An Improved Artificial Neural Network Design for Face Recognition utilizing Harmony Search Algorithm

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Abstract. Face recognition has become an interesting field for researchers where it is used in many applications. One of the most common methods of soft computing is named the artificial neural network (ANN) has been suggested to achieve the face recognition process. Nonetheless, the performance of ANN depends on the number of neurons in the hidden layers and the value of the learning rate. These variables are usually defined based on the trial and error method which is time-consuming. Furthermore, in many cases, it is very difficult to find the optimum value for these variables. Hence, to improve the performance of the ANN for the face recognition process, the optimization algorithm is needed to get promising outcomes. Therefore, this paper introduces an improved ANN design for face recognition using a meta-heuristic optimization algorithm. The ANN represents a distributed processing system consists of neurons which are simply connected elements. One of the most popular techniques for pattern recognition called back propagation algorithm (BP) is used to train the ANN (BP-ANN) to achieve the face recognition process. To enhance the face recognition system performance, the ANN has been hybridized with the well-known meta-heuristic optimization algorithm namely harmony search algorithm (HSA). The HSA based on the principle work of musicians to find the best harmonies. This technique is implemented based on the results of the fitness function evaluation. In this research, the mean squared error (MSE) has been used as a fitness function. The HSA optimizes the ANN such that the face recognition system provides the lowest MSE and thus enhances the performance of the face recognition system. The accuracy of the optimum hybrid system (HSA-ANN) is investigated using the MATLAB environment conducted for 10 persons. The results revealed that the proposed system (HSA-ANN) achieved lower MSE compare with the ANN. Furthermore, the HSA-ANN gives a better face recognition rate than traditional ANN.

1. Introduction

Biometric system represents the pattern recognition system that can be executed by extracting the feature of biometric data from persons and then compares this feature with a set of templates that already saved in the database [1]. One of the most important biometrics approaches is face recognition. It's defined as the system ability to describe or classify the face of the human. The inspiration for such the system is to give computers the ability to perform works such as human do. Furthermore, apply computers to find a solution to the problems that involve classification and analysis. Face recognition research become one of the most intriguing research areas such as computer vision, processing of image, biometric technology, pattern recognition and so on [2, 3]. Recently, artificial intelligence (AI), such as fuzzy logic controller (FLC), adaptive neuro-fuzzy inference system (ANFIS) and random forest (RF), has become increasingly popular in the face recognition system [4, 5, 6]. However, the performance of FLC depends on its rule set and membership functions (MFs). These parameters are usually defined by a trial and error method, which is time-consuming [7]. Thus, several techniques have been mentioned in the previous studies to overcome these limitations in FLC. The ANFIS is one of these methods to determine optimal FLC [8]. However, the more
computational process is one of the ANFIS drawbacks. Another AI technique is RF. However, the complexity of the RF is the main drawbacks. Furthermore, the decision tree needs long training time which is time-consuming. The artificial neural network (ANN) represents one of the most common methods in electronic training systems. It’s trained to achieve complex functions in different applications such as detection and classification of pattern [9]. Different methods were used in the literature to train the ANN such as the back-propagation algorithm (BP) [10]. BP represents one of the most common neural network training algorithms. It has a good ability to self-learning, self-adjustment, generalization, and strength. It has been widely utilized in various applications, such as image processing, pattern recognition, and approximation of function and so on [11]. However, the performance of the ANN depends on the value of learning rate and the number of neurons in the hidden layers. These parameters usually determined by trial and error. Therefore, the optimization algorithms have been proposed to defeat the drawbacks of ANN. Many optimization methods have been mentioned in the literature [12].

The particle swarm optimization (PSO) algorithm is swarm intelligence which is introduced by Kennedy and Eberhart. It’s inspired by the social behavior of birds fly. The PSO uses several particles that flying in the search space to get the optimum solutions [13]. The cuckoo search algorithm (CSA) is a nature-inspired meta-heuristic. The CSA was inspired by the lifestyle of cuckoo birds. The egg laying and breeding attributes of cuckoos are the principal concepts used in this algorithm [14]. The genetic algorithm (GA) is an evolutionary algorithm mimics the biological genetic process of organisms. It consists of several solutions called individuals or chromosomes [15]. The differential evolution algorithm (DEA) is a population-based method that enhances the mathematical vectors to solve optimization problems [16]. However, these optimization methods have been limited by factors such as premature convergence and trapping in a local minimum [17].

In this study, an improved ANN for face recognition system using harmony search algorithm (HSA) is proposed. The HSA is a meta-heuristic algorithm inspired by the improvisation performance of musicians to find better harmony. The main characteristic of HSA is to find better solutions with fewer iterations [18]. In this paper, HSA has been hybridized with ANN to find the optimum number of neurons in each hidden layer and the value of the learning rate to increase the efficiency of the implemented face recognition system and overcome the problem of time-consuming.

This paper is classified as follows: section 2 represents the artificial neural network. The proposed human face recognition based on ANN has been mentioned in Section 3. Section 4 described the harmony search algorithm; meanwhile, problem formulation of the optimum ANN has been illustrated in section 5. Implementation of the HSA to obtain the optimum ANN displayed in section 6. The results have been depicted and discussed in Section 7. Finally, the conclusion has been conducted in section 8.

2. Artificial neural network

An artificial neural network (ANN) is a powerful information processing tool that mimics the principle work of the human brain. The structure of the ANN comprises a large number of simple elements called neurons or nodes associated with the connections which are passing the signals from the input layer to the output layer. Several types of artificial neural networks (ANNs) were mentioned in the previous studies such as the Adaline network, perceptron network, Hebb network, probabilistic network, and back-propagation artificial neural network (BP-ANN) [19]. The BP-ANN is a multilayer, feed-forward, supervised algorithm. It is firstly proposed by Paul Werbos in 1970 and rediscovered again in 1986 by Rumelhart and McClelland [20]. Its network architecture composed of an input layer, one or more hidden layers, and an output layer. The connections between neurons of layers represent the weights of the network. Typically, the training section of BP-ANN passes into two directions called forward and backward directions. The training data is fed to the network from the input layer to the output layer during the forward direction. Therefore, an intermediate output has been generated at the hidden layers and output of the network at the output layer [21]. Then, the actual network's output computed at the output layer is compared with the target output that already trained in the neural network. Therefore, the difference between actual output and target output represents the error of the
network [22]. The mean square error (MSE) equation has been used to define this error as shown below:

\[
\text{MSE} = \frac{1}{n} \sum_{i=1}^{n} (T_i - Y_i)^2
\]

(1)

where \(T_i\) represent the target output, \(Y_i\) represents the actual output of the network, and \(n\) represent the number of network samples [23]. When forward direction completed the backward direction has been started during this direction the error signal fed back towards the lower layer of the network. At each layer of the network, the error signal has been calculated and fed back again to the layer below. Then, the weights of the network are updated after the generation of error signals [21].

3. The proposed human face recognition based on ANN

The proposed system has been implemented to recognize 10 persons using the ANN. This system consists of four stages, which are the detection and pre-processing stage, the training stage, implementation of the ANN stage, and the testing stage. In the detection and pre-processing stage, the face region is detected from the entire image and applies some operations on it to prepare it for the training stage. The most common features extraction method called the principal component analysis algorithm (PCA) has been used to extract the important features from the face image and convert it to the vector format. In this work, each face image is represented by a 1 x 100 feature vector. The implemented ANN has been used to recognize 10 persons as described above, each one with 10 images. In ANN, the number of outputs must be equal to the number of persons to be recognized. To reduce system complexity, the lookup table has been used in this paper as shown in table 1 below. Hence, only 4 outputs have been used instead of 10 outputs. Therefore, the dataset of the proposed system contains 100 samples, with 100 inputs and 4 outputs.

| Target Person | Y1 | Y2 | Y3 | Y4 |
|----------------|----|----|----|----|
| Dima           | 0  | 0  | 0  | 0  |
| Abdulazeez     | 0  | 0  | 0  | 1  |
| Mohammed       | 0  | 0  | 1  | 0  |
| Reem           | 0  | 0  | 1  | 1  |
| Mostafa        | 0  | 1  | 0  | 0  |
| Jumana         | 0  | 1  | 0  | 1  |
| Teeba          | 0  | 1  | 1  | 0  |
| Ibraheem       | 0  | 1  | 1  | 1  |
| Rania          | 1  | 0  | 0  | 0  |
| Hala           | 1  | 0  | 0  | 1  |
In the training stage, the MATLAB environment has been used to implement the physical feed-forward back-propagation neural network. This neural network has been fed and trained with the dataset that already computed in the pre-processing stage. Regarding the implementation of the ANN stage, the proposed architecture of ANN model for face recognition system is shown in Figure 1. It consists of four layers; input layer, two hidden layers, and an output layer which are 100-55-55-4 neurons, respectively. The parameters of the ANN must be defined before the training and testing process of data. These parameters are represented by the input layer, number of neurons in each hidden layer, an output layer, and also the value of the learning rate. The number of neurons in the input layer equals to the number of inputs. Therefore, in this study, the number of neurons in the input layer is 100 neurons. Meanwhile, the number of neurons in the output layer is equal to the number of outputs which is 4 neurons only. Regarding the number of neurons in each hidden layer and the value of learning rate, these values are determined based on the trial and error procedure.

The trained ANN is evaluated using the mean square error (MSE). The aim is to decrease the value of MSE as possible to get the better performance of ANN. After the training process, the proposed face recognition system is tested in the testing stage with number of selected images to evaluate its performance. In this work, 50 images have been used for this purpose. The selected testing image is also converted to a 1x100 feature vector and given to the trained neural network. The proposed system classified the input feature vector as known or unknown.

**4. Harmony search algorithm**

As shown in the design procedures of the traditional ANN, the main disadvantage of the ANN design is the consuming of the time due to the using of trial and error method to adjust the parameters of ANN such as the number of neurons in each hidden layer and also the value of learning rate. Incorrect choice of these parameters may lead to the poor system performance. Thus, this paper presents a methodology for optimizing a tuning of these parameters utilizing a meta-heuristic optimization method. The meta-heuristic optimization method was utilized to solve the complex problems which are become more difficult to solve them by using the traditional techniques. They are population-based
methods produced to solve the problem more quickly or to get a good solution when traditional
techniques fail to get it.
The harmony search algorithm (HSA) was proposed as a meta-heuristic optimization method for
tuning the number of neurons in each hidden layer and the value of learning rate to optimize the ANN
and thus, improving the efficiency of the overall system of face recognition.
Harmony search is a meta-heuristic optimization method introduced in 2001 by Geem et al. It mimics
the improvisation process of harmony in music composition to find the better case of harmony [24].
The HSA has its advantages made it more preferred than other optimization methods such as great
ability to find the global optimum solution with fewer iterations and simplicity of its implementation.
For this reason, HSA has been received growing interest among researchers and it has been widely
applied for several problems of engineering optimization. The HSA uses harmony memory
considering rate (HMCR) and pitch adjusting rate (PAR) to find the solution vector namely harmony
or population in the searching space [25]. In general, the optimization process of the harmony search
algorithm divided into four steps as described in the following subsection [26].

4.1. Initialize harmony memory (HM)
The harmony memory represents a population matrix with the size of harmony memory size (HMS).
Where each harmony in the memory is a m-dimensional input vector in the searching space. In general, the input vector Z can be expressed as:

\[ Z_{ij} = [X_{ij1} X_{ij2} \ldots X_{ijm}] \]  

where \( Z_{ij} \) represents the \( j \)th solution in the population matrix during the \( i \)th iteration, \( X_{ij}^p \) is the \( p \)th element of \( Z_{ij} \), and \( m \) is the total number of parameters. Each element in \( Z_{ij} \) has been generated randomly as shown blow:

\[ X_{ij}^p = X_{ij}^{p\min} + \left( X_{ij}^{p\max} - X_{ij}^{p\min} \right) \times r(0,1) \]  

where \( i =1,2,\ldots,\text{HMS} \); \( j =1,2,\ldots,m \); \( X_{ij}^{p\min} \) and \( X_{ij}^{p\max} \) are the lower and upper bound of \( p \)th element respectively.

4.2. Improvisation process of new harmony
A new harmony input vector \( Y_{ij} = [A_{ij1} A_{ij2} \ldots A_{ijm}] \) has been generated from the harmony memory based on the memory considerations, randomization, and pitch adjustments. In the consideration of memory, the \( p \)th element of \( Y_{ij} \) vector has been selected randomly from HM with HMCR probability. Where \( \text{HMCR} \in [0,1] \). This consideration of memory expressed as follows:

\[ A_{ij}^p = \begin{cases} A_{ij}^p & \text{if } r \leq \text{HMCR} \\ X_{ij}^{p\min} + \left( X_{ij}^{p\max} - X_{ij}^{p\min} \right) \times r(0,1) & \text{otherwise} \end{cases} \]  

Moreover, the elements in the new harmony vector obtained from the HM is modified utilizing the
PAR to find the good solution vector in the searching space. These elements have been adjusted and
tuning using the probability of PAR as described below:

\[ A_{ij}^p = \begin{cases} A_{ij}^p & \text{if } r \leq \text{PAR} \\ A_{ij}^p \pm bw \times r(0,1) & \text{otherwise} \end{cases} \]
where \( bw \) represents the bandwidth-distance utilized for the variation in the decision variables; meanwhile, \( r (0, 1) \) represents the random number has been distributed uniformly between \([0, 1]\).

### 4.3. Updating of harmony memory

To update the harmony memory, the new harmony input vector \( (Y_{ij}) \) has been evaluated using the given fitness function. If the value of fitness function \( f(Y_{ij}) \) of \( Y_{ij} \) is better than \( f(Z_{ij\text{worst}}) \) of the worst harmony vector \( (Z_{ij\text{worst}}) \) has been stored in the harmony memory, then \( (Z_{ij\text{worst}}) \) replaced by \( (Y_{ij}) \). Otherwise, the generated new harmony vector has been ignored.

### 4.4. Stopping condition

The harmony search method has been terminated when the maximum number of improvisation (NI) is reached. Otherwise, step 3 and 4 still repeated.

### 5. Problem formulation of the optimum ANN

Typically, three essential components are necessary to any optimization technique which are the input vector, the fitness function, and also the optimization constraints. Every component has been developed and illuminated to obtain the optimum number of neurons in each hidden layer and the value of the learning rate. The optimization method seeks the optimum solution as mentioned in the fitness function.

#### 5.1. The Input vector

As the first step in ANN design, the dimension of the problem represented by the number of neurons in each hidden layer and the value of the learning rate must be specified to obtain the solution from the optimization method.

#### 5.2. The Fitness function

A fitness function is needed to define and assess the performance of the solution vector \( (Z_{ij}) \). Therefore, the fitness function to obtain the optimum values of ANN parameters is formed in such a way that \( Z_{ij} \) creates the best performance of ANN. The mean square error MSE (1) obtained from the target and measured output is used as the fitness function. In the optimization process, Equation (1) needs to be minimized.

#### 5.3. The optimization constraints

The optimization method must be performed while meeting all constraints utilized to define the optimum values of all parameters. Each parameter has its own boundaries. In other words, the element \( X_{ijp} \) should be between the lower band (LB) and upper band (UB). If the element \( X_{ijp} \) is greater than UB or less than LB. Therefore, this element must be regenerated inside its boundaries. The next constraint must be achieved to ensure that each parameter is inside the designated boundaries.

\[
\text{LB} \leq X_{ijp} \leq \text{UB}
\]  

### 6. Implementation of the HSA to obtain the optimum ANN

The implementation steps of HSA begins by resetting the HSA parameters called, number of improvisation (NI), number of populations or harmonies (HMS), number of parameters (m), and control parameters (HMCR, PAR\(_{\text{min}}\), PAR\(_{\text{max}}\)) with the following values 700, 10, 3, 0.9, 0.4, and 0.9 respectively. The initial populations for the problem represented by the number of neurons in each hidden layer and the value of the learning rate are generated according to Equation (2). After the creation of the original population, the HSA computes the fitness function for every input vector in the population matrix using Equation (1). The HSA algorithm update the population and starts a new improvisation. This process continued to the next improvisation and still repeated until the maximum
number of improvisation count is satisfied. Finally, when the HSA finished, the ANN with the best parameters has been obtained. In general, these steps can be represented in Figure 2 below:

![Proposed HSA-ANN design procedure](image)

**Figure 2.** Proposed HSA-ANN design procedure
7. Results and discussion

The ANN has been used to implement the proposed human face recognition system. In the training of
ANN, two parameters must be adjusted, namely, the learning rate and the number of neurons in
the hidden layer. The range value of the learning rate is greater than 0 and equal to or less than 1. Three
values of the learning rate which are 0.2, 0.4, and 0.8 have been tested in training ANN to determine
the appropriate learning rate value. The ANN with a learning rate of 0.4 gives the most accurate
results compared with other values. Regarding the hidden layer, the ANN was trained using 25, 55,
and 85 neurons. The appropriate neurons are found to be 55 neurons for both hidden layers. 50 images
have been used for testing the trained neural network. The ANN succeeded to recognize 41 images,
meanwhile; it failed to recognize 9 images. Therefore, the success recognition ratio is found to be
82%. However, the trial and error procedure used in the traditional ANN to find the optimum number
of neurons in the hidden layer and the value of the learning rate makes the process very complex and
take a long time. For this purpose, this paper suggests an optimization method to reduce the
consuming time and also increase the efficiency of the entire system by setting these values automatically. A comparison between two optimization methods has been discussed in terms of face
recognition system efficiency. Figure 3 below displays the convergence characteristics of the harmony
search algorithm based on ANN (HSA-ANN) in achieving the minimum fitness function (MSE) along
with the results achieved utilizing hybrid particle swarm optimization based on ANN (PSO-ANN). For
fair comparison, the same general parameters have been used in both optimization methods such as the
number of improvisation, number of parameters, and the number of population. While the control
parameters of the PSO algorithm which are a cognitive parameter (c1), social parameter(c2), and
inertia weight (w) selected to be 2, 2, and 0.5 respectively. Figure 3 also shows that HSA-ANN
generates the minimum fitness function compared with PSO-ANN. Moreover, the time consumed by
the PSO-ANN to find the optimum parameters is around five times that consumed by the HSA-ANN.

Figure 3. The convergence characteristics of HSA-ANN and PSO-ANN
Table 2 below shows the number of neurons in each hidden layer and the learning rate has been obtained from the implementation of both optimization methods based on the minimum fitness function.

| Parameters                                | HSA-ANN | PSO-ANN |
|--------------------------------------------|---------|---------|
| Number of neurons in the first hidden layer| 94      | 37      |
| Number of neurons in the second hidden layer| 96      | 75      |
| The learning rate                          | 0.0659  | 0.7169  |

Then, the ANN has been trained and tested utilizing the new parameters that accomplished the minimum fitness function. Hence, these parameters improved the operation of the ANN. Therefore, the HSA-ANN method increasing the rate of the system compared with the traditional ANN as shown in table 3 below.

| Method         | Total Images | Correctly Recognized | Not-Correctly Recognized | Success Ratio | False Accept Ratio (FAR) | False Reject Ratio (FRR) |
|----------------|--------------|----------------------|--------------------------|---------------|--------------------------|--------------------------|
| Traditional ANN| 50           | 41                   | 9                        | 82%           | 12%                      | 6%                       |
| Hybrid HSA-ANN | 50           | 47                   | 3                        | 94%           | 4%                       | 2%                       |

8. Conclusion
In this paper, the ANN-based optimization approach for face recognition using the HSA has been introduced. This method was developed to automatically optimize the ANN utilized in the proposed face recognition system. Therefore, the desired output can be obtained if the ANN can be effectively optimized by a renowned optimization algorithm. A suitable fitness function (MSE) is utilized to tune the proposed ANN used in the face recognition system. A well-known optimization algorithm named HSA has been used to hybrid with ANN (HSA-ANN). The proposed system has been coded in MATLAB environment. The hybrid HSA-ANN has been proposed for the face recognition system to find the optimum number of neurons in each hidden layer and the value of learning rate which in turn increases the efficiency of the system. The numbers of images that have been used for testing are 50 images. The results show that the HSA-ANN outperforms the traditional ANN in terms of minimum MSE. The face recognition ratio that has been achieved using the proposed HSA-ANN is 94%. While
the recognition ratio achieved using the traditional ANN was 82%. Thus, the efficiency of the face recognition system has been improved using the proposed HSA-ANN method.

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