy perceptron neural network (FPNN) which we have obtained it, after adding fuzzy membership function to the algorithms of (FA and PNN). Four methods were applied into different corrupted or distorted images (gray and colored images) to enhance it and de-noise from them. Fig. 2 shows image samples used in this research to demonstrate the strength of the new method, as the shape contains the original image and the distorted image using different ratios of noise such as salt and pepper noise and gaussian noise.

The RMSE and PSNR values were computed for images as shown in Tables 1–6. And the (FFA) method obtained the best performance and high efficiency, as it got the highest rate (PSNR) and smallest (RMSE) among the methods used in this research, as shown in the tables below. And Figs. 3–8 show the corrupted images and the results methods PNN, FA, FPNN, FFA that enhanced these images.

In this work, the firefly algorithm was applied after adding the midpoint filter to the fitness function, which helped in the process of enhancing the image and increasing the accuracy in removing the corrupt from the image, and then the firefly algorithm was improved by adding the fuzzy membership function, which led to the speed of the work and access to the best global solution. Also, the perceptron network was applied and this network improved by adding the fuzzy membership function to the adjusting weight equation for this network, which obtained satisfactory work accuracy

(a)

(b)

**Fig. 2** Image samples: (a) original images, (b) corrupted images

**Table 1** PSNR, RMSE for (FA, PNN, FFA, FPNN) methods at tomatoes image

| Measures | Methods | | | |
|---|---|---|---|---|
| | PNN | FA | FPNN | FFA |
| RMSE | 1.978495 | 0.946798 | 0.443020 | 0.336153 |
| PSNR | 42.768585 | 49.304357 | 57.092582 | 59.484703 |

**Table 2** PSNR, RMSE for (FA, PNN, FFA, FPNN) methods at gnocchi image

| Measures | Methods | | | |
|---|---|---|---|---|
| | PNN | FA | FPNN | FFA |
| RMSE | 0.888787 | 0.576586 | 0.260534 | 0.205426 |
| PSNR | 49.308476 | 53.141847 | 60.370956 | 62.737723 |

**Table 3** PSNR, RMSE for (FA, PNN, FFA, FPNN) methods at flower image

| Measures | Methods | | | |
|---|---|---|---|---|
| | PNN | FA | FPNN | FFA |
| RMSE | 1.020357 | 0.829426 | 0.706296 | 0.482812 |
| PSNR | 48.244066 | 49.934394 | 51.316915 | 54.757313 |

**Table 4** PSNR, RMSE for (FA, PNN, FFA, FPNN) methods at carrots image

| Measures | Methods | | | |
|---|---|---|---|---|
| | PNN | FA | FPNN | FFA |
| RMSE | 2.464335 | 1.444056 | 0.631878 | 0.485735 |
| PSNR | 41.031435 | 46.112672 | 56.596619 | 59.727109 |

**Table 5** PSNR, RMSE for (FA, PNN, FFA, FPNN) methods at girl image

| Measures | Methods | | | |
|---|---|---|---|---|
| | PNN | FA | FPNN | FFA |
| RMSE | 1.376700 | 0.855286 | 0.646023 | 0.534739 |
| PSNR | 45.354014 | 49.488570 | 51.925844 | 53.567965 |

**Table 6** PSNR, RMSE for (FA, PNN, FFA, FPNN) methods at nature image

| Measures | Methods | | | |
|---|---|---|---|---|
| | PNN | FA | FPNN | FFA |
| RMSE | 3.437904 | 3.239791 | 0.366627 | 0.186951 |
| PSNR | 42.768075 | 43.025642 | 52.488594 | 55.413780 |

(a) (b) (c) (d) (e)

**Fig. 3** Results of tomatoes image with four methods (PNN, FA, FPNN, FFA), (a) corrupted image, (b) enhanced image with PNN, (c) enhanced image with FA, (d) enhanced image with FPNN, (e) enhanced image with FFA

(a) (b) (c) (d) (e)

**Fig. 4** Results of gnocchi image with four methods (PNN, FA, FPNN, FFA), (a) corrupted image, (b) enhanced image with PNN, (c) enhanced image with FA, (d) enhanced image with FPNN, (e) enhanced image with FFA

(a) (b) (c) (d) (e)

**Fig. 5** Results of flower image with four methods (PNN, FA, FPNN, FFA), (a) corrupted image, (b) enhanced image with PNN, (c) enhanced image with FA, (d) enhanced image with FPNN, (e) enhanced image with FFA

(a) (b) (c) (d) (e)

**Fig. 6** Results of carrots image with four methods (PNN, FA, FPNN, FFA), (a) corrupted image, (b) enhanced image with PNN, (c) enhanced image with FA, (d) enhanced image with FPNN, (e) enhanced image with FFA

(a) (b) (c) (d) (e)

**Fig. 7** Results of girl image with four methods (PNN, FA, FPNN, FFA), (a) corrupted image, (b) enhanced image with PNN, (c) enhanced image with FA, (d) enhanced image with FPNN, (e) enhanced image with FFA

(a) (b) (c) (d) (e)

**Fig. 8** Results of nature image with four methods (PNN, FA, FPNN, FFA), (a) corrupted image, (b) enhanced image with PNN, (c) enhanced image with FA, (d) enhanced image with FPNN, (e) enhanced image with FFA

in removing noise from distorted images. These four methods applied in this work obtained a PSNR ranges between (41.031435–62.737723) and an RMSE ratio (0.186951–3.437904). While in previous works in [16] the percentage of PSNR ranged between (37.348–37.9968) using PSO, ACO, and SVD methods. And in [22] using PSO-MSR, ABC-MSR, CS-MSR methods, the PSNR ratio ranged between (2.749–3.928) and the RMSE value ranged between (44.027–45.961). In [23] using PSO, ABC methods, the PSNR was between (23.85–27.62). Therefore, the methods proposed in this work were the best compared to the previous methods.

## 5 Conclusion

The focus of this paper is mainly on the use of artificial intelligence techniques, such as the Firefly algorithm, which is one of the Meta-Heuristic algorithms that adopt the behavior of swarms. And perceptron network that is a supervised training algorithm. It is used to enhance the images and remove noise and corrupt from the images. Different distorted images have been used with different distortion ratios. And to image enhancement we have presented meta-heuristic algorithm represented by firefly algorithm, and also used artificial neural network that represented by perceptron neural network (PNN) algorithm, and then combined the fuzzy membership function to standard FA and PNN to produced two proposed methods called fuzzy firefly algorithm and fuzzy perceptron neural network (FPNN) algorithm. To compare performance of these methods we used different corrupted or distorted images. We used these four methods for enhanced and de-noise from these corrupted images to make it clearer. The proposed method FFA shows better efficiency and performance in terms PSNR, RMSE compared to other methods (PNN, FA, FPNN) used in this paper.

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