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A mathematical model of coronavirus transmission by using the heuristic computing neural networks

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\begin{abstract}
In this study, the nonlinear mathematical model of COVID-19 is investigated by stochastic solver using the scaled conjugate gradient neural networks (SCGNNs). The nonlinear mathematical model of COVID-19 is represented by coupled system of ordinary differential equations and is studied for three different cases of initial conditions with suitable parametric values. This model is studied subject to seven class of human population \(N(t)\) and individuals are categorized as: susceptible \(S(t)\), exposed \(E(t)\), quarantined \(Q(t)\), asymptotically diseased \(I_{a}(t)\), symptomatic diseased \(I_{s}(t)\) and finally the persons removed from COVID-19 and are denoted by \(R(t)\). The stochastic numerical computing SCGNNs approach will be used to examine the numerical performance of nonlinear mathematical model of COVID-19. The stochastic SCGNNs approach is based on three factors by using procedure of verification, sample statistics, testing and training. For this purpose, large portion of data is considered, i.e., 70\%, 16\%, 14\% for training, testing and validation, respectively. The efficiency, reliability and authenticity of stochastic numerical SCGNNs approach are analysed graphically in terms of error histograms, mean square error, correlation, regression and finally further endorsed by graphical illustrations for absolute errors in the range of \(10^{-05}\) to \(10^{-07}\) for each scenario of the system model.
\end{abstract}

1. Introduction

The humanity always encountered numerous challenges and difficulties in different forms like, earthquakes, destructive floods, climate changes, infectious diseases, world wars, which seriously affected the people’s lives and civilizations. Among these challenges the infectious diseases remain always huge challenge for humanity, which seriously affected the economies of many countries, education sector and tourism industry. History is full of such challenging diseases like fever caused by dengue virus [1]. The dengue fever widely spread in many countries and affected many people around globe. Every year many people admitted in hospitals due to dengue fever and most common symptoms of dengue virus include high fever, pain in joints and muscles, headache and vomiting. The HIV/AIDS [2] is another infectious disease whose first case was reported in 1976 at Democratic Republic of the Congo. Currently more than 31 million people around the globe are existing with HIV. Currently due to the awareness and developments of new treatments now HIV is somehow controllable disease. Some other deadly diseases in human history include Ebola, Lassa, Cholera, Influenza, Malaria, Smallpox, Bubonic plague [3].

Recently the world is facing another deadly novel virus known as Coronavirus. A novel Coronavirus is high transmittable and very dangerous virus, whose first case was reported in Wuhan city of China in December 2019 and rapidly spread around the globe [4]. This novel virus has badly affected routine life of the people and slows down the global economy [5-7]. The very large number of peoples died due to...
coronavirus disease and so for many variants of this virus has been discovered. The most common symptoms of COVID-19 contain dry cough, headaches, fever, sore throat and runny nose, shortness of breath. The coronavirus transmitted from people to people due to close contact and spreads rapidly which create degree of fear, worry and concern for every people, especially those having medical problem like cardiovascular disease, respiratory problems, cancer, diabetes and people of older age. The COVID-19 also creates mental and neurological complications such as stroke, agitation and delirium [8–10] among many people. The effective measures are urgently needed to control the further spread of this virus otherwise many problems like poverty, shortage of food, human loss and unemployment will further increase in future. Many countries impose lockdown and advise their peoples to wear mask, keep social distancing, avoid public gatherings, wash their hands regularly and so on [11] so that further spread of virus can be controlled. The COVID-19 badly affected the economies of many countries [12–14] and to avoid further losses proper and effective vaccine is urgently needed.

Thus, it is primary responsibility of researchers to design the mathematical models and examines the dynamics of coronavirus and presents their recommendations to control the further spread of this novel virus. In this connection many linear and nonlinear mathematical models [15–19] has been derived for novel COVID-19 to analyze it dynamics. In order to investigate the effects of different physical parameters in COVID-19 model different approaches has been used. In [20] the authors studied the COVID-19 mathematical model based on four classes namely, susceptible, healthy, infected and quarantine. The Lyapunov function theory and linearization approach has been used for analyzing the stability of possible equilibrium states. In addition to these numerical simulations are also carried and found it good agreement with obtained results. The stability of SIQR epidemic model and its bifurcation value has been studied by using Routh-Hurwitz criterion in [21]. Furthermore, SIQR model also been studied by different numerical methods. It has been found that nonstandard finite difference scheme preserves all important conditions of SIQR model while others fail to preserve its conditions. In [22] authors studied non-integer order derivative mathematical model for novel COVID-19. The Fractional Euler’s method has been used to obtain the numerical results of model. It has been observed that stability occurs rapidly for smaller fractional orders. In addition to this, authors also compared obtained simulations with real data of and found very close to obtained solutions. The qualitative analysis of non-integer mathematical model of COVID-19 has been presented in [23]. The uniqueness and sufficient conditions for existence of the model has been constructed by fixed point theory. Authors also used Laplace transform method together with Adomian decomposition method to construct approximate solutions and finally simulations also presented to support the obtained results. In [24] the authors studied mathematical model of novel COVID-19 via Levenberg-Marquardt artificial neural network (LMANNs) approach. The model derived in nonlinear coupled system of ordinary differential equations with different classes. The derived dataset utilized for training, validation and testing process. The reliability of design LMANNs has been achieved in terms of mean squared errors, error histograms and regression via graphical illustrations. The stochastic numerical approach has also been used to study the HIV mathematical models in [25–27]. In [28] authors used Morlet wavelet neural network (MWNN) approach to investigate second order Lane-Emden equation. In [29] authors studied fourth-order multi-singular nonlinear Emden–Fowler mathematical model by employing artificial neural network (ANN6) in combination of the global application of particle swarm optimization (PSO) enhanced by local search active set (AS) approach i.e. (ANN-PSO-AS). The effectiveness of applied approach has been verified by comparing with true results.

AI algorithm based stochastic numerical/optimization solvers have been implemented recently in different domain of applications including intelligent networks for solving the nonlinear chaotic fractional Rossler system [30], mathematical model for entropy generation in Ree-Eyring dissipative fluid flow [31], food chain models [32–33], Hall effects on

Table 1

| Parameter | Description |
|-----------|-------------|
| $\Lambda$ | Rate of Mortal recruitment |
| $\tau$ | Transmission rate from susceptible persons to quarantine persons |
| $\mu$ | Rate of natural mortality |
| $\beta$ | Rate of interaction among susceptible and exposed persons |
| $\gamma$ | Transmission rate of exposed to quarantine persons |
| $\eta$ | Transmission rate between exposed to symptomatic diseased persons |
| $\sigma$ | Rate of transfer from exposed persons to asymptomatic persons |
| $\omega$ | Transmission rate between quarantined to symptomatic diseased persons |
| $\theta$ | Transmission rate between quarantined to asymptomatic diseased persons |
| $r_1$ | Rate of recovered persons from asymptomatic disease |
| $r_2$ | Rate of recovered persons from symptomatic disease |
| $\delta$ | Rate of mortality in symptomatic diseased persons |

MHD Jeffery fluid flow model [34], mathematical model for the waste plastic management in ocean [35], fractional Bagley–Torvik mathematical model [36], fluidic system involving carbon nanotubes [37], thermal explosion theory [38], and stochastic numerical solution of the computer virus propagation with countermeasures model [39]. Keeping in view of these studies of paramount significance, the aim of presented research work n this paper is to implement/investigate in AI based approach via scaled conjugate gradient neural networks (SCGNNs) for prediction of the solution for the nonlinear mathematical model of COVID-19. The SCGNNs approach has been used to compute the numerical results for proposed mathematical model. The correctness and efficiency of SCGNNs approach to investigate nonlinear mathematical models is analysed with sufficient number of graphical illustrations as well as numerical analysis.

This paper is arranged as follows. The nonlinear mathematical model with associated initial conditions is presented in Section 2. The proposed methodology is given in Section 3 and graphical illustrations of numerical results are also discussed in this Section. Finally, the conclusion is presented in Section 4.

2. Mathematical model

This section presents the nonlinear mathematical model of COVID-19 subject to the suitable initial conditions. The mathematical model of COVID-19 is represented by system of nonlinear ordinary differential equations and this model is based on seven classes of human population $N(t)$ and is given as: $N(t) = S(t) + E(t) + Q(t) + I(t) + I_d(t) + R(t)$, where $S(t)$ represents susceptible persons, the class of exposed persons is denoted by $E(t)$ and the persons quarantined due to COVID-19 are represented by $Q(t)$ whereas $I_d(t)$ represents asymptotically diseased persons and similarly symptomatic diseased persons is denoted by $I(t)$ and finally $R(t)$ represents the class of persons removed from COVID-19. Thus based upon these classes we have following nonlinear system of ordinary differential equations with suitable initial conditions given as under [40]:

\[
\begin{align*}
\frac{dS(t)}{dt} &= \Lambda - (\tau + \mu)S(t) - \beta S(t)E(t), \\
\frac{dE(t)}{dt} &= \beta S(t)E(t) - (\gamma + \mu + \eta + \sigma)E(t), \\
\frac{dQ(t)}{dt} &= \tau S(t) + \gamma E(t) - (\mu + v + \phi)Q(t), \\
\frac{dI(t)}{dt} &= \sigma E(t) + \theta Q(t) - (\mu + r_1)I(t), \\
\frac{dI_d(t)}{dt} &= \eta I(t) + v Q(t) - (\delta + \mu + r_2)I_d(t), \\
\frac{dR(t)}{dt} &= r_1 I_d(t) + r_2 I(t) - \mu R(t),
\end{align*}
\]
The physical parameters of nonlinear mathematical model of COVID-19 pandemic as portrayed in set of equations (1) are taken from reported study [40] and defined in Table 1.

We have considered the following suitable parametric values to study the nonlinear mathematical model given in Eq. (1) and are given as under:

\[ \Lambda = 0.2, \quad \tau = 0.1, \quad \mu = 0.3, \quad \beta = 0.1, \quad \delta = 0.14, \quad \gamma = 0.15, \quad \eta = 0.25, \quad \sigma = 0.35, \quad \theta = 0.4, \quad \upsilon = 0.12, \quad r_1 = 0.35, \quad r_2 = 0.45 \]

The necessary justification along with theoretical convergence proof of the values of parameters in terms of global and local stability index is provided in reported [40] while the mathematical model given in Eq. (1) with above parametric values becomes as under:

Fig. 1. Workflow illustrations of the SCGNNs to study the mathematical of COVID-19.
below: \( (1 - 2) \) for three different set of the initial conditions while the parameter mathematical model of COVID-19 pandemic as portrayed in set of Eqs. networks (SCGNNs) is analyzed in case of sundry scenarios of nonlinear integrated intelligent networks via scaled conjugate gradient neural networks (SCGNNs).

**Case I:**

\[
\begin{align*}
\frac{dS(t)}{dt} &= 0.2 - (0.1 + 0.3)S(t) - 0.1S(t)E(t), \quad S(0) \geq 0, \\
\frac{dE(t)}{dt} &= 0.1S(t)E(t) - (0.15 + 0.3 + 0.25 + 0.35)E(t), \quad E(0) \geq 0, \\
\frac{dQ(t)}{dt} &= 0.1S(t) + 0.15E(t) - (0.3 + 0.12 + 0.4)Q(t), \quad Q(0) \geq 0, \\
\frac{dI_1(t)}{dt} &= 0.35E(t) + 0.4Q(t) - (0.3 + 0.35)I_1(t), \quad I_1(0) \geq 0, \\
\frac{dI_2(t)}{dt} &= 0.25E(t) + 0.12Q(t) - (0.14 + 0.3 + 0.45)I_2(t), \quad I_2(0) \geq 0, \\
\frac{dR(t)}{dt} &= 0.35I_1(t) + 0.45I_2(t) - 0.3R(t), \quad R(0) \geq 0.
\end{align*}
\]

(2)

Furthermore, The viable, robust and stable performance of proposed integrated intelligent networks via scaled conjugate gradient neural networks (SCGNNs) is analyzed in case of sundry scenarios of nonlinear mathematical model of COVID-19 pandemic as portrayed in set of Eqs. (1-2) for three different set of the initial conditions while the parameter values are remained fixed as given in reported study [40] as given below:

- **Case I:** \( S(0) = 0.1, \) \( E(0) = 0.15, \) \( Q(0) = 0.2, \) \( I_1(0) = 0.25, \) \( I_2(0) = 0.3, \) \( R(0) = 0.35 \)
- **Case II:** \( S(0) = 0.15, \) \( E(0) = 0.2, \) \( Q(0) = 0.25, \) \( I_1(0) = 0.3, \) \( I_2(0) = 0.35, \) \( R(0) = 0.4 \)
- **Case III:** \( S(0) = 0.2, \) \( E(0) = 0.25, \) \( Q(0) = 0.3, \) \( I_1(0) = 0.3, \) \( I_2(0) = 0.4, \) \( R(0) = 0.45 \)

In next section we will provide methodology to study nonlinear model subject to three different cases of initial conditions.

### 3. Methodology: SCGNNs

This section presents the methodology to investigate the nonlinear mathematical model of COVID-19 given in Eq. (2) subject to three different cases of initial conditions along with suitable values of different physical parameters. For investigating the nonlinear mathematical model of COVID-19 the scaled conjugate gradient neural networks (SCGNNs) approach has been used. The numerical stochastic SCGNNs approach has great capability to solve large class of (non)linear mathematical models of different fields. In this study, we used SCGNNs approach to compute the numerical performance of nonlinear mathematical model of COVID-19 based on three factors including sample statistics, testing and training. For this purpose the statics considered as 70%, 16% and 14% for training, testing and validations respectively. In addition to this, the effectiveness of numerical stochastic SCGNNs approach to investigate the nonlinear mathematical models has been analyzed graphically by using different graphs of like, error histograms, mean square error, correlation and regression and graphs for absolute errors are also drawn. Some important features of numerical stochastic SCGNNs approach to study the nonlinear mathematical models are given as under:

- The stochastic SCG approach together with artificial neural NNs has never been used before this to investigate COVID-19 nonlinear mathematical model.
- The effectiveness and correctness of the SCGNNs approach to investigate nonlinear mathematical model of COVID-19 is verified by Runge-Kutta scheme.
- The efficiency and authenticity of stochastic numerical SCGNNs approach to study the nonlinear mathematical model of COVID-19 is witnessed the through graphs of negligible absolute error (AE).
- In addition to this, the reliability of designed SCGNNs approach to deal nonlinear mathematical model of COVID-19 has also been

![Fig. 2. The organization of single neuron.](image1)

**Fig. 2.** The organization of single neuron.

![Fig. 3. SCGNNs for nonlinear system with 16 neurons.](image2)

**Fig. 3.** SCGNNs for nonlinear system with 16 neurons.
analyzed through the graphs of regression, EHs, correlation, MSE and STs.

Furthermore, numerical stochastic SCGNNs approach can also be applied to investigate (non)linear mathematical models of with fractional order as well.

Fig. 1 represents an appropriate optimization flow chart with multi neuron model based on stochastic numerical SCGNNs approach to investigate the nonlinear mathematical model of COVID-19. This flow chart shows that, in first step necessary performance by using stochastic SCGNNs will be carried out, and in next step numerical simulations will be drawn. The single neuron structure is presented in Fig. 2. The statics is 70%, 16% and 14% for training, testing and validation is used for investigating the COVID-19 nonlinear mathematical model. The label data is used for training samples, i.e., inputs with prior known targets, for formulations on the networks by optimization of mean square error (MSE) based figure of merit. While for both testing and validation samples unlabelled data is used, i.e., inputs without prior knowledge of target, in order to access the performance of proposed scaled conjugate gradient neural networks fo solving nonlinear mathematical model of COVID-19 pandemic as portrayed in set of equations (1). In this work, the numerical results of proposed system are achieved by utilizing 16 neurons by using stochastic SCGNNs approach and are structured in Fig. 3.

In Fig. 3, the neural networks structure is depicted in terms of inputs, i.e., vector representing the grid of inputs time $t$ that is independent variable of the system (1), output, i.e., matrix represented the approximate solution for 6 different classes as portrayed in system (1), hidden layers operated with 16 neurons and log-sigmoid based activation/transfer function, backpropagation algorithm of Levenberg Marquardt is exploited for learning. Moreover, all these parameter set with care to avoid the degradation of the results due to over/underfilling of the networks.
4. Numerical experimentation with interpretations

The numerical simulations to examine the proposed mathematical model of COVID-19 by using stochastic SCGNNs approach are presented in Figs. 4–7 and are illustrated for three different cases of initial conditions. Fig. 4 represents the STs and MSE performance to investigate the COVID-19 nonlinear mathematical model. The Figures 4(a-c) depicts the illustrations of best curve, verification, training, and testing by MSE, whereas Fig. 4(d-f) represents the STs best values for solving the nonlinear mathematical model of COVID-19 at the epochs 37, 62 and 46 for three different cases of initial conditions respectively. Fig. 4(a-c) depicts that the best validation performance values for solving nonlinear COVID-19 mathematical model for three different cases are $2.782 \times 10^{-10}$, $6.04 \times 10^{-11}$ and $1.379 \times 10^{-10}$ respectively. Furthermore, Fig. 4(d-f) represents the gradient measures values as $9.7088 \times 10^{-08}$, $9.7414 \times 10^{-08}$ and $9.7362 \times 10^{-08}$ for first, second and third case of respectively.

![Fig. 4. Valuations and EHs to investigate the proposed mathematical model of COVID-19.]

![Fig. 5. Valuations and EHs to investigate the proposed mathematical model of COVID-19.]

**Table 2**

| Case | MSE [Training] | MSE [Verification] | MSE [Testing] | Performance | Gradient | Mu | Epoch | Time |
|------|----------------|--------------------|---------------|-------------|----------|----|-------|------|
| 1    | $2.060 \times 10^{-10}$ | $2.782 \times 10^{-10}$ | $1.44 \times 10^{-10}$ | $2.06 \times 10^{-10}$ | $9.71 \times 10^{-08}$ | $1.0 \times 10^{-10}$ | 37 | 1     |
| 2    | $5.549 \times 10^{-11}$ | $6.039 \times 10^{-11}$ | $9.18 \times 10^{-11}$ | $5.55 \times 10^{-11}$ | $9.74 \times 10^{-08}$ | $1.0 \times 10^{-10}$ | 62 | 1     |
| 3    | $6.593 \times 10^{-11}$ | $1.379 \times 10^{-10}$ | $3.63 \times 10^{-10}$ | $6.59 \times 10^{-11}$ | $9.74 \times 10^{-08}$ | $1.0 \times 10^{-10}$ | 46 | 1     |
for solving nonlinear mathematical model of COVID-19. The efficiency and exactness for solving the nonlinear models by stochastic SCGNNs is witnessed by these obtained results.

The Fitting and error histograms EHs for solving nonlinear mathematical model by the approach of SCGNNs are illustrated in Fig. 5. Fig. 5 (a-c) depicts the training, validation, test target error and fit relationship for each case of initial conditions. However, it can easily observed from Fig. 5(d-f) that EHs values i.e. zero error occurs at $1.8 \times 10^{-6}$, $3.22 \times 10^{-7}$ and $1.11 \times 10^{-6}$ for first, second and third case respectively for considered nonlinear mathematical model. Furthermore, the statistical values for training, verifications testing and performance for each case is presented in Table 2 as under:

Fig. 6. Comparison of the result to investigate proposed mathematical model of COVID-19.

Finally, the graphical illustration for comparison and absolute error AE are drawn in Figs. 6 and 7, respectively for each case to study the proposed mathematical model of COVID-19. The authenticity and efficiency of stochastic numerical SCGNNs approach to examine the nonlinear mathematical model of COVID-19 is clearly depicted in graphs drawn for AE. The graphs drawn in Fig. 6 depict the matching of proposed and reference results that justify the authenticity and exactness of designed stochastic SCGNNs approach for solving nonlinear mathematical models. In this study, nonlinear mathematical model of COVID-19 has been studied seven different classes of human population subject to three different initial conditions.

The AE for each class and each case of nonlinear mathematical model
are illustrated in Fig. 7. It can be observed from Figure 8(a) that for susceptible individuals $S(t)$ the AE lies between $10^{-04}$ to $10^{-05}$, $10^{-05}$ to $10^{-07}$ and $10^{-07}$ to $10^{-06}$, for first, second and third case of initial conditions respectively. Fig. 7(b) depicts the AE based exposed individuals $E(t)$ lies between $10^{-05}$ - $10^{-06}$, $10^{-05}$ - $10^{-07}$ and $10^{-05}$ - $10^{-06}$ for first, second and third case respectively. The AE for quarantined individuals $Q(t)$ is drawn in Fig. 7(c) and it can be observed that the AE for each case lies between, $10^{-05}$ to $10^{-07}$, $10^{-05}$ to $10^{-06}$ and $10^{-05}$ to $10^{-07}$ for first, second and third case respectively for nonlinear mathematical model of COVID-19. Similarly, Fig. 7(e) is drawn to depict the AE for asymptotically infected individuals $I_A(t)$ and AE values lies for $10^{-04}$ to $10^{-08}$, $10^{-05}$ to $10^{-06}$ and $10^{-04}$ to $10^{-06}$, for first, second and third case respectively. Finally, it can easily be seen that the AE for removed individuals $R(t)$ lies between $10^{-05}$ to $10^{-07}$, for each case. These all values of AE for each case for nonlinear mathematical model of COVID-19 provide the efficiency and correctness of designed stochastic SCGNNs approach.

Fig. 7. AE to investigate proposed mathematical model of COVID-19.
5. Conclusions

In this paper, the nonlinear mathematical model of COVID-19 has been studied subject to seven classes of human population. The COVID-19 nonlinear mathematical model represented by system of ordinary differential equations with suitable initial conditions. This nonlinear system of ODEs has been investigated by using scaled conjugate gradient neural network (SCGNNs) and has been studied for three different cases of initial conditions with suitable values of physical parameters. Furthermore, the numerical computations has been carried out by using stochastic computing SCGNNs for verification purpose based on sample statistics, testing and training. For this purpose, 70%, 16% and 14% data has selected for training, testing and validations respectively. The exactness and efficiency of stochastic SCGNNs approach has been validated by Runge-Kutta method. The obtained results have been illustrated graphically using error histograms, mean square error correlation and regression. The efficiency and correctness of proposed stochastic SCGNNs approach has been witnessed from numerical simulations. The ease in implementations of SCGNNs, simple concept, extendibility and applicability for still and non-stiff problems are other noticeable advantages of the proposed approach.

In future, the stochastic numerical SCGNNs approach can also be used to study the same mathematical model of COVID-19 in terms of non-integers derivative. Moreover, the proposed scheme will be implemented to solve various differential models [41–44].

Declaration of Competing Interest

All authors describe that there are no potential conflicts of interest.

Data availability

Data will be made available on request.

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