Deep Learning Model For The Prediction And Prevention Of Covid-19

Joseph Romaric Cheuteu[1], **Samuel Bowong Tsakou**[2] **and Andre Nana Yakam**[3]

Laboratory of Mathematics, Department of Mathematics and Computer Science, The University of Douala

Corresponding author: Tel. +237 679 163 031/+237 690 452 187/677 869 539

Email: cheuteuromaric@gmail.com-sbowong@gmail.com-nanayakam@yahoo.com

Abstract

Covid-19 is an infectious disease caused by a strain of Coronavirus called SARCOV-2. This disease started in China on November 16, 2019 in Wuhan in Hubei province and was declared by the World Health Organization as a state of emergency on March 11, 2020. This epidemic started in Cameroon on March 14, 2020 in the far north region and up to our the whole world has experienced over 650 million confirmed cases with over 7 million deaths. This work concerns mathematical modeling of COVID-19 transmission in Cameroon using a deep learning. We establish first a mathematical model that describes the transmission of COVID-19 within the Cameroonian population using time-depending parameters and known constant parameters. We present a theoretical analysis of the model, more precisely, we prove the existence, uniqueness, the positivity, the boundedness of the solutions. We also determine the points of equilibrium. Secondly, we establish two deep learning models, namely an LSTM (Long Short Term Memory) and a GRU (Gated Recurrent Unit) and then we make the identification of the time-dependent parameters thanks to the daily data that we have had and during the training, the test and the predictions we obtain the best scores with the coefficient of determination which is between 0.96 and 0.98. Then we will extend our study by studying several other digital intelligence models such as machine learning models and we will also be able to adjust our mathematical model of transmission of COVID-19 in Cameroon and apply our model in several other countries.

Keywords: COVID-19; Mathematical models; Deep Learning; LSTM; GRU.

1 Introduction

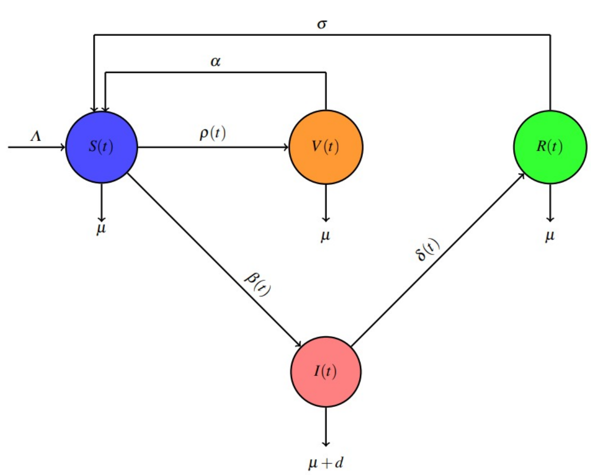
The world has known so far several types of event such as natural disasters. Since antiquity many of them have had to mark history. Up to the current COVID-19 declared on March 11, 2020 by the WHO as a pandemic [1]. It started in Wuhan at the end of December 2019 in China in the province of Hubei. Coronavirus disease is an infectious disease caused by a new virus (SARS-COV2) belonging to the beta coronavirus family. It is mainly spread by contact with an infected person. Until today there is no official measure to avoid contracting this disease and its spread is fast and controlling it becomes a difficult task. Therefore, the question arises as to how can Deep Learning help us predict and prevent Covid-19? To answer this question we build a mathematical model of the transmission of COVID-19 and then a deep learning model.

2 Model framework

2.1 Model construction

The mathematical formulation of the model is based on the following biological facts.

1. We consider the demographic effects by assuming a proportional natural mortality rate in each of the model sub-populations.
2. The model includes a net influx of susceptible individuals into our context which includes new births.
3. Infected cases are subjected to an additive mortality rate caused by the disease.
4. Vaccinated individuals are susceptible to contracting the disease again because of the partial immunity of the vaccine and recovered individuals can also contract the disease again.
5. The population is considered homogeneous and grouped into classes and the different compartments are constructed using real data that we have.



$$\begin{cases} S'(t) &= \Lambda + \alpha V(t) + \sigma R(t) - \rho(t) S(t) - \dfrac{\beta(t) S(t) I(t)}{N(t)} - \mu S(t), \\ V'(t) &= \rho(t) S(t) - (\alpha + \mu) V(t), \\ I'(t) &= \dfrac{\beta(t) S(t) I(t)}{N(t)} - \delta(t) I(t) - (\mu + d) I(t), \\ R'(t) &= \delta(t) I(t) - (\sigma + \mu) R(t). \end{cases}$$

Figure 1: Flowchart of the model and Mathematical Equations.

Table 1: Variables of system of Mathematical Equations

Parameters	Biological significance	Units
Λ	Human recruitment rate	individual.day^{-1}
σ	Wanning of recovery induced immunity	day^{-1}
α	Wanning of vaccine induced immunity	day^{-1}
μ	Natural mortality rate for human	day^{-1}
d	Additional mortality rate of detected cases	day^{-1}
$\rho(t)$	Vaccination rate at time t	day^{-1}
$\beta(t)$	Covid-19 transmission rate of detected cases at time t	day^{-1}
$\delta(t)$	Recovery rate of Covid-19 detected cases at time t	day^{-1}

2.2 Estimation of time-dependent parameters as a function of model states

By discretizing the mathematical system equations we have the following system and we deduce the formulation of $\beta(t)$, $\delta(t)$ and $\rho(t)$:

$$\begin{cases} S(t+1)-S(t) &= \Lambda+\alpha V(t)+\sigma R(t)-\rho(t)S(t)-\dfrac{\beta(t)S(t)I(t)}{N(t)}-\mu S(t), \\ V(t+1)-V(t) &= \rho(t)S(t)-(\alpha+\mu)V(t), \\ I(t+1)-I(t) &= \dfrac{\beta(t)S(t)I(t)}{N(t)}-\delta(t)I(t)-(\mu+d)I(t), \\ R(t+1)-R(t) &= \delta(t)I(t)-(\sigma+\mu)R(t). \end{cases} \qquad \begin{cases} \rho(t) &= \dfrac{V(t+1)-V(t)+(\mu+\alpha)V(t)}{S(t)}, \\ \beta(t) &= \dfrac{I(t+1)-I(t)+R(t+1)-R(t)+(\mu+\sigma)R(t)+(\mu+d)I(t)}{S(t)I(t)}\times N(t), \\ \delta(t) &= \dfrac{R(t+1)-R(t)+(\mu+\sigma)R(t)}{I(t)}. \end{cases}$$

3 Tools and Methods

3.1 Dataset

After estimating the parameters of the model, We use the parameters of the estimated model $\rho(t)$, $\beta(t)$ and $\delta(t)$ as prediction targets of the deep learning method. Since the parameters of the model constantly change during the development of the epidemic, in order to measure this change, we construct a time window of size w as the dimension of the input time series data in the deep learning model. Let the parameter of the model be x, and x is one of the elements of the set $\{\rho(t),\ \beta(t),\ \delta(t)\}$, then the time series can be obtained as $(x_0, \cdots\cdots, x_{T-2})$. Data: $\{\rho(t),\ \beta(t),\ \delta(t),\ 0 \leq t \leq T-2\}$. We use in this work 650 data from January 2020 to September 2021.

3.2 Deep Learning Model

Since our data is time dependent here and our data is time series, so we are going to do a study on time series analysis and for that we are going to use a recurrent neural network but since these are encountering a vanishing gradient problem, so we are going to take a sub variant which LSTM (long Short Term Memory) which is going to solve this problem and we will have the optimal results [2, 3].

3.3 Illustration using real data of COVID-19 epidemic in Cameroon

We present here the different results, namely: the training and test curves, the different scores with our four evaluation metrics and finally by the forecasts from each of our models (LSTM and GRU).

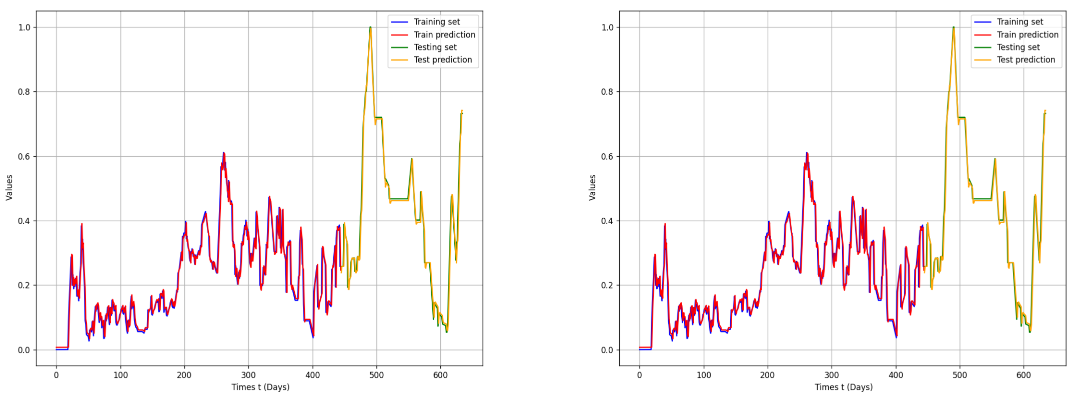


Figure 2: Train and test and of transmission rate and recovered rate using LSTM.

The two curves above represent the training and testing of our model using real data from Cameroon. On the left we have the rate of transmission of the disease which evolves over time and on the right we have the daily recovered rate as well.

Table 2: Prediction results of the train set of transmission rate of infected.

Beta	**Evaluations metrics values**			
Methods	**mse**	**rmse**	**nrmse**	**R^2**
LSTM	0.000476	0.021822	0.078567	0.991807

These different metrics that our train well and test well for our beta transmission rate.

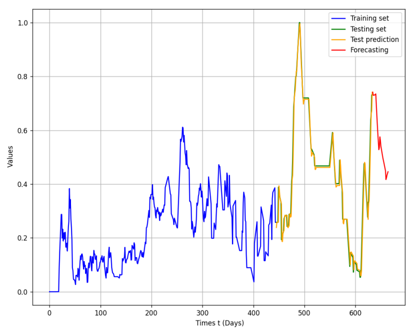
Table 3: Prediction results of the test set of transmission rate of infected.

Beta	Evaluations metrics values			
Methods	**mse**	**rmse**	**nrmse**	**R^2**
LSTM	0.000826	0.028749	0.112435	0.982225

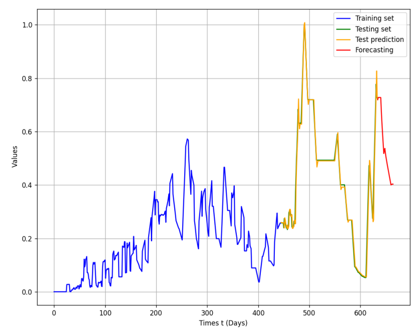
These different metrics that our train well and test well for our delta recovered rate.

3.4 Forecasting over 30 days

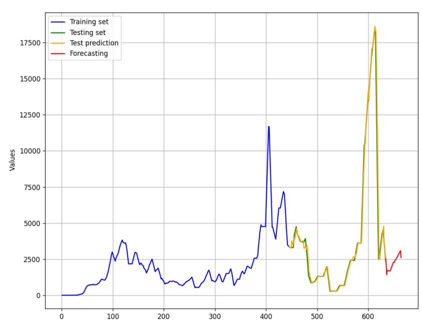
Here, we present the forecast for the next 30 days of transmission rate of infected, recovered rate, vaccination rate and the number of new infected cases.



(a)



(b)



(c)

Figure 3: (a) Forecasting of transmission rate, (b) Forecasting of recovered rate and (c) Forecasting of Infected Cases.

4 Discussions, Conclusion and Perspectives

In conclusion, our work here consisted of predicting and preventing Covid-19 using a Deep Learning model. In order to solve this problem, we have combined a mathematical model which describes the transmission dynamics of Covid-19 associated with a Deep Learning model which will retrieve the estimated parameters as a function of time in the mathematical model and use it in the Deep Learning model and these parameters are the vaccination rate, the infection rate and the cure rate. These parameters allow us at any time to know the evolution of the disease and the interpretation is more robust. We use a particular case of RNN which is the LSTM because we have data which is chronological data. During the study of the mathematical model by estimating the time-dependent parameters, we observe several and several variations, the disease tends to decrease and then it resumes ascending and this may be due to several mutations of the virus. It should be noted that the raw data we have are the number of confirmed cases, the number of vaccinated individuals, the number of cases of infections detected, the number of cured and the number of deaths, and it is with these data that we make our estimates on our rates quoted above and carry out our work. We studied the rate of transmission and cure of the disease and we have good results in the training and validation of the model and so in the forecasts over the next 30 days we find that the different decrease and grow slowly. However, from which we conclude that the disease is still present in Cameroon and is gradually disappearing, hence the need to always respect the barrier measures. To talk about limitations of this work, One limitation is the accuracy of the data. The data we use is official statistics, and there will be some differences from the actual data in the real world. Another limitation of our research is that the deep learning method we use for parameter prediction may not be optimal, and there may be better ways to solve the model and predict the parameters. We will improve our model in future work.

In perspectives, We are going in the next works to build a mathematical model which takes into account several other states and parameters and to develop several other models of digital intelligence such as automatic learning models and to make comparisons.

Acknowledgments

My sincere thanks and deep appreciation to my supervisors Prof. Bowong Tsakou Samuel and Dr. Nana Yakam Andre for their unlimited availability, their unconditional support, their constant benevolence and the thousand criticisms brought to improve this work.

My sincere thanks to the Mathematics and Computer Science Laboratory of the University of Douala.

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