Interval type-2 fuzzy logic gravitational search algorithm for the optimization of modular neural networks in echocardiogram recognition

Beatriz González, Patricia Melin and Fevrier Valdez
Tijuana Institute of Technology
Tijuana, Mexico
E-mail: betygm8@hotmail.com, pmelin@tectijuana.mx, fevrier@tectijuana.mx

German Prado-Arechiga
Cardio-Diagnostico,
Paseo de los Heroes No. 2507,
Zona Rio, Tijuana, Mexico

***Abstract*— Research in echocardiogram imaging it's very important because it allows assessing both anatomy and cardiac function, help diagnose various diseases. In this paper to find the optimal architecture of a MNN, where means finding the number of layers and nodes. In this case the Type-2 fuzzy logic gravitational search algorithm is used for optimizing the MNN for pattern recognition in echocardiogram imaging.**

Keywords— echocardiography images, GSA, MNN.

I. INTRODUCTION

The algorithms inspired of natural phenomena [1, 2, 3, 4, 5], are suited to solve computational problems, for example the optimization [6], pattern recognition [7], optimization of modular neural networks [8, 9, 10, 11, 12, 13, 14] etc. The Algorithm GSA is based in populations; this algorithm is based on law the Newton. The agents are the objects and the heavy masses are good solutions because move more slowly than lighter ones, this guarantees the exploitation [15]. Some works most relevant of the algorithm GSA are [16, 17].

Echocardiography is an imaging technique performed with ultrasound, which allows assessing both anatomy and cardiac function and these images are used to help diagnose problems with the heart.

However, we proposed in this work the use of system Mamdani with type-2 fuzzy logic in the gravitational search algorithm (FGSA) to change the alpha parameter [18, 19], and encounter the optimal architecture of MNN for a pattern recognition application in echocardiography images. A comparison between type-2 fuzzy logic system with triangular membership function (images with preprocessing) and the method type-2 fuzzy logic system with Gaussian membership functions (images with preprocessing).

This paper is organized this way: in Section II show concepts, in Section III proposed method, in Section IV the architecture of the proposed, in Section V results are presented and in Section VI conclusions.

II. GRAVITATIONAL SEARCH ALGORITHM

Esmat Rashedi [15] proposed in year 2009 an algorithm called the GSA inspired in of the laws of Newton: the law of gravitation and motion [15].

A. *Law of gravitational forces*

The gravitational force between two particles is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. In the Equation (1) is represented the gravity law:

$$F = G\frac{M_1 M_2}{R^2} \quad (1)$$

In the Equation (1), F is the gravitational force, G is a physic constant, which determines the intensity of the force between the objects, M_1 and M_2 are the masses of the first and second particles and R is the distance between the two particles.

B. *Motion law*

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass [15] is represented in Equation (2):

$$\alpha = \frac{F}{M} \quad (2)$$

In Equation (2), a is the acceleration, F is the gravitational force and M is the mass of the object.

C. *Generate initial population*

To explain the algorithm GSA, in the Equation (3) the position of each object is a solution for the problem.

$$X_i = \left(X_i^1, \ldots, X_i^d, \ldots, X_i^n\right) \text{ for } i = 1, 2, \ldots, N, \quad (3)$$

N represented the number of objects are initialized and x_i^d is the position of the ith object in the dth dimension:

D. Evaluate the fitness

In the Equation (4) presented the *best* (t) and Equation(5)presented worst (t) for a minimization problem.

$$\mathrm{best}(t) = \min_{j\in\{1,\dots,N\}} \mathrm{fit}_j(t) \qquad (4)$$

$$\mathrm{worst}(t) = \max_{j\in\{1,\dots,N\}} \mathrm{fit}_j(t) \qquad (5)$$

In the Equation (6) presented the *best* (t) and in Equation (7) presented *worst*(t) for a maximization problem.

$$\mathrm{best}(t) = \min_{j\in\{1,\dots,N\}} \mathrm{fit}_j(t) \qquad (6)$$

$$worst(t) = \min_{j\in\{1,\dots,N\}} fit_j(t) \qquad (7)$$

E. Gravitational constant

Where G is a physic constant, which determines the intensity of the gravitational force between the objects are calculated as follows:

$$G(t) = G_0 e^{-\alpha\, t/T} (8)$$

F. Masses of the agents

Masses for each agent are calculated in the Equation (9) and (10).

$$\mathrm{m_i}(t) = \frac{\mathrm{fit_i(t)-worst(t)}}{\mathrm{best\ \ (t)-worst(t)}} \qquad (9)$$

$$M_i(t) = \frac{m_i\,(t)}{\sum_{j=1}^{N} m_j(t)} (10)$$

G. Accelerations of agents' calculation

In the Equation (11) is calculated total force in dimension d that acts on object i.

$$F_i^d(t) = \sum_{j\epsilon kbest, j\neq i} rand_j\, F_{ij}^d(t) \qquad (11)$$

where $\mathrm{rand_j}$ is a random number between [0, 1].

Acceleration of the ith agents at iteration *t* is computed

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} (12)$$

H. Velocity and positions of agents

In the Equation (13) is calculated the velocity, in the Equation (14) is calculated position of the objects.

$$\mathrm{V_i^d}(t+1) = \mathrm{rand_i}\ \mathrm{x}\ \mathrm{V_i^d}(t) + \mathrm{a_i^d}\ (t)\ (13)$$

$$\mathrm{X_i^d}(t+1) = \mathrm{X_i^d}(t) + \mathrm{V_i^d}(t+1)(14)$$

The process the algorithm GSA is presented in Fig. 1.

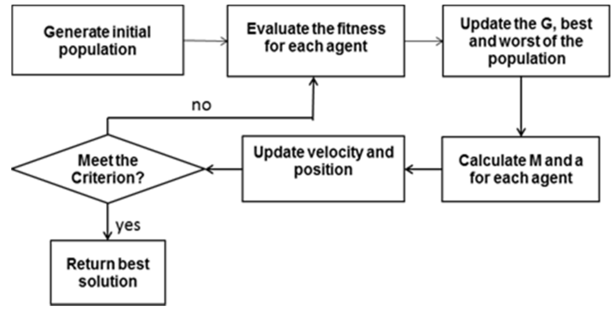

Fig. 1. Process gravitational search algorithm in [15]

III. METHOD PROPOSED

In first iterations we have a small alpha and a high G value in order to apply a force and acceleration in large quantities, helping the exploration, and in later iterations we have to give a high alpha value and small G value to help the algorithm with the exploitation task.

A. Interval type-2 fuzzy logic with triangular membership functions

In

Fig. 2. Show the proposed approach, a Mamdani fuzzy system to dynamically obtain the value of alpha.

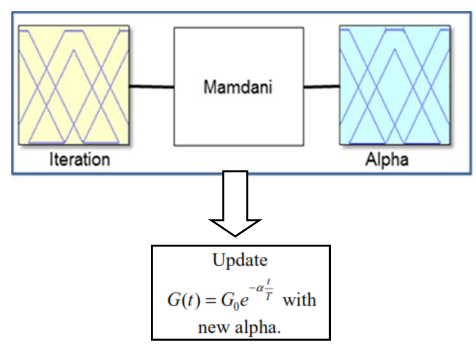

Fig. 2. Representation of the approachuse a Mamdani fuzzy system with triangular functions.

If we change the alpha value, the algorithm apply a different G value, and to change its acceleration, to agents explore other good solutions in the search space and improve the final result.

Shown in the Fig. 3.The input variable is number of iterations

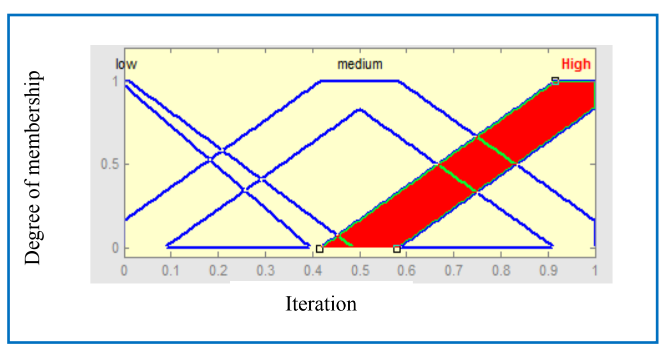

Fig. 3. Input variable with triangular membership functions

Shown in Fig. 4.The output variable is the alpha value

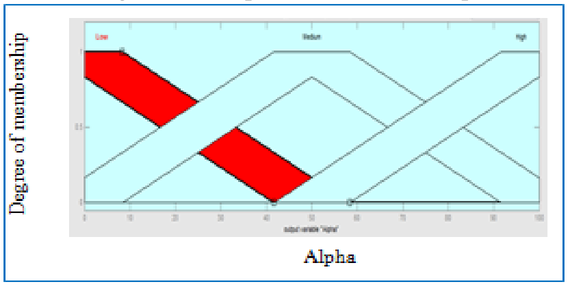

Fig. 4. Output variable is the alpha value with triangular functions

The fuzzy rules are:

1. If (Iteracion is Bajo) then (Alfa is Bajo) (1)
2. If (Iteracion is Medio) then (Alfa is Medio) (1)
3. If (Iteracion is Bajo) then (Alfa is Bajo) (1)

B. *Interval type-2 fuzzy logic with Gaussian functions*

In Fig. 5.Show the proposed approach, a Mamdani fuzzy system to dynamically obtain the value of alpha.

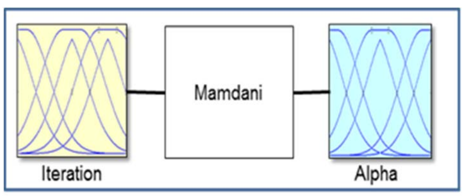

Fig. 5. Representation of the approachuse a Mamdani fuzzy system with Gaussian functions.

Shown in Fig.6.The input variable is number of iterations

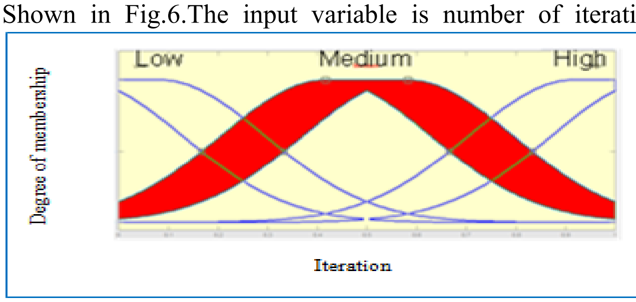

Fig. 6. Input variable with Gaussian membership functions

Shown in Fig. 7.The output variable is the alpha value

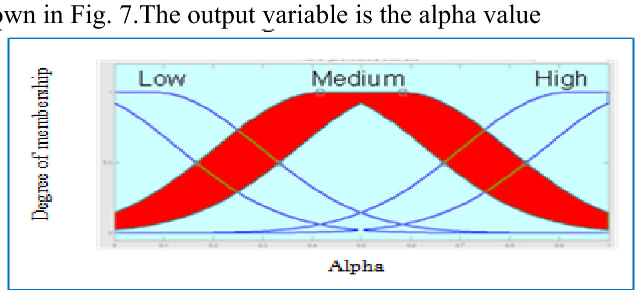

Fig. 7. Output variable is the alpha value with gaussian functions

The fuzzy rules are:

1. If (Iteracion is Bajo) then (Alfa is Bajo) (1)
2. If (Iteracion is Medio) then (Alfa is Medio) (1)
3. If (Iteracion is Bajo) then (Alfa is Bajo) (1)

IV. Architecture of the Proposed Method

The proposed method gravitational search algorithm for general optimization of MNN.

A. *Architecture of the proposed methodMNN*

The main dare is to locate the optimal architecture MNN for finding out the number layers and nodes of the MNN with the FGSA. In the Fig. 8 shows the architecture.

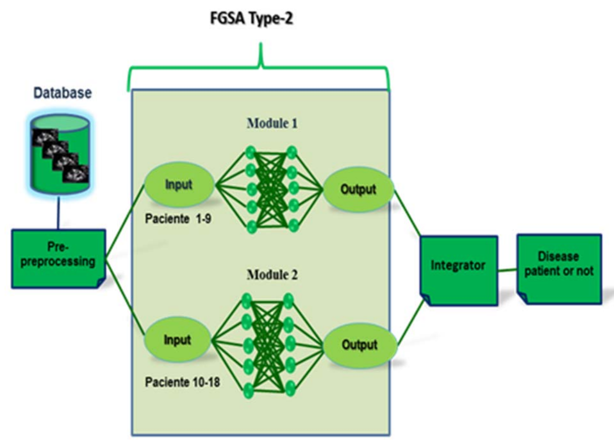

Fig. 8. The architecture of the proposed method

B. *Database for echocardiograms*

The database we use: it include data from eighteen patients, there are ten images per patient. A database with 180 images in the BMP, captured on September 30, 2014, and six images for training and four for testing, captured of the page www.CardiologyImages.com.

Fig. 9 Shows steps for images preprocessing, using only the region of interest (ROI).

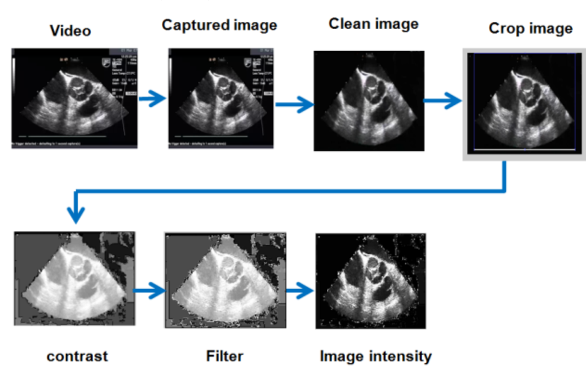

Fig. 9. Step for images processing

V. RESULTS

We present the results obtained with the proposed method.

In Table I we show results of FGSA with Type-2 fuzzy logic system with triangular membership functions with the scaled conjugate gradient (trainscg method) to increase the alpha value in the optimization of MNN (images with preprocessing).

TABLE I. RESULTS WITH TRIANGULAR FUNCTIONS AND THE TRAINSCG METHOD

Training	Neurons	Epoch	Error	% Rec.
1	16, 19	500	0.0001	100
2	27, 12	500	0.0001	100
3	24, 12	500	0.0001	100
4	16, 3	500	0.0001	100
5	12, 12	500	0.0001	100
6	9, 9	500	0.0001	100
7	13, 11	500	0.0001	98.61
8	11, 13	500	0.0001	100
9	13, 13	500	0.0001	100
10	17, 18	500	0.0001	100
11	15, 13	500	0.0001	100
12	11, 11	500	0.0001	98.61
13	10, 11	500	0.0001	94.44
14	11, 13	500	0.0001	97.22
15	10, 12	500	0.0001	100

In Table II we show results of the Type-2 fuzzy logic system with triangular membership functions with the gradient descent with adaptive learning (traingda method) to increase the alpha value for the optimization of MNN (images with preprocessing).

TABLE II. RESULTS WITH TRIANGULAR FUNCTIONS AND THE TRAINGDA METHOD

Training	Neurons	Epoch	Error	% Rec.
1	11, 5	500	0.0001	100
2	11, 8	500	0.0001	100
3	14, 13	500	0.0001	98.61
4	14, 15	500	0.0001	98.61
5	11, 13	500	0.0001	94.44
6	10, 15	500	0.0001	100
7	17, 15	500	0.0001	100
8	15, 15	500	0.0001	100
9	13, 10	500	0.0001	100
10	12, 13	500	0.0001	98.61
11	16, 12	500	0.0001	100
12	14, 14	500	0.0001	100
13	16, 19	500	0.0001	100
14	13, 10	500	0.0001	98.61
15	12, 13	500	0.0001	93.05

In Table III we show results of the Type-2 fuzzy logic system with triangular membership functions with the gradient descent with adaptive learning and momentum (traingdx method) to increase the alpha value for the optimization of MNN (images with preprocessing).

TABLE III. RESULTS WITH TRIANGULAR FUNCTIONS AND THE TRAINGDX METHOD

Training	Neurons	Epoch	Error	Training Time	% Rec.
1	18, 20	500	0.0001	00:26:40	98.61
2	15, 17	500	0.0001	00:24:25	94.44
3	16, 18	500	0.0001	00:25:11	100
4	16, 15	500	0.0001	00:24:40	100
5	15, 20	500	0.0001	00:27:26	100
6	14, 13	500	0.0001	00:24:04	98.61
7	18, 16	500	0.0001	00:27:55	100
8	15, 14	500	0.0001	00:23:53	100
9	14, 15	500	0.0001	00:23:13	97.22
10	12, 15	500	0.0001	00:23:33	98.61
11	15, 15	500	0.0001	00:23:01	100
12	13, 16	500	0.0001	00:22:59	94.44
13	15, 16	500	0.0001	00:27:27	100
14	14, 15	500	0.0001	00:23:31	100
15	15, 13	500	0.0001	00:24:13	95.83

In Table VI we show results of FGSA with Type-2 fuzzy logic system with triangular membership functions with the scaled conjugate gradient (trainscg method) to increase the alpha value in the optimization of MNN (images without preprocessing).

TABLE IV. RESULTS WITH TRIANGULAR FUNCTIONS AND THE TRAINSCG METHOD

Training	Neurons	Epoch	Error	Training Time	% Rec.
1	14, 14	500	0.0001	00:42:46	100
2	6 , 8	500	0.0001	00:29:45	88.8
3	7, 6	500	0.0001	00:24:45	98.6
4	5, 9	500	0.0001	00:24:15	90.2
5	7, 9	500	0.0001	00:22:07	88.8

6	8, 6	500	0.0001	00:32:49	77.7
7	6, 7	500	0.0001	00:29:00	81.9
8	8, 6	500	0.0001	00:21:21	83.3
9	8, 5	500	0.0001	00.23:35	80.5
10	10, 9	500	0.0001	00:25:28	94.4
11	8, 8	500	0.0001	00:22:12	94.4
12	6, 10	500	0.0001	00:29:27	88.8
13	6, 7	500	0.0001	00:22:05	83.3
14	9, 9	500	0.0001	00:24:48	94.4
15	5, 9	500	0.0001	00:26:43	94.4

In Table V we show results of the Type-2 fuzzy logic system with triangular membership functions with the gradient descent with adaptive learning (traingda method) to increase the alpha value for the optimization of MNN (images without preprocessing).

TABLE V. RESULTS WITH TRIANGULAR FUNCTIONS AND THE TRAINGDA METHOD

Training	Neurons	Epoch	Error	Training Time	% Rec.
1	7, 7	500	0.0001	00:34:28	86.11
2	9, 9	500	0.0001	00:39:10	77.7
3	8, 7	500	0.0001	00:41:05	88.8
4	9, 4	500	0.0001	00:34:19	88.8
5	12, 9	500	0.0001	00:41:07	100
6	11, 10	500	0.0001	00:40:55	83.3
7	13 , 9	500	0.0001	00:53:40	81.9
8	10, 10	500	0.0001	00:32:11	77.7
9	10, 7	500	0.0001	00:38:15	100
10	9, 11	500	0.0001	00:44:28	88.8
11	9, 3	500	0.0001	00:35:37	77.7
12	10, 11	500	0.0001	00:36:35	88.8
13	9, 3	500	0.0001	00:35:57	100
14	7, 11	500	0.0001	00:33:46	88.8
15	10, 13	500	0.0001	00:51:06	79

In Table VI we show results of the Type-2 fuzzy logic system with triangular membership functions with the gradient descent with adaptive learning and momentum (traingdx method) to increase the alpha value for the MNN (images without preprocessing).

TABLE VI. RESULTS WITH TRIANGULAR FUNCTIONS AND THE TRAINGDX METHOD

Training	Neurons	Epoch	Error	Training Time	% Rec.
1	9, 8	500	0.0001	00:33:44	66.60
2	9, 10	500	0.0001	00:38:50	77.7
3	11, 7	500	0.0001	00:38:00	65.2
4	8, 9	500	0.0001	00:33:48	63.6
5	8, 10	500	0.0001	00:38:45	61.1
6	11, 13	500	0.0001	00:37:47	100
7	7, 10	500	0.0001	00:33:28	68.05
8	9, 10	500	0.0001	00:58:15	88.8
9	11, 9	500	0.0001	01:17:59	81.9
10	12, 11	500	0.0001	00:55:21	72.2
11	5, 11	500	0.0001	00:43:43	61.1
12	13, 12	500	0.0001	00:55:45	100
13	13,10	500	0.0001	00:52:15	93.05
14	12, 10	500	0.0001	01:02:12	81.9
15	10, 12	500	0.0001	00:58:14	94.4

In Table VII we show results of FGSA with Type-2 fuzzy logic system with Gaussian membership functions with the scaled conjugate gradient (trainscg method) to increase the alpha value in the MNN (images with preprocessing).

TABLE VII. RESULTS WITH GAUSSIAN FUNCTIONS AND THE TRAINSCG METHOD

Training	Neurons	Epoch	Error	Training Time	% Rec.
1	15, 8	500	0.0001	00:47:13	100
2	14, 14	500	0.0001	00:28:09	100
3	11, 6	500	0.0001	00:21:04	100
4	9, 8	500	0.0001	00:20:57	100
5	4, 10	500	0.0001	00:21:46	100
6	10, 9	500	0.0001	00:19:53	100
7	10, 6	500	0.0001	00:20:53	100
8	10, 7	500	0.0001	00:20:59	97.2
9	9, 8	500	0.0001	00:21:45	86.1
10	11, 10	500	0.0001	00:22:34	98.6
11	8, 11	500	0.0001	00:23:37	94.4
12	11, 9	500	0.0001	00:24:58	98.6
13	10, 11	500	0.0001	00:22:52	97.2
14	10, 10	500	0.0001	00:22:26	93.05
15	9, 11	500	0.0001	00:22:58	90.2

In Table VIII we show results of the Type-2 fuzzy logic system with Gaussian membership functions with the gradient descent with adaptive learning (traingda method) to increase the alpha value for the optimization of MNN (images with preprocessing).

TABLE VIII. RESULTS WITH GAUSSIAN FUNCTIONS AND THE TRAINGDA METHOD

Training	Neurons	Epoch	Error	Training Time	% Rec.
1	11, 13	500	0.0001	00:39:52	86.1
2	11, 12	500	0.0001	00:45:14	94.4
3	8, 10	500	0.0001	00:36:44	51.3
4	10 10	500	0.0001	00:31:36	62.5
5	14, 13	500	0.0001	00:59:27	94.4
6	15, 13	500	0.0001	00:56:50	100
7	12, 15	500	0.0001	00:46:33	94,4
8	11, 11	500	0.0001	01:00:01	88.8
9	13, 13	500	0.0001	00:47:22	94.4
10	14, 14	500	0.0001	00:44:25	94.4
11	13, 13	500	0.0001	00:52:20	94.4
12	15, 14	500	0.0001	00:46:46	100
13	10, 15	500	0.0001	00:47:53	83.3
14	12, 14	500	0.0001	00:50:02	95.80
15	14, 15	500	0.0001	00:52:46	100

In Table IX we show results of the Type-2 fuzzy logic system with Gaussian membership functions with the gradient descent with adaptive learning and momentum (traingdx method) to increase the alpha value for the optimization of MNN (images with preprocessing).

TABLE IX. RESULTS WITH GAUSSIAN FUNCTIONS AND THE TRAINGDX METHOD

Training	Neurons	Epoch	Error	Training Time	% Rec.
1	14, 13	500	0.0001	00:47:04	94.4
2	14, 14	500	0.0001	01:04:15	88.80
3	15, 13	500	0.0001	00:57:01	98.60
4	15, 11	500	0.0001	00:45:56	91.6
5	12, 15	500	0.0001	00:39:46	87.5
6	13, 15	500	0.0001	00:41:45	98.61
7	13, 13	500	0.0001	00:45:55	98.6
8	13, 12	500	0.0001	00:47:57	98.6
9	12, 13	500	0.0001	00:54:13	93.05
10	10, 13	500	0.0001	00:45:43	100
11	8, 13	500	0.0001	00:42:21	87.5
12	14, 13	500	0.0001	01:03:13	100
13	14, 14	500	0.0001	00:54:12	100
14	10, 14	500	0.0001	00:54:31	86.1
15	11, 15	500	0.0001	00:56:46	97.2

VI. CONCLUSION

In this paper proposed the algorithm FGSA with type-2 fuzzy logic for optimization of modular neural networks pattern recognition of echocardiogram images, three types of learning algorithms are used for testing the proposed approach. In analyzing the results conclusion that best learning algorithm is the scaled conjugate gradient. The type-2 fuzzy system with triangular membership functions (images without preprocessing) gives a 89.3% accuracy, type-2 fuzzy logic system with triangular membership functions (images with preprocessing) with 99.2% accuracy and type-2 fuzzy system with Gaussian membership functions (images with preprocessing) produces a 97.02 % accuracy.

In the comparison between type-2 fuzzy system with triangular membership function (images with preprocessing) and type-2 fuzzy system with Gaussian membership functions (images with preprocessing), we arrived to the conclusion that the best approach is with type-2 fuzzy system with triangular membership functions (images with preprocessing).

ACKNOWLEDGMENT

I would like to express to thank CONACYT and Tijuana Institute of Technology for the facilities and resources granted for the development of this research.

REFERENCES

[1] V. Maniezzo, and M. Dorigo, A. Colorni, "The ant system: optimization by a colony of cooperating agents," IEEE Transactions on Systems, Man, and Cybernetics – Part B 26 (1), 1996, pages 29–41.

[2] J. Kennedy, and R. Eberhart, "Particle swarm optimization," in: Proceedings of IEEE International Conference on Neural Networks, vol. 4, 1995, pages 1942–1948.

[3] K. Tang, K. Man, S. Kwong, and Q. He, "Genetic algorithms and their applications," IEEE Signal Processing Magazine 13 (6), 1996 pages 22–37.

[4] F. Bergh, and A. Engelbrecht, "A study of particle swarm optimization particle trajectories," Information Sciences, 2006, pages 937–971.

[5] X. Yang, "Bat Algorithm: a novel approach for global engineering optimization," Eng. Comput.: Int. J. Comput. Aided Eng. Softw. 29(5), 2012, pages 464-483.

[6] W. Du, and B. Li, "Multi-strategy ensemble particle swarm optimization for dynamic optimization," Information Sciences 178, 2008, pages 3096–3109.

[7] X. Tan, and B. Bhanu, "Fingerprint matching by genetic algorithms," Pattern Recognition 39, 2006, pages 465–477.

[8] D. Sanchez, P. Melin, and O. Castillo, "Optimization of modular granular neural networks using a hierarchical genetic algorithm based on the database complexity applied to human recognition," Information Sciences, Volume 309, 2015, pages 73-101.

[9] L. Mauro, R. Célio, and M. Roisenberg, "Optimization of neural networks through grammatical evolution and a genetic algorithm," Expert Systems with Applications, Volume 56, 2016, pages 368-384.

[10] G. Martinez, P. Melin, and O. Castillo, "Optimization of modular neural networks using hierarchical genetic algorithms applied to speech recognition," in: Proceedings of International Joint Conference on Neural Network, Montreal, Canada, 2005, pages 1400–1406.

[11] B. Pandey, and N. Garg, "Swarm optimized modular neural network based diagnostic system for breast cancer diagnosis," Int. J. Soft Comput. Artif. Intell. Appl. (IJSCAI) 2 (4), 2013, pages 11–20.

[12] F. Valdez, P. Melin, and O. Castillo, "Modular neural networks architecture optimization with a new nature inspired method using a fuzzy combination of particle swarm optimization and genetic algorithms, " Inf.Sci.270, 2014, pages 143–153.

[13] I. Multaba, and M. Hussain., "Application of Neural Networks and Other Learning," Technologies in Process Engineering. Imperial Collage Press. 2001.

[14] D. Goldberg. "Genetic Algorithms in search, optimization and machine learning". Ed. Addison Wesley 1989.

[15] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "GSA: a gravitational search algorithm, " Inf.Sci.179(13), 2009, pages 2232–2248.

[16] S. Mahmoudi, M. Aghaie, M. Bahonar, and N. Poursalehi, "A novel optimization method, Gravitational Search Algorithm (GSA), for PWR core optimization," Annals of Nuclear Energy, Volume 95, 2016, pages 23-34.

[17] Y. Chao, M. Dai, K. Chen, P. Chen, and Z. Zhang, "A novel gravitational search algorithm for multilevel image segmentation and its application on semiconductor packages vision inspection," International Journal for Light and Electron Optics, Volume 127, Issue 14, July 2016, pages 5770-5782.

[18] A. Sombra, F. Valdez, P. Melin, and O. Castillo, "A new gravitational search algorithm using fuzzy logic to parameter adaptation," in: IEEE Congress on Evolutionary Computation, Cancun, México,2013, pages.1068–1074.

[19] B. González, F. Valdez, P. Melin, G. Prado-Arechiga, "Fuzzy logic in the gravitational search algorithm enhanced using fuzzy logic with dynamic alpha parameter value adaptation for the optimization of modular neural networks in echocardiogram recognition", Applied Soft Computing, Volume 37, December 2015, pages 245-254