This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3113986, IEEE Access

RaDate of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS. 2017.Doi Number

IoT Technology Enabled Heuristic Model with Morlet wavelet neural network for numerical treatment of Heterogeneous Mosquito Release Ecosystem

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The manuscript APC is supported by University Malaysia Sabah, Jalan UMS, 88400, KK, Malaysia. This paper collaboration among Department of Electrical Engineering, COMSATS institute of information technology, Attock Campus, Attock, Pakistan, Department of Mathematics, Hazara University, Mansehra, Pakistan, and Faculty of Computing and Informatics, University Malaysia Sabah, Jalan UMS, 88400, KK, Malaysia.

ABSTRACT The utmost advancements of artificial neural networks (ANNs), software-defined networks (SDNs) and internet of things (IoT) technologies find beneficial in different applications of the smart healthcare sector. Aiming at modern technology's use in the future development of healthcare, this paper presents an advanced heuristic based on Morlet wavelet neural network for solving the mosquito release ecosystem in a heterogeneous atmosphere. The mosquito release ecosystem is dependent of six classes, eggs density, larvae density, pupae density, mosquitoes searching for hosts density, resting mosquito's density and mosquitoes searching for ovipositional site density. An artificial neural network with the layer structure of Morlet wavelet (MWNN) kernel is presented using the global and local search optimization schemes of genetic algorithm (GA) and active-set algorithm (ASA), i.e., MWNN-GA-ASA. The accurateness, reliability and constancy of the proposed MWNN-GA-ASA is established through comparative examinations with Adams method based numerical results to solve the proposed nonlinear system with matching of order 10^{-06} to 10^{-09}. The accuracy and convergence of the proposed MWNN-GA-ASA is certified using the statistical operators based on root mean square error (RMSE), Theil's inequality coefficient (T.I.C) and mean absolute deviation (MAD) operators.

INDEX TERMS Mosquito release ecosystem, IoT, SDN, artificial neural networks, heuristic algorithm, Adams's method.

I. INTRODUCTION

The Internet of Things (IoT) is an innovation embedded with software, sensors, actuators, electronics, and network connectivity through which data can be collected and exchanged over the Internet. Artificial neural network (ANN) [1-4], software-defined networks (SDN) [5-7], and internet of things (IoT) [8-14] technologies find useful in different applications from the smart healthcare sector [15-20] to the satellite [21]. The exponential utilization of the Internet of Things (IoT) is expanding and is of ongoing interest as it is broadly utilized in numerous applications and devices like remote sensors, clinical devices, delicate home sensors, and other related IoT devices as shown in Fig. 1. The Internet of Things [22-23] is an illustration of a new network that utilizes detecting units to gather ecological data. It is on a suitable server on the internet for decision-making utilizing ZigBee [24], WiMAX [25-28], and then some. Software Defined Networking (SDN) presents centralized programmability [29-36] that permits general control of the network. Thus, utilizing SDN is an undeniable answer for improving the presentation of IoT networking and beating existing complexity. IoT can implement using software-defined networking [37-44], named data networking (NDN) [45-47] and cloud computing network [48] with future applications such as voice over IP (VoIP) [49–52] fiber optic [53–55], worldwide interoperability for microwave access (WiMAX) [56–58], and artificial intelligence (AI) and machine learning (ML) [59].

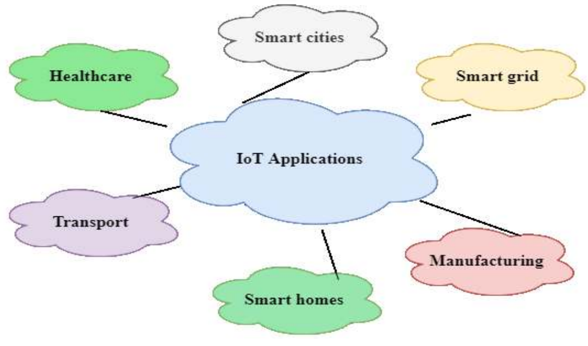
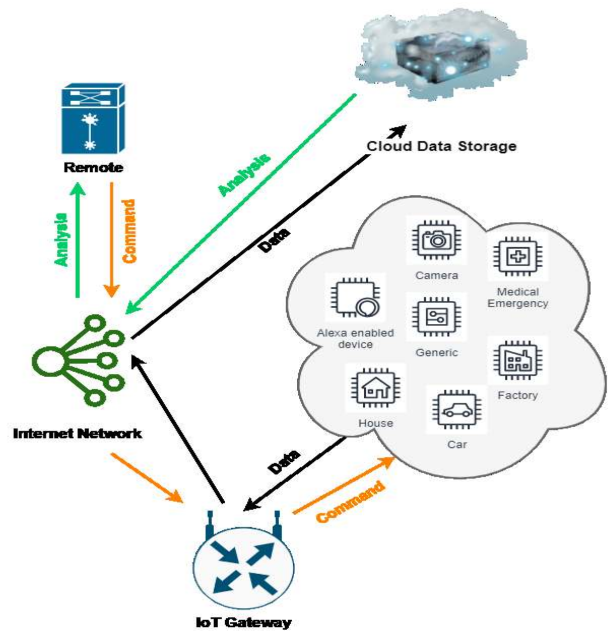


FIGURE 1. IoT Applications.

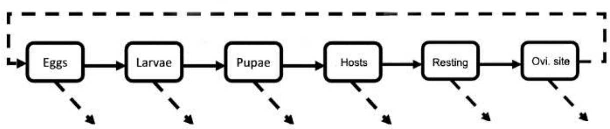
The embedded sensing devices are employed in IoT-based systems to efficiently and economically gauge real-time environmental parameters [60–66]. A sensor is a device that can sense the change in its surrounding environment [67], [68]. The Internet of Things can fabricate and advance numerous areas of action we can discover the IoT eHealth Ecosystem [69], [70], [71], the loT Intelligent Transportation Ecosystem [72], the IoT Smart Home Ecosystem [73], [74], [75], and mosquito release Ecosystem etc as shown graphically in Fig. 2.

The release of mosquito's ecosystem is a main factor in disrupting the persistence and resurgence of numerous vector diseases. Features of spatial heterogeneity based on mosquitoes, i.e., host sites and reproduction, human association with vectors, affect the distribution and population structure of mosquitoes and the ability to control disease transmission. Mosquitoes transmit dengue, malaria, filarial, yellow fever and many other vital diseases. Malaria represents a significant spatial disparity primarily determined by climatic variations, primarily response coverage and human movement [75-76]. At a range of 100m-1000m, the mosquito environment plays a dominant role in controlling the spread [77]. Mosquitoes as well as other animals can travel in any direction, but can travel partial distances inspired by the availability of resources. Control interfering should replicate the capacity and location of mosquitoes to move, in order to achieve a higher level of effectiveness in the collapse of the mosquito population.

The impact of vector-borne disease propagation and control was first highlighted a century ago by Ronald Ross [78]. However, he recognized that the public health community does not place a high priority on this issue. Ross stated that the density of mosquitoes depends on four variables in any region, which contain reproduction rates, mortality rates, immigration and emigration rates. Manga et al. [79] accessible that the spatial disparity in the spreading of possessions applied by mosquitoes affects their rate of dispersion and reproduction. This contributes to the variation in densities, human knowledge of vectors and the capacity to control disease communication [80],[81]. The characteristics of the resource on transport can be incredible. For example, even the presence of non-productive larval habitats can impact bite densities [82]. However, experimental investigations of mosquito dispersal are stimulating [83]-[84].



(a) IoT Ecosystem.



(b) Six classes of mosquito release ecosystem.

FIGURE 2. Ecosystem of IoT and mosquito release

Mathematical systems play a dynamic role in understanding and providing the phenomena's solutions that are stimulating for the assortment of fields, however, insufficient systems have integrated dispersal or heterogeneity wide-ranging characteristic of a close population vector [85-87]. The researchers split the mature phase of the mosquitoes into various phases [88]. To discover the effects of dispersion and heterogeneity, a system can integrate mosquito life-cycle structures, spatial heterogeneity based on mosquito properties, distribution and feeding cycle. Space systems have usually implemented the diffusion scheme which reproduces space as a constant variable. Despite the reality of dissemination models that take heterogeneity into account, it is difficult to incorporate the many factors that disturb the movement [89-90]. For example, in areas where possessions are located in discrete patches, mosquito dispersal is more appropriately modelled using a metapopulational technique, the population is allocated into isolated spots. At each location, the population is subdivided into subgroups, resulting in a set of subgroups corresponding to different states and multiple compartmentalized systems. There are various diffusion systems have incorporated the heterogeneity present in the atmosphere on the release of disease vectors [91-92]. Nevertheless, each has understood the aquatic phases of mosquitoes to provide a general or simple framework to model random spatial designs of mosquito control interference.

The mosquito dynamics represents a nonlinear differential system of six classes named as eggs density (E), larvae density (L), pupae density (L), mosquitoes searching based hosts density (A_h), density of resting mosquitoes (A_r) and mosquitoes searching based on ovipositional site density (A_0). The mathematical form of these classes based on nonlinear mosquito's dispersal system (NMDS) in the heterogeneous environment is give as [93]:

$$\begin{cases} E'(x) = b\rho_{A_0}A_0(x) - \rho_E E(x) - \mu_E E(x), & E(0) = i_1, \\ L'(x) = \rho_E E(x) - (\mu_{L_1} + \rho_L + \mu_{L_2}L(x))L(x), & L(0) = i_2, \\ P'(x) = \rho_L L(x) - \rho_P P(x) - \mu_P P(x), & P(0) = i_3, \\ A_h'(x) = \rho_{A_0}A_0(x) + \rho_P P(x) - (\mu_{A_h} + \rho_{A_h})A_h(x), & A_h(0) = i_4, \\ A_r'(x) = \rho_{A_h}A_h(x) - (\mu_{A_r} + \rho_{A_r})A_r(x), & A_r(0) = i_5, \\ A_0'(x) = \rho_{A_r}A_r(x) - (\mu_{A_0} + \rho_{A_0})A_0(x), & A_0(0) = i_6. \end{cases} \tag{1}$$

The variables defined for each class of the NMDS in the heterogeneous environment (1) and the appropriate selections and ranges are given in Table I as reported in [93]. The motive of this work is to solve the above NMDS in the heterogeneous environment using the layer structure of Morlet wavelet (MWNN) kernel together with global and local search optimization schemes of genetic algorithm (GA) and active-set algorithm (ASA), i.e., MWNN-GA-ASA. Numerical stochastic approaches have been widely applied to solve a wide variety of applications, like delay singular functional model [94]-[95], COVID-19 dynamical model [96]-[97], singular fractional models [98]-[99], prey-predator system [100], singular nonlinear higher order models [101]-[103], HIV infection system [104], multi-singular differential systems [105]-[106] and dengue fever nonlinear system [107]. Based on these renowned applications, the authors are motivated to solve the NMDS with the help of the MWNN-GA-ASA. Some main factors of the MWNN-GA-ASA are briefly discussed as:

- The proposed MWNNs are designed and presented using GA-ASA optimization procedures to solve the nonlinear mosquito's dispersal system in a heterogeneous atmosphere.
- Steady, constant and trustworthy outcomes for nonlinear mosquito's dispersal system authenticate the value of the proposed MWNN-GA-ASA.
- The values of the absolute deviation from reference are found in the good agreement that further represents the dependability of the MWNN-GA-ASA.
- The MWNN-GA-ASA performance is certified using different statistics via root mean square error (RMSE), Theil's inequality coefficient (T.I.C) and mean absolute deviation (MAD) observations to solve the NMDS in a heterogeneous atmosphere for 30 independent trials.
- The proposed MWNN-GA-ASA is smoothly implemented to solve the nonlinear mosquito's dispersal system in a heterogeneous atmosphere with understandable processes, robust effective and stable.

The rest of the paper is organized as: Sect 2 presents the proposed MWNN-GA-ASA and statistical procedures. Sect 3 proves the simulation of the numerical outcomes. Sect 4 indicates the final explanations and future research reports.

TABLE I
VARIABLES DEFINED FOR EACH CLASS OF THE NMDS IN THE HETEROGENEOUS ENVIRONMENT (1).

Index	Description	Chosen standards	Range
ρ_L	Mature larvae rate into pupae	0.12	0.08 to 0.17
b	Female eggs located per ovipositional	60	50 to 300
ρ_{A_0}	Ovipositional rate	3.2	3 to 4
μ_{L_1}	Density-independent based larvae mortality rate (MR)	0.4	0.30 to 0.58
μ_E	MR of eggs	0.5	0.32 to 0.8
ρ_E	Eggs rate producing into larvae	0.4	0.33 to 1
μ_{L_2}	Density-dependent rate based on larvae mortality	0.02	0 to 1
ρ_{A_h}	Host searching mosquitoes rate for the latent state	0.46	0.322 to 0.6
μ_P	Pupae MR	0.4	0.22 to 0.52
ρ_P	Pupae develop rate into mature	0.7	0.33 to 1
μ_{A_h}	Mosquitoes MR for hosts penetrating	0.18	0.12 to 0.23
μ_{A_0}	Mosquitoes MR pointed for ovipositional places	0.41	0.41 to 0.56
μ_{A_r}	Resting mosquitoes MR	0.0043	0.03 to 0.01
ρ_{A_r}	Resting MR to enter ovipositional places	0.5	0.30 to 0.56

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II. METHODOLOGY

To implement the proposed MWNN-GA-ASA, it is possible to use different IoT sensors and hardware components to detect six classes of mosquito release Ecosystem as shown in Fig. 3.

The planned construction of the ANN-GA-ASA to solve NMDS in a heterogeneous atmosphere is designed in two phases:

Step 1: Introduce a merit function by operating the system of MWNN.

Step 2: Necessary explanations are provided to optimize the merit function to solve NMDS in a heterogeneous atmosphere (1) by the hybrid computing GA-ASA. The proposed MWNN-GA-ASA is accessible as demonstrated in Fig. 4.

A. MODELING: MWNN-GA-ASA

The mathematical relations in case of system (1) are provided with MWNN in the proposed results form $\hat{E}(x)$, $\hat{L}(x)$, $\hat{P}(x)$, $\hat{A}_h(x)$, $\hat{A}_r(x)$ and $\hat{A}_0(x)$ together with the n^{th} derivatives are given as:

$$\begin{bmatrix}\hat{E}(x) & \hat{L}(x)\\ \hat{P}(x) & \hat{A}_h(x)\\ \hat{A}_r(x) & \hat{A}_0(x)\end{bmatrix}=\begin{bmatrix}\sum_{i=1}^{m}U_{E,i}f(V_{E,i}x+S_{E,i}) & \sum_{i=1}^{m}U_{L,i}f(V_{L,i}x+S_{L,i})\\ \sum_{i=1}^{m}U_{P,i}f(V_{P,i}x+S_{P,i}) & \sum_{i=1}^{m}U_{A_h,i}f(V_{A_h,i}x+S_{A_h,i})\\ \sum_{i=1}^{m}U_{A_r,i}f(V_{A_r,i}x+S_{A_r,i}) & \sum_{i=1}^{m}U_{A_0,i}f(V_{A_0,i}x+S_{A_0,i})\end{bmatrix},$$

$$\begin{bmatrix}\hat{E}^{(n)}(x) & \hat{L}^{(n)}(x)\\ \hat{P}^{(n)}(x) & \hat{A}_h^{(n)}(x)\\ \hat{A}_r^{(n)}(x) & \hat{A}_0^{(n)}(x)\end{bmatrix}=\begin{bmatrix}\sum_{i=1}^{m}U_{E,i}f^{(n)}(V_{E,i}x+S_{E,i}) & \sum_{i=1}^{m}U_{L,i}f^{(n)}(V_{L,i}x+S_{L,i})\\ \sum_{i=1}^{m}U_{P,i}f^{(n)}(V_{P,i}x+S_{P,i}) & \sum_{i=1}^{m}U_{A_h,i}f^{(n)}(V_{A_h,i}x+S_{A_h,i})\\ \sum_{i=1}^{m}U_{A_r,i}f^{(n)}(V_{A_r,i}x+S_{A_r,i}) & \sum_{i=1}^{m}U_{A_0,i}f^{(n)}(V_{A_0,i}x+S_{A_0,i})\end{bmatrix}, \quad (2)$$

where the unknown weight vector (***W***) is shown as:
$W=[W_E,W_L,W_P,W_{A_\square},W_{A_r},W_{A_0}]$, for $W_E=[U_E,V_E,S_E]$, $W_L=[U_L,V_L,S_L]$, $W_P=[U_P,V_P,S_P]$, $W_{A_\square}=[U_{A_\square},V_{A_\square},S_{A_\square}]$, $W_{A_r}=[U_{A_r},V_{A_r},S_{A_r}]$ and $W_{A_0}=[U_{A_0},V_{A_0},S_{A_0}]$,
Where

$$\begin{aligned}
U_E&=[U_{E,1},U_{E,2},U_{E,3},\dots,U_{E,m}],\\
U_L&=[U_{L,1},U_{L,2},U_{L,3},\dots,U_{L,m}],\\
U_P&=[U_{P,1},U_{P,2},U_{P,3},\dots,U_{P,m}],\\
U_{A_\square}&=[U_{A_\square,1},U_{A_\square,2},\dots,U_{A_\square,m}],\\
U_{A_r}&=[U_{A_r,1},U_{A_r,2},\dots,U_{A_r,m}],\\
U_{A_0}&=[U_{A_0,1},U_{A_0,2},\dots,U_{A_0,m}],\\
V_E&=[V_{E,1},V_{E,2},V_{E,3},\dots,V_{E,m}],\\
V_L&=[V_{L,1},V_{L,2},V_{L,3},\dots,V_{L,m}],\\
V_P&=[V_{P,1},V_{P,2},V_{P,3},\dots,V_{P,m}]\\
V_{A_\square}&=[V_{A_\square,1},V_{A_\square,2},\dots,V_{A_\square,m}],\\
V_{A_r}&=[V_{A_r,1},V_{A_r,2},\dots,V_{A_r,m}],\\
V_{A_0}&=[V_{A_0,1},V_{A_0,2},\dots,V_{A_0,m}],\\
S_E&=[S_{E,1},S_{E,2},S_{E,3},\dots,S_{E,m}],\\
S_L&=[S_{L,1},S_{L,2},S_{L,3},\dots,S_{L,m}],\\
S_P&=[S_{P,1},S_{P,2},S_{P,3},\dots,S_{P,m}],\\
S_{A_\square}&=[S_{A_\square,1},S_{A_\square,2},\dots,S_{A_\square,m}],\\
S_{A_r}&=[S_{A_r,1},S_{A_r,2},\dots,S_{A_r,m}],\\
S_{A_0}&=[S_{A_0,1},S_{A_0,2},\dots,S_{A_0,m}].
\end{aligned}$$

The Morlet wavelet neural network $f(x)=\cos(1.75x)e^{(-0.5x^2)}$ [108]. The updated form of the system (2) is given as:

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$$\begin{bmatrix} \hat{E}(x),\ \hat{L}(x), \\ \hat{P}(x), \hat{A}_h(x), \\ \hat{A}_r(x), \hat{A}_0(x) \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{m} U_{E,i} \cos\left(1.75(V_{E,i}x + S_{E,i})\right) e^{-0.5(V_{E,i}x+S_{E,i})^2},\ \sum_{i=1}^{m} U_{L,i} \cos\left(1.75(V_{L,i}x + S_{L,i})\right) e^{-0.5(V_{L,i}x+S_{L,i})^2}, \\ \sum_{i=1}^{m} U_{P,i} \cos\left(1.75(V_{P,i}x + S_{P,i})\right) e^{-0.5(V_{P,i}x+S_{P,i})^2},\ \sum_{i=1}^{m} U_{A_h,i} \cos\left(1.75(V_{A_h,i}x + S_{A_h,i})\right) e^{-0.5(V_{A_h,i}x+S_{A_h,i})^2}, \\ \sum_{i=1}^{m} U_{A_r,i} \cos\left(1.75(V_{A_r,i}x + S_{A_r,i})\right) e^{-0.5(V_{A_r,i}x+S_{A_r,i})^2},\ \sum_{i=1}^{m} U_{A_0,i} \cos\left(1.75(V_{A_0,i}x + S_{A_0,i})\right) e^{-0.5(V_{A_0,i}x+S_{A_0,i})^2} \end{bmatrix}, \tag{3}$$

$$\begin{bmatrix} \hat{E}^{(n)}(x), \hat{L}^{(n)}(x), \\ \hat{P}^{(n)}(x), \hat{A}_h^{(n)}(x), \\ \hat{A}_r^{(n)}(x), \hat{A}_0^{(n)}(x) \end{bmatrix} = \frac{d^{(n)}}{dx^{(n)}} \begin{bmatrix} \sum_{i=1}^{m} U_{E,i} \cos\left(1.75(V_{E,i}x + S_{E,i})\right) e^{-0.5(V_{E,i}x+S_{E,i})^2},\ \sum_{i=1}^{m} U_{L,i} \cos\left(1.75(V_{L,i}x + S_{L,i})\right) e^{-0.5(V_{L,i}x+S_{L,i})^2}, \\ \sum_{i=1}^{m} U_{P,i} \cos\left(1.75(V_{P,i}x + S_{P,i})\right) e^{-0.5(V_{P,i}x+S_{P,i})^2},\ \sum_{i=1}^{m} U_{A_h,i} \cos\left(1.75(V_{A_h,i}x + S_{A_h,i})\right) e^{-0.5(V_{A_h,i}x+S_{A_h,i})^2}, \\ \sum_{i=1}^{m} U_{A_r,i} \cos\left(1.75(V_{A_r,i}x + S_{A_r,i})\right) e^{-0.5(V_{A_r,i}x+S_{A_r,i})^2},\ \sum_{i=1}^{m} U_{A_0,i} \cos\left(1.75(V_{A_0,i}x + S_{A_0,i})\right) e^{-0.5(V_{A_0,i}x+S_{A_0,i})^2} \end{bmatrix},$$

Using the network (3), a merit function (E) is written as:

$$E = E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7. \tag{4}$$

$$E_1 = \frac{1}{N}\sum_{j=1}^{N}\left(\hat{E}'_j - \rho_E \hat{E}_j + \rho_E \hat{E}_j - b\rho_{A_0}\left(A_0\right)_j\right)^2, \tag{5}$$

$$E_2 = \frac{1}{N}\sum_{J=1}^{N}\left(\hat{L}'_j + \mu_{L1}\hat{L}_j + (\mu_{L_2}\hat{L}_j + \rho_L)\hat{L}_j - \rho_E \hat{E}_j\right) \tag{6}$$

$$E_3 = \frac{1}{N}\sum_{j=1}^{N}\left(\hat{P}'_j + \rho_p \hat{\rho}_j - \rho_L \hat{L}_j + \mu_P \hat{P}_j\right)^2, \tag{7}$$

$$E_4 = \frac{1}{N}\sum_{j=1}^{N}(\hat{A}'_h)_j - \left((\mu_{A_h} + \rho_{A_h})(\hat{A}_h)_j - \rho_p \hat{P}_j - \rho_{A_0}(\hat{A}_0)_j\right)^2, \tag{8}$$

$$E_5 = \frac{1}{N}\sum_{j=1}^{N}\left((\hat{A}'_r)_j + (\mu_{A_r} + \rho_{A_r})(\hat{A}_r)_j - \rho_{A_r}(A_h)_j\right)^2, \tag{9}$$

$$E_6 = \frac{1}{N}\sum_{j=1}^{N}\left((\hat{A}'_0)_j - \rho_{A_r}(\hat{A}_r)_j + (\mu_{A_0} + \rho_{A_0}) \times (\hat{A}_0)_j\right)^2, \tag{10}$$

$$E_7 = \tfrac{1}{6}\Big(\big(\hat{E}_0 - i_1\big)^2 + \big(\hat{L}_0 - i_2\big)^2 + \big(\hat{P}_0 - i_3\big)^2 + \big((\hat{A}_{\square})_0 - i_4\big)^2 + \big((\hat{A}_r)_0 - i_5\big)^2 + \big((\hat{A}_0)_0 - i_6\big)^2\Big), \tag{11}$$

where $N\square = 1, x_j = j\square, \hat{E}_j = \hat{E}(x_j), \hat{L}_j = \hat{L}(x_j), \hat{P}_j = \hat{P}(x_j), (\hat{A}_{\square})_j = \hat{A}_{\square}(x_j), (\hat{A}_r)_j = \hat{A}_r(x_j)$ and $(\hat{A}_0)_j = \hat{A}_0(x_j)$. The approximate solutions of eggs density (E), larvae density (L), pupae density (L), mosquitoes searching based hosts density (A_h), density of resting mosquitoes (A_r) and mosquitoes searching based on ovipositional site density (A_0), respectively signified as $\hat{E}_m$, $\hat{L}_m$, $\hat{P}_m$, $(\hat{A}_h)_m$, $(\hat{A}_r)_m$ and $(\hat{A}_0)_m$. Accordingly, E_1, E_2, E_3, E_4, E_5 and E_6 are the merit functions associated with NDMS in a heterogeneous atmosphere and E_7 represents the initial conditions of the system (1).

B. OPTIMIZATION PROCESS: GA-ASA

In this section, a brief explanation of GA-ASA combination to optimize the merit function as shown in system (4) is provided for solving the NDMS in a heterogeneous atmosphere.

Genetic algorithm is an efficient global optimization tool introduced by Holand in the last century [109]. GA is mathematical genetic procedure of humans, which is applied broadly using the optimization of decision variables in various domains. The process of GA is implemented in many applications include expenditure system of the hospitals [110], brain tumor models [111], feature collection in cancer systems [112], bismuth-borate glasses optimizations [113], prediction based differential systems [114], air blast systems of prediction [115], monorail vehicle networks [116], prediction of liver diseases [116], optimization through cloud services [118] and periodic boundary values networks [119].

Active-set approach is known as a local search process, rapidly optimize to solve the constrained/unconstrained systems generally. ASA is used to execute various stiff, complex and nonlinear systems. Recently, ASA is executed to pricing the American option [120], the actual control through optimization [121], pressure-dependent system of water distribution [122], embedded model predictive control [123], overcurrent relays in microgram optimization [124] and frictional contact models based on electrodynamic [125]. The pseudocode detail of MWNN-GA-ASA based procedures is given in Table II, while the procedure construction is shown in Figure.4.

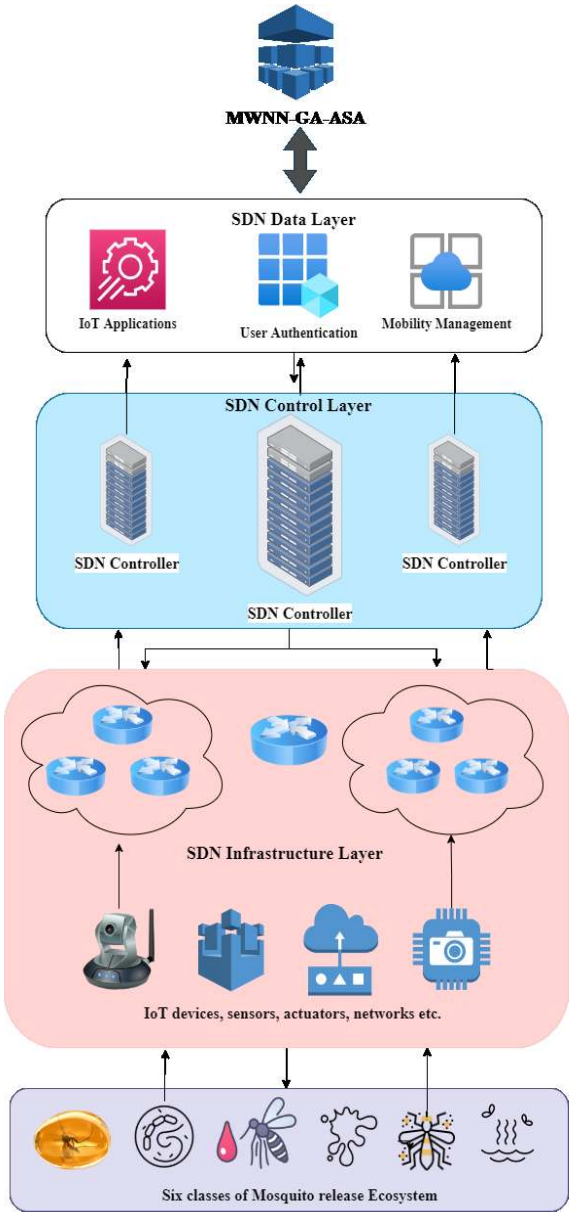

FIGURE 3. **MWNN-GA-ASA, SDN, and IoT infrastructure.**

C. PERFORMANCE MEASURES

The performance operators to solve the NDMS in a heterogeneous atmosphere are presented using the root mean square error (RMSE) operator, mean absolute deviation (MAD) operator and Theil's inequality coefficient (TIC) operator, mathematically given as:

$$\begin{bmatrix} \text{RMSE}_E & \text{RMSE}_L \\ \text{RMSE}_P & \text{RMSE}_{A_h} \\ \text{RMSE}_{A_r} & \text{RMSE}_{A_0} \end{bmatrix} = \begin{bmatrix} \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(\hat{E}_i - E_i\right)^2} & \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(\hat{L}_i - L_i\right)^2} \\ \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(\hat{P}_i - P_i\right)^2} & \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left((\hat{A}_h)_i - (A_h)_i\right)^2} \\ \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left((\hat{A}_r)_i - (A_r)_i\right)^2} & \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left((\hat{A}_0)_i - (A_0)_i\right)^2} \end{bmatrix}, \quad (12)$$

$$\begin{bmatrix} \text{TIC}_E & \text{TIC}_L \\ \text{TIC}_P & \text{TIC}_{A_h} \\ \text{TIC}_{A_r} & \text{TIC}_{A_0} \end{bmatrix} = \begin{bmatrix} \dfrac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(\hat{E}_i - E_i\right)^2}}{\left(\sqrt{\frac{1}{m}\sum_{i=1}^{m}\hat{E}_i^2} + \sqrt{\frac{1}{m}\sum_{i=1}^{m}E_i^2}\right)} & \dfrac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(\hat{L}_i - L_i\right)^2}}{\left(\sqrt{\frac{1}{m}\sum_{i=1}^{m}\hat{L}_i^2} + \sqrt{\frac{1}{m}\sum_{i=1}^{m}L_i^2}\right)} \\ \dfrac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(\hat{P}_i - P_i\right)^2}}{\left(\sqrt{\frac{1}{m}\sum_{i=1}^{m}\hat{P}_i^2} + \sqrt{\frac{1}{m}\sum_{i=1}^{m}P_i^2}\right)} & \dfrac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left((\hat{A}_h)_i - (A_h)_i\right)^2}}{\left(\sqrt{\frac{1}{m}\sum_{i=1}^{m}(\hat{A}_h)_i^2} + \sqrt{\frac{1}{m}\sum_{i=1}^{m}(A_h)_i^2}\right)} \\ \dfrac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left((\hat{A}_r)_i - (A_r)_i\right)^2}}{\left(\sqrt{\frac{1}{m}\sum_{i=1}^{m}(\hat{A}_r)_i^2} + \sqrt{\frac{1}{m}\sum_{i=1}^{m}(A_r)_i^2}\right)} & \dfrac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}\left((\hat{A}_0)_i - (A_0)^2{}_i\right)^2}}{\left(\sqrt{\frac{1}{m}\sum_{i=1}^{m}(\hat{A}_0)_i^2} + \sqrt{\frac{1}{m}\sum_{i=1}^{m}(A_0)_i^2}\right)} \end{bmatrix}, \quad (13)$$

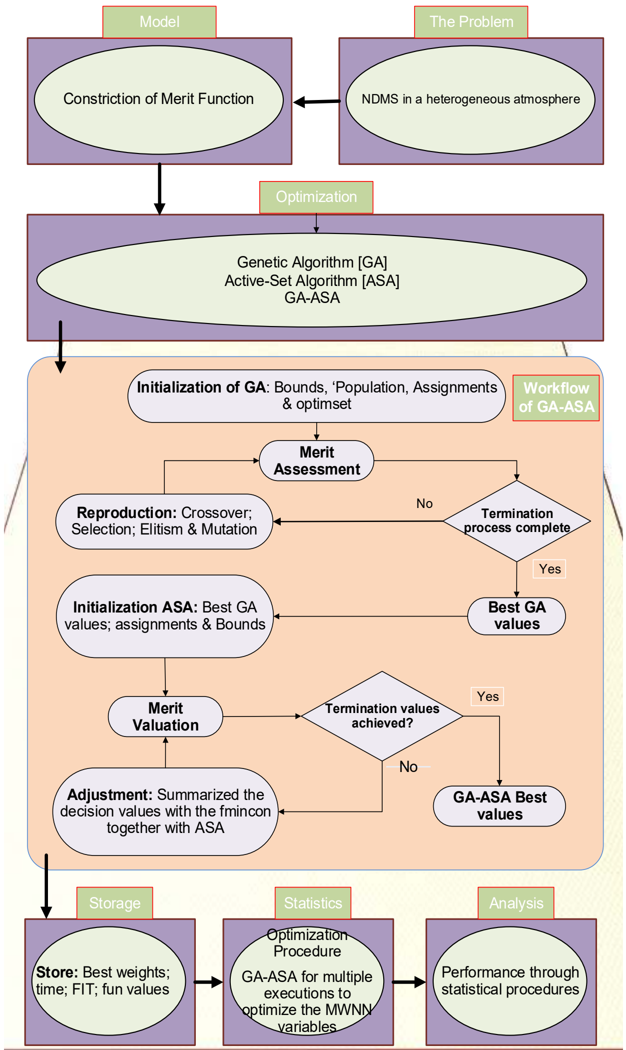

FIGURE 4. **Proposed structure of the present MWNN-GA-ASM for solving the nonlinear Heterogeneous Mosquito Release Ecosystem model**

TABLE II
. PSEUDOCODE BASED ON MWNN-GA-ASA FOR SOLVING THE NDMS IN A HETEROGENEOUS ATMOSPHERE

Start of GA

Inputs: The individual represents the identical elements as:

$W = [W_E, W_L, W_P, W_{A_h}, W_{A_r}, W_{A_0}],$

for $W_E = [U_E, V_E, S_E]$, $W_L = [U_L, V_L, S_L]$, $W_P = [U_P, V_P, S_P]$,

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$W_{A_{\square}} = [U_{A_{\square}}, V_{A_{\square}}, S_{A_{\square}}]$, $W_{A_r} = [U_{A_r}, V_{A_r}, S_{A_r}]$ and $W_{A_0} = [U_{A_0}, V_{A_0}, S_{A_0}]$ as given in system (3).
Population: The population is defined using the chromosomes number as:
$P = [W_1, W_2, W_3, \ldots, W_n]^t$,
for j^th component $W_j = [W_{E,j}, W_{L,j}, W_{P,j}, W_{A_h,j}, W_{A_r,j}, W_{A_0,j}]$ with
Output: The global best decision variables $\boldsymbol{W}_{\mathbf{B\text{-}GA}}$
Initialization: Produce $\boldsymbol{W}$ and $\boldsymbol{P}$ with the initials of pseudo random numbers.
Fit formulations: Evaluate the FIT E as shown in system (4) and along with systems (5-11).
Termination process: Stop, if any of the criteria meets
- FIT = $E \rightarrow 10^{-21}$, Generations→ 30, Tolerances: [TolCon = 10^{-20} & TolFun =10^{-21}], GenLimit → 120, Pop size= 210, Other: default

Go to **storage**
Ranking: For each $\boldsymbol{W}$ of $\boldsymbol{P}$ shows the obtained FIT E.
Reproduction: This process is completed using the four criteria of (Selection), (Mutations), (Crossover) & (Elitism).
Go **FIT valuation.**
Storage: $\boldsymbol{W}_{\mathbf{B\text{-}GA}}$, FIT, generations, time and function counts for the GA.
GA process End

ASA Start
Inputs: Start point $\boldsymbol{W}_{\mathbf{B\text{-}GA}}$
Output: The best GA-ASA are signified as $\boldsymbol{W}_{\mathbf{GA\text{-}ASA}}$
Initialize: Regulate the iterations, bounded constraints and other limits in (optimset).
Terminate: ASA stops, if
Iterations = 500, FIT = 10^{-19}, (TolFun= 10^{-23}, TolX = 10^{-21}, TolCon = 10^{-20}) and MaxFunVal = 268000.
While (Terminate)
Fit Evaluations: Calculate FIT of each $\boldsymbol{W}$ of $\boldsymbol{P}$ by taking systems (4) to (11)
Adjustments: Regulate "fmincon" with 'ASA' to adjust '$\boldsymbol{W}$' and the FIT values by taking systems (4)-(11).
Store: Accumulate FIT, $\boldsymbol{W}_{\mathbf{GA\text{-}ASA}}$, time, iterations and weight vector.
ASA process End
Data Generations
Repeat 30 times ASA process to find an enlarge data-set using the optimization MWNN variables to solve the NDMS in a heterogeneous atmosphere

III. RESULTS AND DISCUSSION

In this section, the considerations of the results to solve the NDMS in a heterogeneous atmosphere given in system (1) are described. The relative investigations with the Adams methods precise the exactness of the proposed MWNN-GA-ASA. Moreover, statistical outcomes are plotted to authenticate the accuracy of the proposed MWNN-GA-ASA.

A. PRESENTATIONS OF NDMS IN A HETEROGENEOUS ATMOSPHERE

The efficient form of NDMS in a heterogeneous atmosphere given in system (1) using the suitable values is given as:

$$\begin{cases} E'(x) = 192A_0(x) - 0.9E(x), & E(0) = 0.00001, \\ L'(x) = 0.4E(x) - \left(0.02L(x) + 0.52\right)L(x), & L(0) = 0.00001, \\ P'(x) = 0.12L(x) - 1.11P(x), & P(0) = 0.0003, \\ A_h'(x) = 0.7P(x) + 3.2A_0(x) - 0.64A_h(x), & A_h(0) = 0.0001, \\ A_r'(x) = 0.46A_h(x) - 0.5043A_r(x), & A_r(0) = 0.00001, \\ A_0'(x) = 0.5A_r(x) - 3.61A_0(x), & A_0(0) = 0.0003. \end{cases} \tag{14}$$

A merit function of the model (14) is written as:

$$E = \frac{1}{N}\sum_{i=1}^{N}\left(\begin{array}{l} \left[\hat{E}_i' + 0.9\hat{E}_i - 192(\hat{A}_0)_i\right]^2 \\ +\left[\hat{L}_i' - 0.4\hat{E}_i + \left(0.02\hat{L}_i + 0.52\right)\hat{L}_i\right]^2 + \\ \left[\hat{P}_i' + 1.11\hat{P}_i - 0.12\hat{L}_i\right]^2 \\ +\left[(\hat{A}_h')_i - 0.7\hat{P}_i - 3.2(\hat{A}_0)_i + 0.64(\hat{A}_h)_i\right]^2 + \\ \left[(\hat{A}_r')_i + 0.5043(\hat{A}_r)_i - 0.46(\hat{A}_h)_i\right]^2 \\ +\left[(\hat{A}_0')_i + 3.61(\hat{A}_0)_i - 0.5(\hat{A}_r)_i\right]^2 \end{array}\right) + \frac{1}{6}\left(\begin{array}{l} \left(\hat{E}_0 - \frac{1}{100000}\right)^2 + \left(\hat{L}_0 - \frac{1}{100000}\right)^2 + \left(\hat{P}_0 - \frac{3}{10000}\right)^2 + \\ \left((\hat{A}_h)_0 - \frac{1}{10000}\right)^2 + \left((\hat{A}_r)_0 - \frac{1}{100000}\right)^2 + \left((\hat{A}_0)_0 - \frac{3}{10000}\right)^2 \end{array}\right). \tag{15}$$

The optimization of the NDMS in a heterogeneous atmosphere given in system (1) is accomplished by the hybrid based computing structure GA-ASA for 30 trials to achieve the MWNNs parameter with 15 variables of the system. The best weight values of the MWNN through GA-ASA are derived and presented graphically 3-D bar plots in Figure. 5. These weigh vectors are provided to get the estimated numerical outcomes of the system (1) for 15 number of variables. These weights are used in set of equation (3) to derive the approximate solution. Accordingly, the mathematical representations of the approximate solutions of MWNN-GA-ASA are given as:

$$\begin{aligned} \hat{E}(x) = & -8.088\cos\left(1.75(2.6205x - 0.70061)\right)e^{-0.5(2.6205x-0.70061)^2} - 0.3553\cos\left(1.75(13.7892x + 10.2188)\right)e^{-0.5(13.7892x+10.218)^2} \\ & + 5.8798\cos\left(1.75(12.0839x + 14.5856)\right)e^{-0.5(2.0839x+14.5856)^2} - 12.311\cos\left(1.75(-16.408x - 13.2114)\right)e^{-0.5(-16.408x-13.211)^2} \\ & - 10.1012\cos\left(1.75(-13.27x + 19.8460)\right)e^{-0.5(-13.271x+19.846)^2}, \end{aligned} \tag{16}$$

$$\begin{aligned} \hat{L}(x) = & -18.56\cos\left(1.75(0.7210x + 8.0268)\right)e^{-0.5(0.7210x+8.0268)^2} - 14.867\cos\left(1.75(-4.8892x + 19.092)\right)e^{-0.5(-4.889x+19.09)^2} \\ & - 15.276\cos\left(1.75(-7.9992x + 19.939)\right)e^{-0.5(-7.99x+19.939)^2} - 3.9997\cos\left(1.75(5.2199x + 11.7840)\right)e^{-0.5(5.2199x+11.784)^2} \\ & - 9.4720\cos\left(1.75(2.1831x + 13.2200)\right)e^{-0.5(2.1831x+13.220)^2}, \end{aligned} \tag{17}$$

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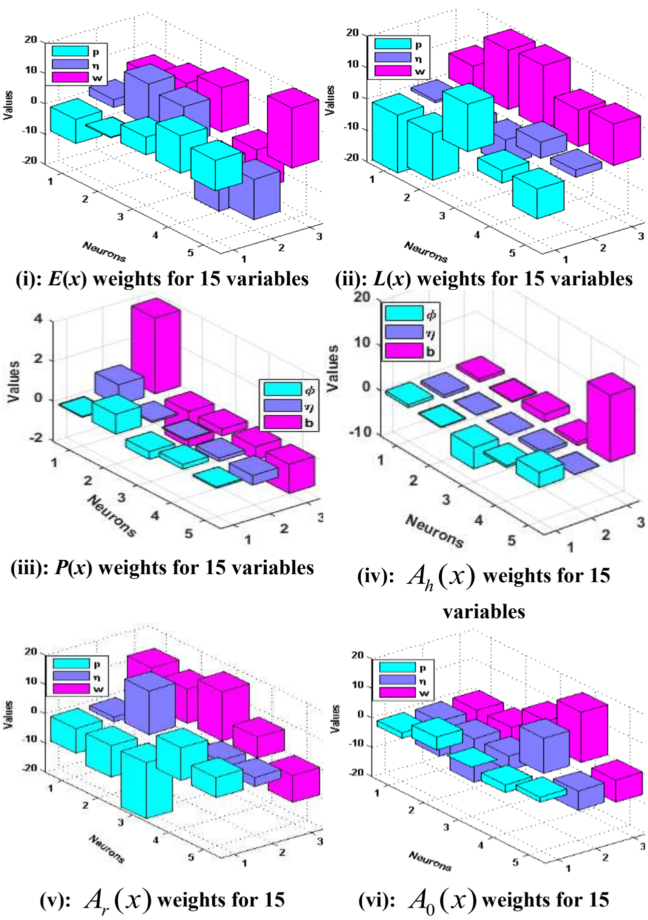
$$\hat{P}(x) = -12.69\cos\left(1.75(-1.429x-12.2142)\right)e^{-0.5(-1.429x-12.214)^2} + 0.0416\cos\left(1.75(-16.944x-3.0000)\right)e^{-0.5(-16.944x-3.000)^2} -5.7786\cos\left(1.75(7.7621x+16.4515)\right)e^{-0.5(7.7621x+16.4515)^2} -17.211\cos\left(1.75(-4.8001x+17.678)\right)e^{-0.5(-4.8001x+17.678)^2} -8.0307\cos\left(1.75(-6.6616x-14.164)\right)e^{-0.5(-6.6616x-14.164)^2}, \tag{18}$$

$$\hat{A}_h(x) = -1.89\cos\left(1.75(-4.2760x+12.932)\right)e^{-0.5(-4.2760x+12.932)^2} + 12.4445\cos\left(1.75(5.6583x+12.7042)\right)e^{-0.5(5.6583x+12.7042)^2} -10.8442\cos\left(1.75(-3.107x-18.337)\right)e^{-0.5(-3.1077x-18.337)^2} +1.83540\cos\left(1.75(-1.421x+17.337)\right)e^{-0.5(-1.4216x+17.337)^2} -10.9402\cos\left(1.75(1.6979x-11.587)\right)e^{-0.5(1.6979x-11.5876)^2}, \tag{19}$$

$$\hat{A}_r(x) = -8.526\cos\left(1.75(-1.4536x+13.16)\right)e^{-0.5(-1.453x+13.169)^2} -10.8500\cos\left(1.75(14.9588x+11.678)\right)e^{-0.5(14.958x+11.678)^2} -19.1727\cos\left(1.75(-4.0145x+16.887)\right)e^{-0.5(-4.01x+16.887)^2} +11.0907\cos\left(1.75(2.9139x+7.2165)\right)e^{-0.5(2.9139x+7.2165)^2} +6.90340\cos\left(1.75(3.0355x-9.2621)\right)e^{-0.5(3.0355x-9.2621)^2}, \tag{20}$$

$$\hat{A}_0(x) = -2.003\cos\left(1.75(0.2561x-0.2972)\right)e^{-0.5(0.2561x-0.2972)^2} +4.3088\cos\left(1.75(-14.808x-13.669)\right)e^{-0.5(-0.957x-0.663)^2} +1.3561\cos\left(1.75(-4.8472x+8.1792)\right)e^{-0.5(0-4.847x+8.179)^2} -2.7569\cos\left(1.75(0.7574x-0.8275)\right)e^{-0.5(11.9774x+17.0851)^2} +1.7627\cos\left(1.75(-6.5040x-7.617)\right)e^{-0.5(-6.5040x-7.6175)^2}. \tag{21}$$



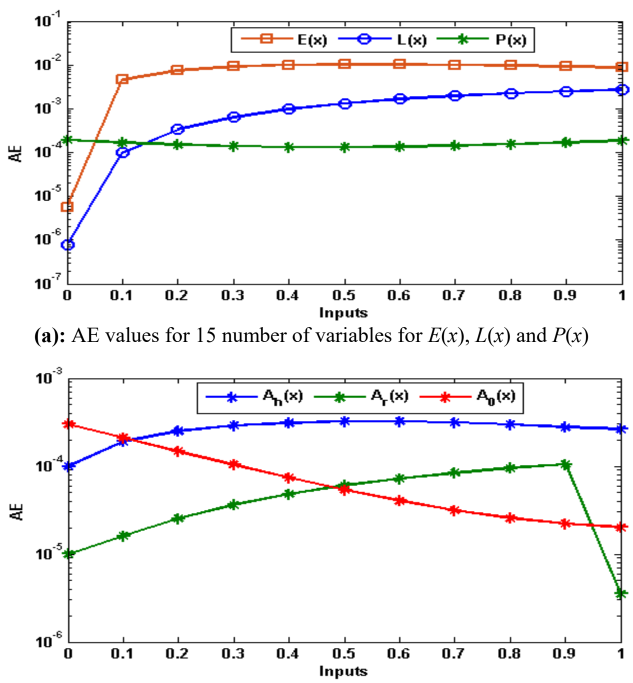
(i): $E(x)$ weights for 15 variables (ii): $L(x)$ weights for 15 variables

(iii): $P(x)$ weights for 15 variables (iv): $A_h(x)$ weights for 15 variables

(v): $A_r(x)$ weights for 15 variables (vi): $A_0(x)$ weights for 15 variables

FIGURE 5. Decision variables of MWNN-GA-ASA for 15 number of variables for solving NDMS in a heterogeneous atmosphere.

The trained weight vectors for 15 variables based MWNN system are plotted in subfigures 5(i), 5(ii), 5(iii), 5(iv), 5(v) and 6(vi) for the classes $E(x)$, $L(x)$, $P(x)$, $A_h(x)$, $A_r(x)$ and $A_0(x)$, respectively.The equations (16-21) are used to show the outcomes of the NDMS in a heterogeneous atmosphere using the MWNN-GA-ASA and plot of results are given in Figures 6-10 for 15 weights or decision variable in the networks.



(a): AE values for 15 number of variables for $E(x)$, $L(x)$ and $P(x)$

(b): AE values for 15 number of variables for $A_h(x)$, $A_r(x)$ and $A_0(x)$

FIGURE 6. AE values based on best and mean solutions for each category of the heterogeneous mosquito release ecosystem

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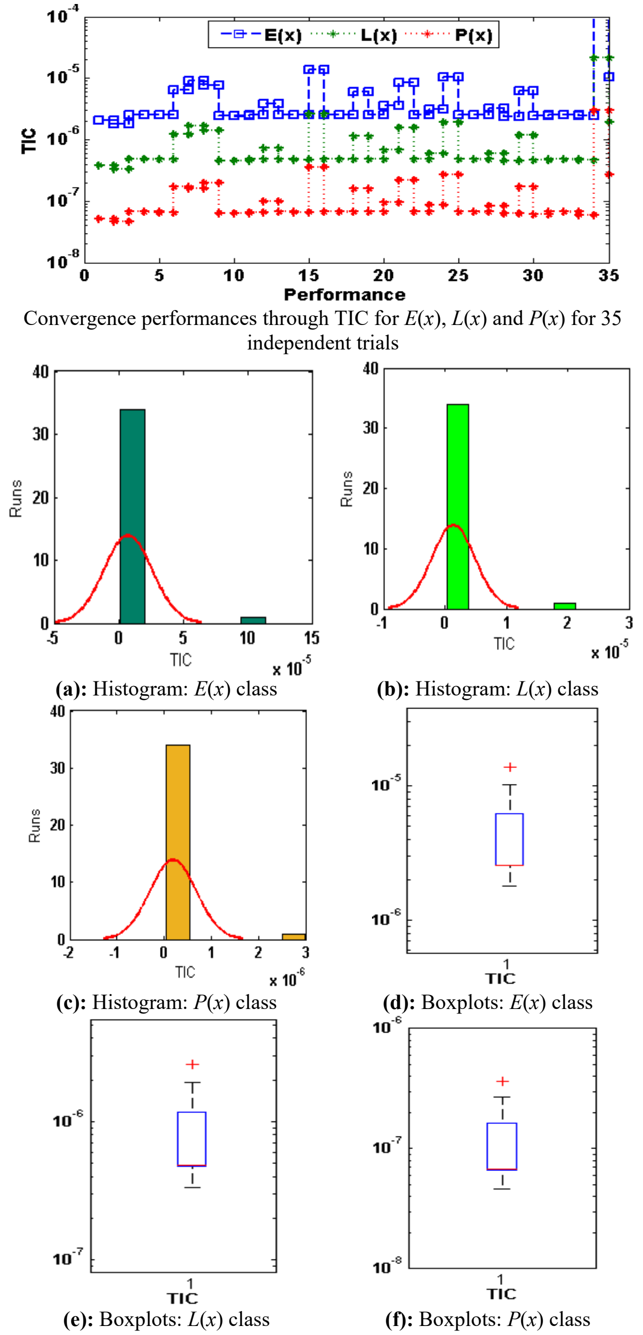
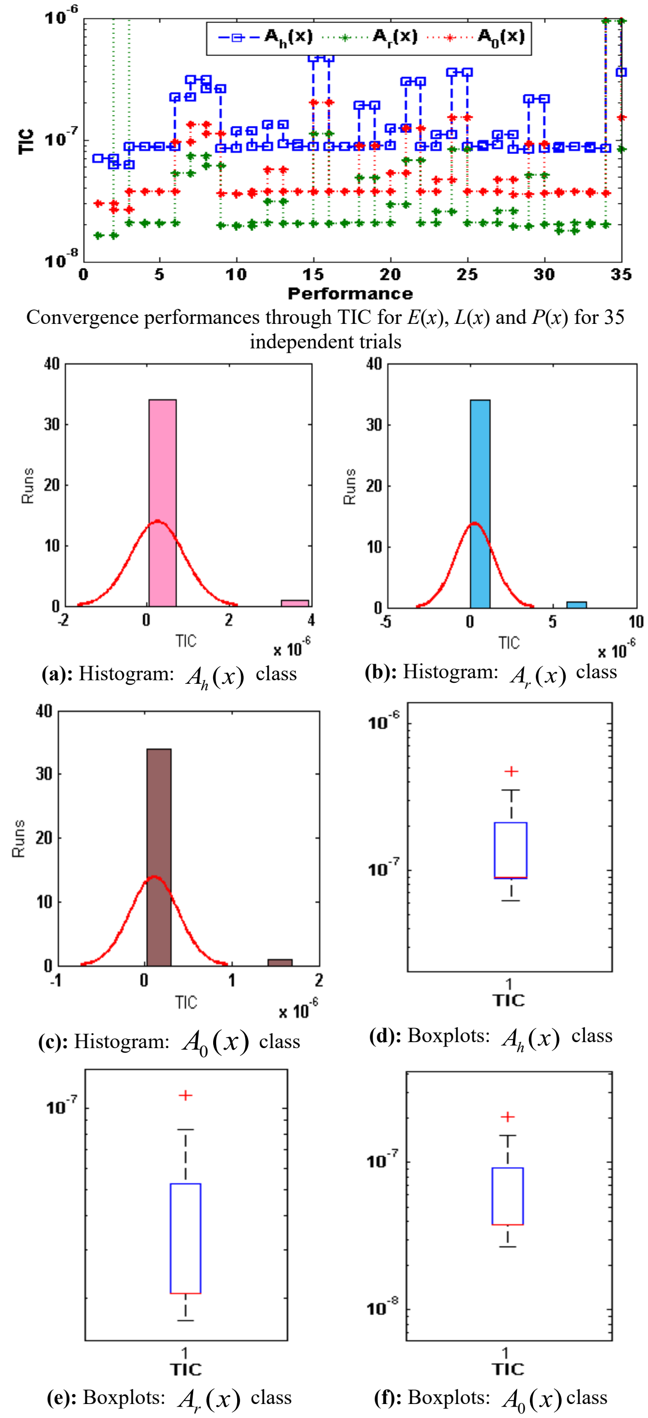


Convergence performances through TIC for $E(x)$, $L(x)$ and $P(x)$ for 35 independent trials

(a): Histogram: $E(x)$ class
(b): Histogram: $L(x)$ class
(c): Histogram: $P(x)$ class
(d): Boxplots: $E(x)$ class
(e): Boxplots: $L(x)$ class
(f): Boxplots: $P(x)$ class

FIGURE 7. Convergence performances through TIC for $E(x)$, $L(x)$ and $P(x)$ classes histograms and boxplots for 15 variables.

The graphs of AE are shown in Figure. 3. The classes $E(x)$, $L(x)$ and $P(x)$ plots are given in the subfigures 6(a), while, the plots of the rest of the classes $A_h(x)$, $A_r(x)$ and $A_0(x)$ of the NDMS in a heterogeneous atmosphere are given in subfigures 6(b). The best AE shown in subfigure 6(a) for the classes $E(x)$, $L(x)$ and $P(x)$ lie around 10^{-02} to 10^{-03}, 10^{-03} to 10^{-06} and 10^{-04} to 10^{-05}, respectively. While, the best AE shown in subfigure 6(b) for the classes $A_h(x)$, $A_r(x)$ and $A_0(x)$ lie about 10^{-03} to 10^{-05}, 10^{-04} to 10^{-06} and 10^{-03} to 10^{-05}, respectively.



Convergence performances through TIC for $E(x)$, $L(x)$ and $P(x)$ for 35 independent trials

(a): Histogram: $A_h(x)$ class
(b): Histogram: $A_r(x)$ class
(c): Histogram: $A_0(x)$ class
(d): Boxplots: $A_h(x)$ class
(e): Boxplots: $A_r(x)$ class
(f): Boxplots: $A_0(x)$ class

FIGURE 8. Convergence performances through TIC for $A_h(x)$, $A_r(x)$ and $A_0(x)$ classes histograms and boxplots for 15 variables.

The performance of the MWNN-GA-ASA is observed through the statistical based TIC and RMSE operators using the histograms and boxplots are provided in Figures 7-10. The performance of TIC operator for the classes $E(x)$, $L(x)$ and $P(x)$ is plotted in figure 7, while the rest of the classes $A_h(x)$, $A_r(x)$ and $A_0(x)$ of the NDMS in a heterogeneous atmosphere are illustrated in figure 8.

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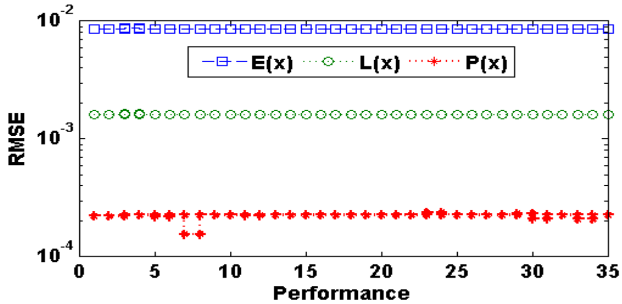
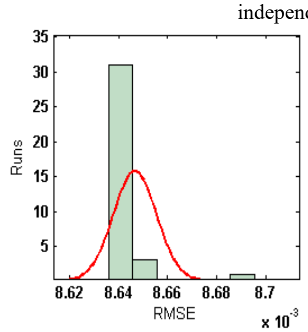
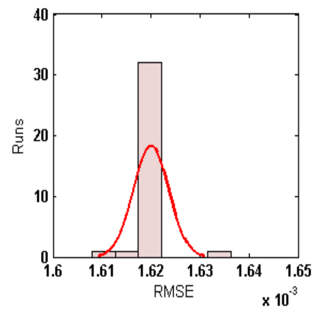


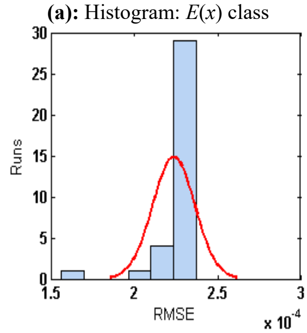
Convergence performances through RMSE for $E(x)$, $L(x)$ and $P(x)$ for 35 independent trials



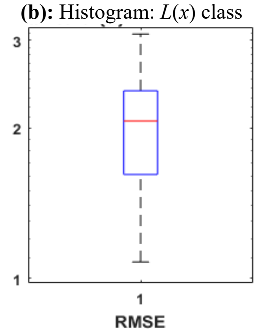
(a): Histogram: $E(x)$ class



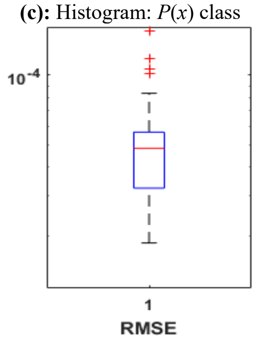
(b): Histogram: $L(x)$ class



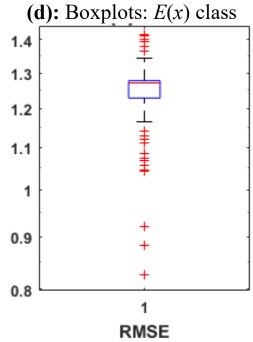
(c): Histogram: $P(x)$ class



(d): Boxplots: $E(x)$ class



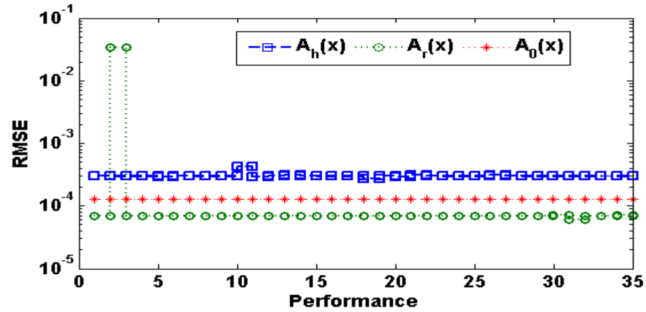
(e): Boxplots: $L(x)$ class



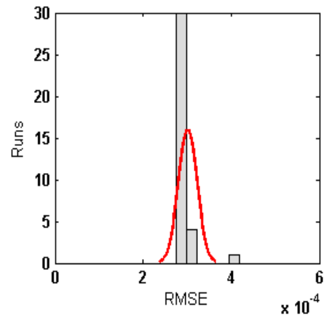
(f): Boxplots: $P(x)$ class

FIGURE 9. Convergence performances through RMSE for *E*(*x*), *L*(*x*) and *P*(*x*) classes histograms and boxplots for 15 variables.

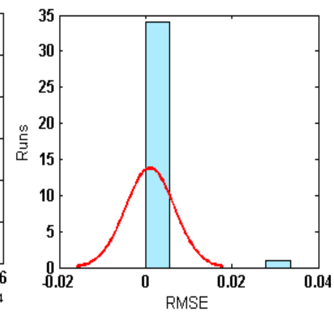
The best RMSE performances shown in figure 9 for the classes $E(x)$, $L(x)$ and $P(x)$ lie around 10^{-02} to 10^{-03}, 10^{-02} to 10^{-04} and 10^{-03} to 10^{-04}, respectively. While, the best RMSE performances as presented in figure 10 for the classes $A_h(x)$, $A_r(x)$ and $A_0(x)$ lie about 10^{-03} to 10^{-04}, 10^{-03} to 10^{-04} and 10^{-04} to 10^{-05}, respectively. These accurate results, i.e., values in good agreement with the desire level for the near to perfect modelling, on different performance operator calculated for 35 trials of MWNN-GA-ASA show that most of the executions achieved higher level of accuracy for TIC and RMSE operators, which further prove the worth of the designed MWNN-GA-ASA for solving the system model.



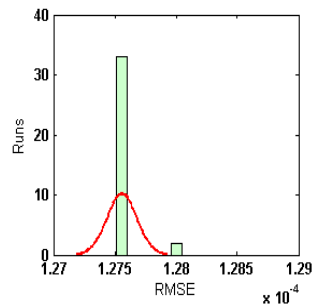
Convergence performances through RMSE for $A_h(x)$, $A_r(x)$ and $A_0(x)$ for 35 independent trials



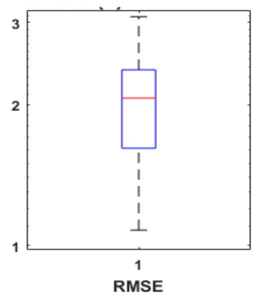
(a): Histogram: $A_h(x)$ class



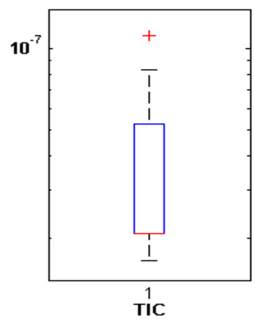
(b): Histogram: $A_r(x)$ class



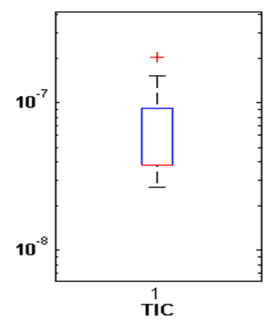
(c): Histogram: $A_0(x)$ class



(d): Boxplots: $A_h(x)$ class



(e): Boxplots: $A_r(x)$ class



(f): Boxplots: $A_0(x)$ class

FIGURE 10. Convergence performances through RMSE for $A_h(x)$, $A_r(x)$ and $A_0(x)$ classes histograms and boxplots for 15 variables.

Measure of central tendency and variations are exploited for better analysis of the precision and accuracy of the numerical outcome of MWNN-GA-ASA. The statistical results/observations for minimum (MIN), maximum

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3113986, IEEE Access

(MAX), median (MED) and semi interquartile range (S.I.R) using the proposed MWNN-GA-ASA for solving the NDMS in a heterogeneous atmosphere are calculated. The statistical observation in terms of MIN, MAX, MED and S.I.R for $E(x)$ and $L(x)$ are provided in Table III, while these indices for $P(x)$ and $A_r(x)$ are shown in Table IV and the other two classes for $A_r(x)$ and $A_0(x)$ these metrics are tabulated in Table V. The MIN and MAX values shows the best and worst results and a relatively small variation exist in these parameter which show the consist accuracy of MWNN-GA-ASA. The S.I.R is the difference of third and first quartiles and near to zero value of this metric is consistently achieved by MWNN-GA-ASA. The statistical performances of central tendency, i.e., mean and MED values, are found in reasonably accurate ranges for each class of the NDMS in a heterogeneous atmosphere consistently.

TABLE III
STATISTICS PERFORMANCES FOR $\boldsymbol{E(x)}$ AND $\boldsymbol{L(x)}$.

Index	x	Statistical indices			
		Min	Max	Med	S.I.R
$E(x)$	0	5.758E-06	3.497E-05	1.000E-05	5.665E-10
	0.1	4.605E-03	4.650E-03	4.625E-03	1.293E-11
	0.2	7.451E-03	7.479E-03	7.457E-03	3.748E-14
	0.3	9.083E-03	9.110E-03	9.087E-03	8.674E-19
	0.4	9.913E-03	9.946E-03	9.916E-03	8.674E-18
	0.5	1.022E-02	1.026E-02	1.022E-02	8.674E-19
	0.6	1.020E-02	1.025E-02	1.020E-02	0.000E+00
	0.7	9.971E-03	1.004E-02	9.974E-03	0.000E+00
	0.8	9.632E-03	9.714E-03	9.635E-03	1.188E-16
	0.9	9.235E-03	9.330E-03	9.241E-03	1.791E-12
	1	8.765E-03	8.922E-03	8.831E-03	1.258E-09
$L(x)$	0	7.708E-07	8.184E-05	1.000E-05	1.009E-09
	0.1	9.873E-05	1.294E-04	1.076E-04	6.802E-11
	0.2	3.343E-04	3.573E-04	3.428E-04	6.720E-14
	0.3	6.432E-04	6.626E-04	6.513E-04	4.224E-15
	0.4	9.832E-04	1.002E-03	9.909E-04	2.929E-15
	0.5	1.327E-03	1.347E-03	1.335E-03	2.392E-15
	0.6	1.659E-03	1.680E-03	1.666E-03	3.936E-17
	0.7	1.968E-03	1.992E-03	1.975E-03	3.996E-16
	0.8	2.251E-03	2.278E-03	2.257E-03	2.392E-13
	0.9	2.504E-03	2.535E-03	2.511E-03	8.778E-11
	1	2.662E-03	2.764E-03	2.736E-03	3.360E-10

TABLE IV
STATISTICS PERFORMANCES FOR $P(x)$ AND $A_r(x)$

Index	x	Statistical indices			
		Min	Max	Med	S.I.R
$P(x)$	0	6.327E-05	3.490E-04	3.000E-04	1.243E-07
	0.1	1.675E-04	2.696E-04	2.693E-04	5.640E-10
	0.2	1.499E-04	2.473E-04	2.437E-04	9.846E-11
	0.3	1.381E-04	2.268E-04	2.239E-04	3.039E-11
	0.4	1.320E-04	2.107E-04	2.100E-04	8.030E-14
	0.5	1.313E-04	2.014E-04	2.014E-04	2.660E-15
	0.6	1.354E-04	1.975E-04	1.975E-04	1.889E-13
	0.7	1.435E-04	1.977E-04	1.977E-04	2.349E-12
	0.8	1.550E-04	2.025E-04	2.012E-04	2.159E-12
	0.9	1.691E-04	2.274E-04	2.074E-04	1.181E-11
	1	1.498E-04	2.996E-04	2.156E-04	1.790E-10
$A_r(x)$	0	8.281E-06	1.857E-04	1.000E-04	6.767E-08
	0.1	1.814E-04	3.643E-04	1.911E-04	6.638E-10
	0.2	2.506E-04	4.136E-04	2.511E-04	1.161E-15
	0.3	2.883E-04	4.423E-04	2.898E-04	1.116E-12
	0.4	3.104E-04	4.568E-04	3.137E-04	2.708E-15
	0.5	3.207E-04	4.618E-04	3.278E-04	2.711E-20
	0.6	3.213E-04	4.608E-04	3.354E-04	1.027E-16
	0.7	3.133E-04	4.561E-04	3.390E-04	4.358E-17
	0.8	2.973E-04	4.495E-04	3.403E-04	2.433E-15
	0.9	2.769E-04	4.421E-04	3.404E-04	9.127E-11
	1	2.638E-04	4.391E-04	3.401E-04	4.854E-11

TABLE V
STATISTICS PERFORMANCES FOR $A_r(x)$ AND $A_0(x)$.

Index	x	Statistical indices			
		Min	Max	Med	S.I.R
$A_r(x)$	0	2.745E-07	3.942E-05	1.000E-05	8.339E-11
	0.1	1.619E-05	2.795E-05	1.619E-05	2.606E-10
	0.2	9.276E-07	2.547E-05	2.542E-05	4.772E-14
	0.3	2.189E-05	3.639E-05	3.638E-05	5.908E-17
	0.4	4.105E-05	4.818E-05	4.817E-05	1.848E-17
	0.5	5.704E-05	6.024E-05	6.022E-05	1.167E-15
	0.6	7.086E-05	7.221E-05	7.215E-05	5.112E-17
	0.7	8.327E-05	8.388E-05	8.374E-05	2.161E-15
	0.8	9.472E-05	9.531E-05	9.487E-05	4.525E-13
	0.9	7.505E-06	1.066E-04	1.055E-04	1.196E-11
	1	3.547E-06	1.111E-01	1.155E-04	1.173E-09
$A_0(x)$	0	2.999E-04	3.024E-04	3.000E-04	6.108E-12
	0.1	2.096E-04	2.097E-04	2.096E-04	2.140E-15
	0.2	1.470E-04	1.470E-04	1.470E-04	1.178E-17
	0.3	1.038E-04	1.038E-04	1.038E-04	8.132E-20
	0.4	7.410E-05	7.410E-05	7.410E-05	1.808E-13
	0.5	5.393E-05	5.394E-05	5.394E-05	2.3080-15
	0.6	4.038E-05	4.039E-05	4.039E-05	1.7654-18
	0.7	3.144E-05	3.144E-05	3.144E-05	2.033E-20
	0.8	2.567E-05	2.568E-05	2.567E-05	1.623E-16
	0.9	2.211E-05	2.218E-05	2.211E-05	8.626E-17
	1	2.006E-05	4.320E-05	2.007E-05	4.498E-10

VII. CONCLUSION

The design of IoT technology enabled Morlet wavelet neural network is presented viably and effectively for solving a class of nonlinear mosquito's dispersal system in the heterogeneous atmosphere. A merit function is considered in accordance with the representation of differential system of mosquito's dispersal system and corresponding initial conditions with MWNNs. The optimization of merit function to solve the nonlinear biological system is performed by using the global and local search techniques, GA-ASA. One can observe that the proposed results through MWNN-GA-ASA are overlapped with the Adams results that shows the accurateness of the scheme for solving the nonlinear mosquito's dispersal system. The comparison through AE is also observed in good ranges for each class of the mosquito's dispersal system. The mosquito's dispersal system is proficiently measured by the numerical MWNN-GA-ASA along with the layer construction neural networks using 15 numbers of variables. The stability of the solver MWNN-GA-ASA is examined with a reasonable level of accuracy for solving each class of the nonlinear mosquito's dispersal system in the heterogeneous atmosphere. Statistical explanations for 35 executions of MWNN-GA-ASA using the MIN, MAX, MED and S.I.R operators show the precision of the designed MWNN-GA-ASA. The MIN and

MAX operators show the best and worst performances of the MWNN-GA-ASA. Moreover, the TIC and RMSE operators authenticate the worth and values of the proposed MWNN-GA-ASA for solving the nonlinear mosquito's dispersal system in the heterogeneous atmosphere.

In future, the accessible MWNN-GA-ASA is promoted to solve the singular higher order, fractional models, smart cities model, and fluid dynamics systems [126-143].

ACKNOWLEDGMENT

We thank Professor D. P. Kothari (IEEE Fellow & IEEE Access Journal, Senior Editor) for his valuable comments and suggestions on improving the paper.

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