ISSN 2395-8618

Early Detection of Aortic Stenosis for the Prevention of Heart Failure in High-Risk Population using Whale Optimization Algorithm

Elda Betsabé Pérez Martínez, David Luviano Cruz, Soledad Vianey Torres Argüelles, and Carlos Alto Ochoa Ortiz Zezzatti

Abstract—**Currently, the pace of life of people in a Smart City has been incrementally affected due to several factors such as stress and risk diseases, including hypertension, diabetes, and even SARS. COVID'19 pandemic with a future prognostic of 7,87 million deaths to the middle of 2022- that leads to cardiovascular diseases and conduct to a heart attack, it has been observed that in Mexico it is recurrent from the range age near of 45 and one of the most common heart diseases is aortic stenosis and can reach be fatal if it is not detected in time. In practice, the echocardiogram is the fastest means to detect abnormalities anatomically and physiologically in real-time. However, the interpretation can be affected by the image quality. Therefore, there are techniques to improve noise for image processing and, where appropriate, separate the regions of interest. This is known as segmentation. In this research, a model inspired by artificial intelligence for diagnosis is proposed, the model uses Convolutional Neural Networks (CNN) as a deep learning technique for classifying images of Aortic Stenosis, and an innovative metaheuristic named Whale Optimization Algorithm (WOA) is implemented to select the most relevant segmentation feature of the Aortic echocardiographic view. The results show promising performance for the diagnosis.**

Index Terms—**Whale optimization algorithm, image segmentation, convolutional neural networks.**

I. Introduction

Cardiovascular diseases are the leading cause of death globally and it is estimated that by 2030 the mortality rate will double, however, the statistics have changed due to the SARS variant and the current COVID 19 pandemic, the future forecast for 2022 is 7.87 million deaths. It has been recorded that this disease causes damage to the heart, even in patients who had not had any previous heart disease, causing heart failures that damage internal structures to cause a heart attack [1,2].

One of the main cardiovascular diseases is Aortic Stenosis that occurs in advanced age in adults and predominates more in the male gender, since it is presented by the narrowing of the valve or accumulations of calcium known as stenosis, also can be genetic conditions or in patients who have had a history of rheumatic fever, hypercalcemia or risk factors such as smoking, cholesterol, diabetes, hypertension among others. Once severe aortic stenosis occurs, the survival rate is only 50% at 2 years and 20% at 5 years without an aortic valve replacement, as long as the patient presents symptoms as it can go unnoticed for years until the first symptoms such as chest pains, shortness of breath and fainting [3]. That is why one of the devices of interest in the clinical practice to detect aortic stenosis is the echocardiogram since it does not represent a danger to the patient and is able to show images in real time of the physiology and anatomy of the heart, however, it is essential the detection and interpretation of the specialist so sometimes the quality of the image may be not optimal or the interpretation requires of time for detection and there are usually cardiopathies that go against time.

For the interpretation, detection and diagnosis in medical images, the processing of medical images allows us to determine the characteristics of the images obtained by the echocardiogram obtained from the different views, so segmentation is a key component in image processing to isolate physiological and biological structures of interest. Therefore, in this work the segmentation of the medical image is the fundamental part to obtain the main parameters of Aortic Stenosis and facilitate its interpretation. One of the most widely used applications of Artificial Intelligence is Deep Learning where Convolutional Neural Networks aids to classify, the idea of this architecture is to achieve a learning model that is capable of learning to filter the most relevant characteristics of an image. Likewise, metaheuristic algorithms, which are stochastic search algorithms use heuristics for any problem to accelerate convergences to nearby solutions in this case the main characteristic of the image segmentation allowing precision in the detection of Aortic Stenosis.

II. Related Works

In a review of the literature associated with metaheuristics, it was determined that there are various algorithms that are focused on solving multi-combinatorial and multi-restrictive problems associated with the resolution and identification of possible plausible solutions that involve a set of longitudinal variables [4].

The parameter optimization study and evaluation metrics are useful for image segmentation. Within the works, different heuristics and metaheuristics have been implemented that have been applied to grayscale images that an echocardiogram gives us, for this type of images the use of the Particle Swarm (PSO) optimization algorithm or the optimization algorithm was found based on biogeography (BBO) with optimal results for segmentation problems and provide faster convergence with relatively less processing time. In recent studies according to Table 1.

Manuscript received 15/03/2021, accepted for publication on 11/12/2021.

The authors are with the Universidad Autónoma de Ciudad Juárez, Chihuahua, Mexico (ebetsypm87@gmail.com, {david.luviano, vianey.torres, alberto.ochoa}@uacj.mx).

ISSN 2395-8618

TABLE I
Comparative studies with WOA algorithm in medical images

Author	Year	Paper	Segmentation Technique
Aziz Abd El et al. [6]	2018	Multi-objective Whale Optimization algorithm for Multilevel Thresholding Segmentation	Multilevel thresholding
Nasiri et al. [7]	2018	A whale optimization algorithm (WOA) approach for clustering	Clustering
Vijh et al. [8]	2020	An intelligent lung tumor diagnosis system using whale optimization algorithm and support vector machine	Support Vector Machine Kernel
Fang et al. [9]	2021	Automatic breast cancer detection based on optimized neural network using whale optimization algorithm	Edge detection
Tongbram et al. [10]	2021	A novel image segmentation approach using FCM and whale optimization algorithm	Fuzzy C Means Clustering

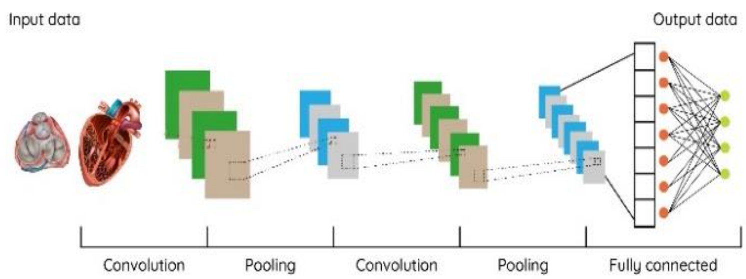

Fig. 1. Convolutional Neural Network

Multilevel segmentation to determine the optimal threshold values to segment a set of images using the Otsu method, diffuse entropy and Kapur's entropy as a fitness function has been favorable with the Whale Optimization Algorithm (WOA) [5]. Other segmentation techniques such as edge detection or Fuzzy C Means clustering or Support Vector Machine, simultaneously show an improvement in finding the local optimum and a higher convergence speed [6-10]. This algorithm is used even in others important applications as a parameter estimation of photovoltaic cells using an improved chaotic WOA [9].

III. Exploratory Approach

In this section, the concepts used to image segmentation like convolutional neuronal networks, whale optimization algorithm, encircling prey, bubble-net attacking model, search for prey and WOA algorithm, that will be used for this work are analyzed.

IV. Image Segmentation

Image segmentation is a digital image processing technique that allows the image to be divided into regions with similar properties such as gray levels, textures, brightness, and contrast. In the case of medical images, the segmentation in cardiac images varies depending on the specific application on the internal structure to be evaluated from the echocardiogram. However, factors such as noise, low resolution, artifacts, or movement may be found in the image that distort the image [11].

One of the most used methods for this type of image is the threshold technique where the gray level (g) is compared in two segments (0 and 1) where the 0 is the darkest and gray level 1 is the lightest as Equation 1:

$$\text{Tglobal}(g) = \begin{cases} 0 & \text{if } g < t, \\ 1 & \text{if } g > t. \end{cases} \quad (1)$$

To analyze and process any image we should know that an image is generated from a set of pixels denoted as N; for each image level there are a set of pixels denoted as n1.

Gray level histogram is normalized and regarded as a probability distribution. (L-1 is the lightest):

$$\sum_{i=0}^{L-1} iPi \quad Pi = \frac{ni}{N}. \quad (2)$$

The total mean of the image can be represented as:

$$\mu T = \sum_{i=0}^{L-1} iPi. \quad (3)$$

V. Convolutional Neuronal Networks

Convolutional Neural Networks (CNN) as shown in Figure1. is a Deep Learning algorithm which can take in an input image, assign importance (learned weights and biases) to various aspects in the image and be able to differentiate one from the other.

These types of networks are based on a mathematical operation called convolution, since they carry out the convolution of the input signal layer with respect to a transfer function found at the output of the neuron. These layers perform operations that alter the data in order to learn specific characteristics of that data.

The 3 most frequent layers are the convolution which subjects the input images to a set of convolutional filters, each of which activates certain characteristics of the images, an activation that is the Rectified Linear Unit (ReLU), this allows to assign the negative values to zero and keep the positive values, since only the activated characteristics go to the next

ISSN 2395-8618

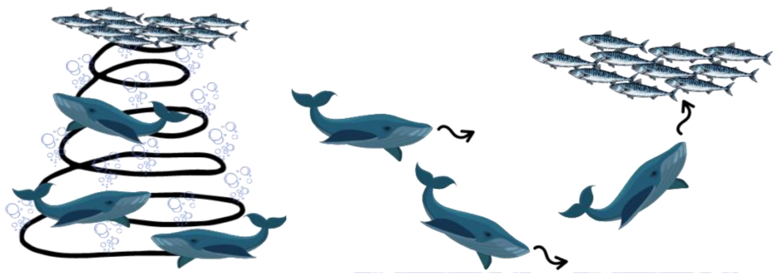

Fig. 2. Hunting prays process of Whales in Bubble Nets

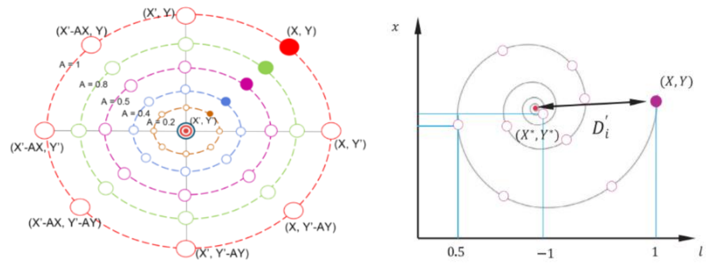

Fig. 3. Exploration mechanism implemented in WOA (a) X is randomly chosen search agent, (b) the encircling mechanism and spiral updating position

layer and the Pooling layer that helps to simplify the output by decreasing the non-linear sample rate, reducing the number of parameters that the network needs to learn [12].

VI. Whale Optimization Algorithm

The Whale Optimization Algorithm (WOA) as show in Figure 2. Is a meta-heuristic optimization algorithm and was proposed by Mirhalili and Lewis in 2016 [13].

It is inspired by the strategy of hunting prey in the form of Bubble Nets, and there are two maneuvers associated with feeding the bubble network are the upward spirals where the whales dive about 12 meters down and then begin to create spiral-shaped bubbles around the prey and swim to the surface and double loops that include three different stages [14].

VII. Encircling Prey

In first stage the search agent (whale) looks for the best solution (the prey) randomly based on the position of each agent. We update the position of a search agent during this phase by using a randomly selected search agent rather than the best search agent. The equation is the following:

$$\vec{D} = |\vec{C}.\vec{X}best(t) - \vec{X}(t)|, \quad (4)$$

$$\vec{X}(t+1) = \vec{X}best(t) - \vec{A}\vec{D}, \quad (5)$$

where:

$\vec{D}$ is the distance vector,

$\vec{A}$and $\vec{C}$ are coefficient vectors,

$\vec{X}best$ is the position vector of the best solution,

t indicates the current iteration.

The coefficients $\vec{A}$and $\vec{C}$ represent the iteration for search the prey, in the above formula, rand is a random number between [0, 1], is a control parameter, and it decreases linearly from 2 to 0 with increasing of the iterations. The expression is as follows:

$$\vec{A} = 2a.rand - a, \quad (6)$$

$$\vec{C} = 2.rand. \quad (7)$$

VIII. Bubble-Net Attacking Model

In this phase of exploitation, the bubble network is used to attack the prey. Spiral updating position: This approach first calculates the distance between the whale located at (X, Y) and prey located at (X', Y') as shown in Figure 3. A spiral equation is then created between the position of whale and prey to mimic the helix-shaped movement of humpback whales as follows:

$$\vec{X}(t+1) = \vec{D}'.e^{bl}.\cos(2\pi l) + \vec{X}best(t), \quad (8)$$

where $\vec{D} = \left|\vec{C}.\vec{X}best(t) - \vec{X}(t)\right|$ and indicates the distance of the iteration whale to the prey (best solution obtained so far), b is a constant for defining the shape of the logarithmic spiral, l is a random number in [−1,1].

IX. Search for Prey

If |A|>1, randomly select the whale to replace the current optimal solution; it can keep the whale away from the current reference target and enhance the algorithm's global exploration capabilities and also need to find a better prey to replace the current reference whale. The mathematical model is:

$$C = |\vec{C}.\vec{X}rand(t) - \vec{X}(t)|, \quad (9)$$

$$\vec{X}(t+1) = \vec{X}rand(t) - \vec{A}\vec{D}, \quad (10)$$

where $\vec{X}rand$ means randomly selecting the new position vector of the whale.

X. Data Set and Analysis

For this work, 20 echocardiographic images of the view of the Aortic Valve with Stenosis with a maximum size of 125 x 125 pixels were used, obtained from the free database page: https://openi.nlm.nih.gov.

It was analyzed under medical supervision that the database was indeed of Severe Aortic Stenosis to determine the region

ISSN 2395-8618

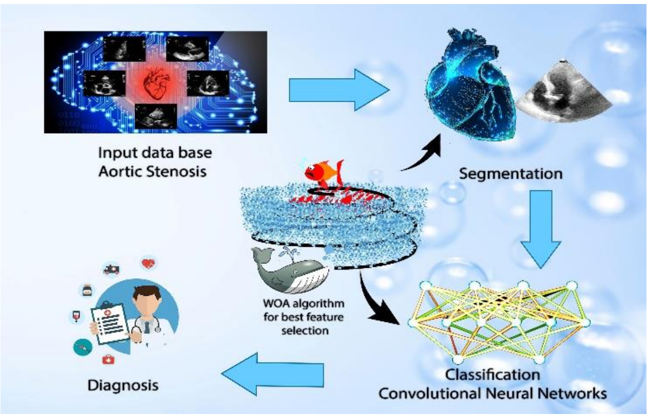

Fig. 4. Proposed model Detection of Stenosis Aortic using WOA

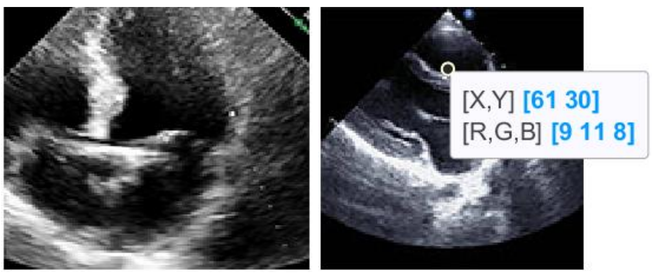

Fig. 5. Input Dataset of Stenosis Aortic Echocardiogram

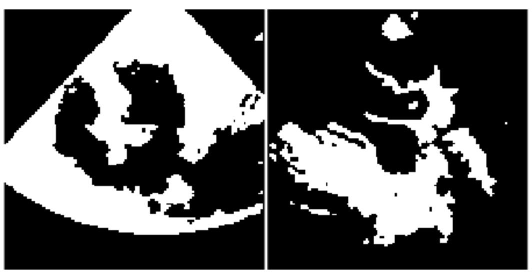

Fig. 6. Image preprocessing output segmentation

that needs to be highlighted with the segmentation and images with noises or echocardiographic views that did not comply with this parameter were discarded.

XI. WOA Algorithm

Step 1: Initialize the whale's population $X = (i = 1,2, \dots . n)$
Step 2: Calculates fitness of each search agent $\vec{X}best$
Step 3: while (t < maximum number of iterations)
For each agent update a, $\vec{A}$, $\vec{C}$, l and p
if ($|\vec{A}| < 1$)
Update agent in equation (4)
Else:
Select a random agent $\vec{X}rand$
Update current agent by equation (10)

end-for
Check if any search agent goes beyond the search space and amend it
Calculate fitness of each search agent
Update $\vec{X}best$ if there is a better solution
t=t+1
end-while
Step 4: return $\vec{X}best$

XII. Proposed Model

As shown in figure 4, to initialize the echocardiogram database is loaded into the Matlab interpreter program, using Live Script and the Deep Learning Toolbox. To initialize the segmentation process, the images have a maximum resolution of 125x125 pixels when going through the first cycle, so we start by applying a medfilt2 media filter. To test the WOA algorithm with echocardiographic images, the threshold technique will be used, which consists of a pixel-by-pixel comparison determining the threshold and it is necessary to analyze the region of interest to be isolated in order to find a characteristic gray level. With the global method of the threshold value, the optimum is chosen for each image, it is very sensitive to variations in the brightness of the image, however, it serves very well to separate background objects in the image, such as echocardiograms, the technique is simple, the lowest value is chosen as the threshold. Then the CNN compare the database against a manually segmented echocardiogram of Severe aortic Stenosis valve equally supervised with the specialist.

XIII. Results

Comparison of performance in echocardiographic images Figure 5 shows the original images and Figure 6 shows the performance of image preprocessing as a result of a fast fitness function convergence. The Table 1. Presents MSE, PNSR and SSIM of the sample images. With the help of these parameters, the efficiencies of the algorithm are evaluated.
MSE (Mean Square Error) - It is the cumulative square error between the segmented image and the original, the equation used is as follows:

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{i=1}^{N} [I(i,j) - I'(i,j)]. \qquad (11)$$

The PSNR (Peak Signal to Noise Ratio) is the relationship between the peak signal and the noise signal that is introduced by segmentation. It is usually measured in dB and a high PSNR value indicates better reconstruction, the equation is as follows:

$$PSNR = 10log10 \left(\frac{255^2}{MSE} \right). \qquad (12)$$

The Structural Similarity Index (SSIM) measures the similarity between two images the equation is as follows:

$$SSIM(x,y) = \frac{(2\mu_X\mu_Y + C1)(2\sigma_{XY} + C2)}{(\mu^2{}_X + \mu^2{}_Y + C1)(\sigma^2{}_X + \sigma^2{}_Y + C2)}. \qquad (13)$$

XIV. Neuronal Network Result

The configuration of the neural network as input the images are 125 x125 pixels, a total of 15626 neurons with 25 convolutional filters size 5 and 2 by 2 max pooling, the padding is used so that the resulting image has the same size as the input and to activation is used by RELU.

An epoch refers to a cycle through the complete training data set, it is once all the images are processed once individually or back and forth, in this case we evaluate in 4 epochs, the loss is calculated in the training and validation and your interpretation

ISSN 2395-8618

TABLE I
WOA PARAMETER RESULTS

Image	T Global (g)	MSE	PSNR	SSIM
AO1	0.341176470588235	204.9158	25.0490	0.9682
AO2	0.396078431372549	161.1288	26.0931	0.9678
AO3	0.286274509803922	144.2471	26.5737	0.96432
AO4	0.290196078431373	92.0355	28.5252	0.8954
AO5	0.266666666666667	138.3398	26.7556	0.9634
AO6	0.360784313725490	89.9684	28.6239	0.9888
AO7	0.321568627450980	159.6673	26.1326	0.9678
AO8	0.309803921568627	184.5939	25.5105	0.9694
AO9	0.482352941176471	246.7908	24.2415	0.9756
AO10	0.337254901960784	195.8529	25.2455	0.9634
AO11	0.431372549019608	199.3229	25.2455	0.9682
AO12	0.462745098039216	228.8476	24.5996	0.96432
AO13	0.333333333333333	121.5998	27.5078	0.9854
AO14	0.396078431372549	131.1748	26.9863	0.9854
AO15	0.360431372549067	89.9684	28.6239	0.9743
AO16	0.360784313725490	207.827	24.9878	0.9523
AO17	0.266666666666667	62.2687	30.2221	0.9877
AO18	0.454901960784314	223.3310	24.5514	0.96432
AO19	0.360784313725490	89.9684	28.6239	0.9567
AO20	0.376470588235294	230.6970	24.5344	0.9634

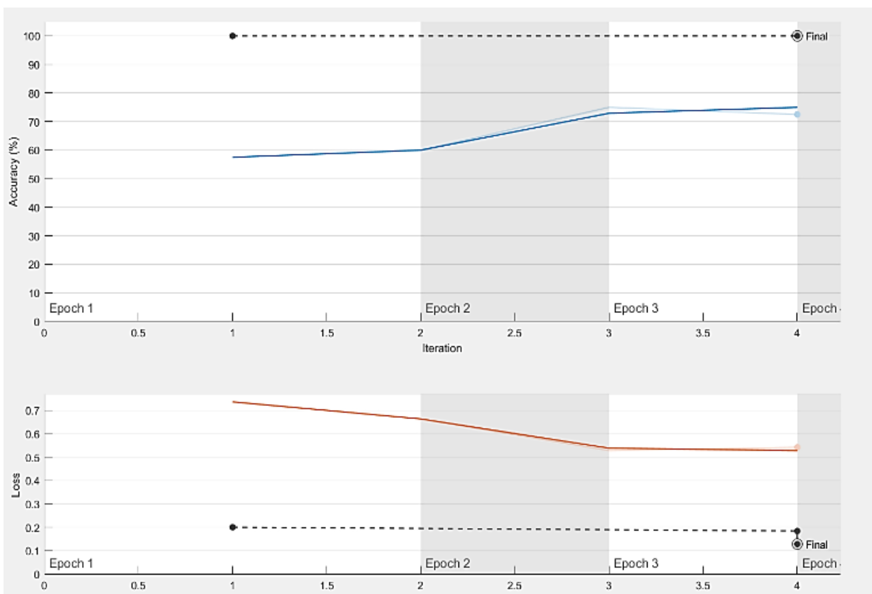

Fig. 7. Accuracy and Loss from Convolutional Neural Network

is how well the model is doing for these two sets. Unlike precision, it is a sum of the errors made for each example in the training or validation sets for this training of 30 iterations, so the precision of the model is 78%.

XV. CONCLUSIONS

A WOA whale search optimization technique has been proposed to find the global optimal threshold in severe aortic stenosis segmentation images and the results demonstrate that WOA can be used effectively, and convergence is fast.

The input performance is compared to the input and output images and shows the effectiveness of the proposed design on the existing segmentation. As for CNN, a larger database is recommended to obtain better accuracy parameters.

XVI. FUTURE RESEARCH

Echocardiographic image segmentation, convolutional neural networks, and the whale optimization algorithm (WOA) are novel fields of research to explore and implement reliable, robust, and accurate algorithms. The study can be extended to compare it with other new algorithms to improve performance such as metaheuristic algorithms associated with bubble models of cetaceans (blue whales) and their variants such as Location of prey for tracking the navigation of the Whale Shark, Echolocation based on Herd -Beluga Whale and Segmentation. of Multipoint Monitoring as "Vaquita Marina". Likewise, through an Environmental Intelligence System (AmI) it is proposed to use a Medical Blackboard that allows the use of Echocardiograms to determine if a congenital disease is

ISSN 2395-8618

associated with a variety of symptoms and a comparison with specialists in other parts of the world. Finally, and very important, future work is intended to use a large database obtained from a medical center in Mexico with its proper bioethics formats, to obtain more parameters that can determine the degree of damage or prediction of aortic stenosis with the help of the specialist.

REFERENCES

[1] M. Y. I. Fonseca, R. Y. L. Díaz and F. M. A. Vargas, "Relación entre la COVID-19 y las enfermedades cardiovasculares", *Revista 16 de abril*, vol. 59, no. 277, pp. 1–6, 2020.

[2] A. D. Martínez, A. Ochoa and J. R. Rodríguez, "A Hybrid Intelligent System for Improving a Health Model Associated with Cardiovascular Disease," *Research in Computing Science*, vol. 148, no. 6, pp. 13–23, 2019.

[3] P. Carità, G. Coppola, G. Novo, G. Caccamo, M. Guglielmo, F. Balasus, S. Novo, S. Castrovinci, M. Moscarelli, K. Fattouch and E. Corrado, "Aortic stenosis: insights on pathogenesis and clinical implications," *Journal of Geriatric Cardiology: JGC*, vol. 13, no. 6, pp. 489–498, 2016. DOI:10.11909/j.issn.1671-5411.2016.06.001.

[4] A. Ochoa, A. Hernández, L. Cruz, J. Ponce, F. Montes, L. Li and L. Janacek, "Artificial societies and social simulation using ant colony, particle swarm optimization and cultural algorithms," *New Achievements in Evolutionary Computation*, IntechOpen, 2010. DOI:10.5772/8058.

[5] M. Abd, El Aziz, A. A. Ewees and A. E. Hassanien, "Whale optimization algorithm and moth-flame optimization for multilevel thresholding image segmentation," *Expert Systems with Applications*, vol. 83, pp. 242–256, 2017. DOI: 10.1016/j.eswa.2017.04.023.

[6] J. Nasiri, and F. M. Khiyabani, "A whale optimization algorithm (WOA) approach for clustering," *Cogent Mathematics & Statistics*, vol. 5, no. 1, 2018. DOI:10.1080/25742558.2018.1483565.

[7] S. Vijh, D. Gaur and S. Kumar, "An intelligent lung tumor diagnosis system using whale optimization algorithm and support vector machine," *International Journal of System Assurance Engineering and Management*, vol. 11, no. 2, pp. 374– 384, 2019. DOI:10.1007/s13198-019-00866-x.

[8] H. Fang, H. Fan, S. Lin, Z. Qing and F. R. Sheykhahmad, "Automatic breast cancer detection based on optimized neural network using whale optimization algorithm," *International Journal of Imaging Systems and Technology*, vol. 31, no. 1, pp. 425–438, 2021. DOI:10.1002/ima.22468.

[9] S. Tongbram, B. A. Shimray, L. S. Singh and N. Dhanachandra, "A novel image segmentation approach using fcm and whale optimization algorithm," *Journal of Ambient Intelligence and Humanized Computing*, pp. 1–15. 2021. DOI:10.1007/s12652-020-02762-w.

[10] D. Oliva, M. Abd, E. Aziz and A. E. Hassanien, "Parameter estimation of photovoltaic cells using an improved chaotic whale optimization algorithm," *Applied Energy*, vol. 200, pp. 141–154, 2017. DOI:10.1016/j.apenergy.2017.05.029.

[11] R. C. Gonzalez and R. E. Woods, "*Digital image processing*," Fourth Edition, Pearson, 2018.

[12] S. Haykin, "*Neural Networks and Learning Machines*," Third Edition, Prentice Hall, 2009.

[13] S. Mirjalili and A. Lewis, "The whale optimization algorithm," *Advances in Engineering Software*, vol. 95, pp. 51–67, 2016. DOI:10.1016/j.advengsoft.2016.01.008.

[14] M. H. Zhong and W. Long, "Whale optimization algorithm based on stochastic adjustment control parameter," *Science Technology and Engineering*, vol. 17, no. 12, pp. 68–73, 2017. DOI:10.1051/matecconf/201713900157.