IOP Institute of Physics
The Physics of Infection

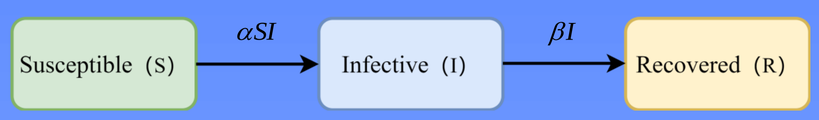
The dynamics model of time-varying infectious disease based on machine learning

*Jinxuan Luo, Guangyi Jia**

School of Science, Tianjin University of Commerce, Tianjin 300134, P. R. China
*Email: gyjia87@163.com

ABSTRACT: The outbreak and spread of COVID-19 have significantly influenced global economics and people's lives. By the end of August 31, 2022, there have been 599,071,265 confirmed cases of COVID-19 and reported 6,467,023 deaths in the world, according to the most recent WHO real-time statistics. COVID-19 has severely impacted lifestyles worldwide. It is meaningful to exploit effective dynamics models to exactly predict the development trend of COVID-19 patients. Among various prediction models, the mathematical model of infectious disease dynamics has been extensively used to forecast the COVID-19. However, in the actual development of the epidemic, as the national governments continue to take effective control and prevention strategies, the self-isolation and protection awareness of susceptible people are increasingly enhanced, both of which will cause the infection coefficients to change over time. Besides, the accumulation of clinical experience and the development of vaccines further make the healing factor constantly change. All of these variation factors are not taken into account by the infectious disease dynamics. In view of this, we proposed a time-varying model with specific parameters on the basis of machine learning. In this model, we make full use of polynomial regression and back propagation (BP) neural network to fit the time-varying parameters, and then optimize the epidemic transmission model via adjusting parameters. By using the gradient search technology, BP neural network minimizes the mean square error of the actual output value and the expected output value of the network. The final fitting results show that our proposed method can be utilized to more effectively predict the variation tendency of COVID-19 patients than the current infectious disease dynamics.

➢ Mystem dynamics model



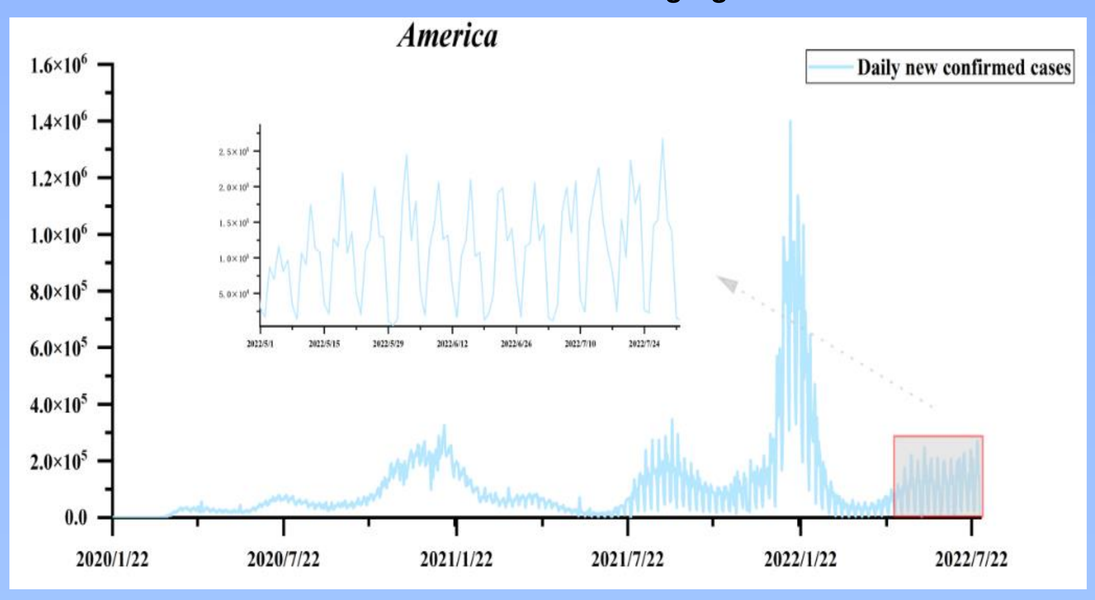
$$\begin{cases} \dfrac{dS}{dt} = -\alpha SI \\ \dfrac{dI}{dt} = \alpha SI - \beta I \\ \dfrac{dR}{dt} = \beta I \\ S + I + R = N \end{cases} \rightarrow \begin{cases} S_t = \dfrac{(\alpha S_{t-1} + \alpha I_{t-1} + 1 + \beta) - \sqrt{(\alpha S_{t-1} + \alpha I_{t-1} + 1 + \beta)^2 - 4\alpha S_{t-1}(1+\beta)}}{2\alpha} \\ I_t = \dfrac{I_{t-1}}{1 + \beta - \alpha S_t} \\ R_t = N - S_t - I_t \end{cases}$$

➢ Methods

- Polynomial regression is an extension of linear regression that allows us to model nonlinear relationships. Linear regression uses straight lines to fit the data, while polynomial regression uses curves to fit the data.
- BP neural network is known as a multilayer feedforward neural network, which is utilized to solve nonlinear problems. The steps of the whole neural network are: 1. The input layer receives the external input; 2. The input features or signals are processed by the neurons in hidden and output layers through the weight matrix; 3. The results are outputed. The most important part of the process is to obtain the weights required for processing, essentially the learning process of neural networks is learning the weights of the connections between neurons and neurons.

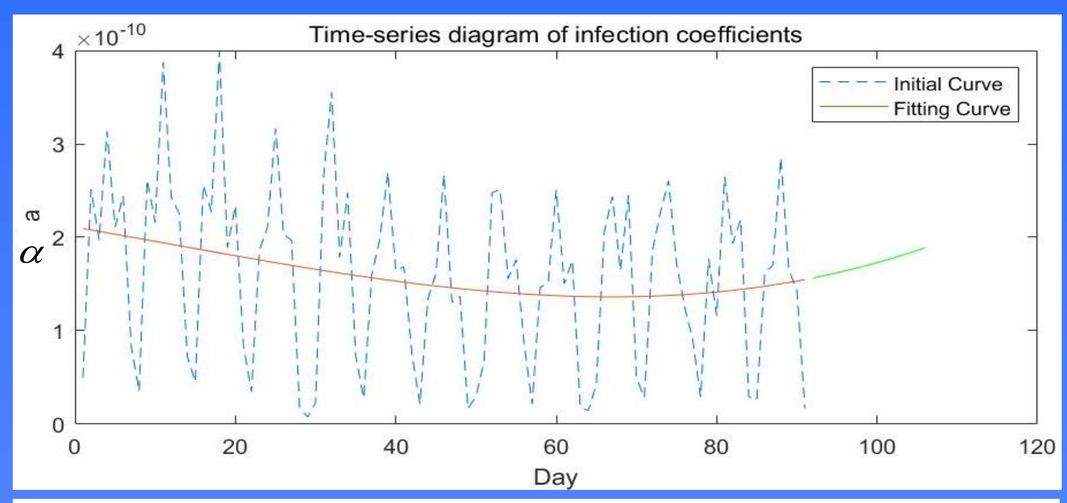
➢ Data visualization

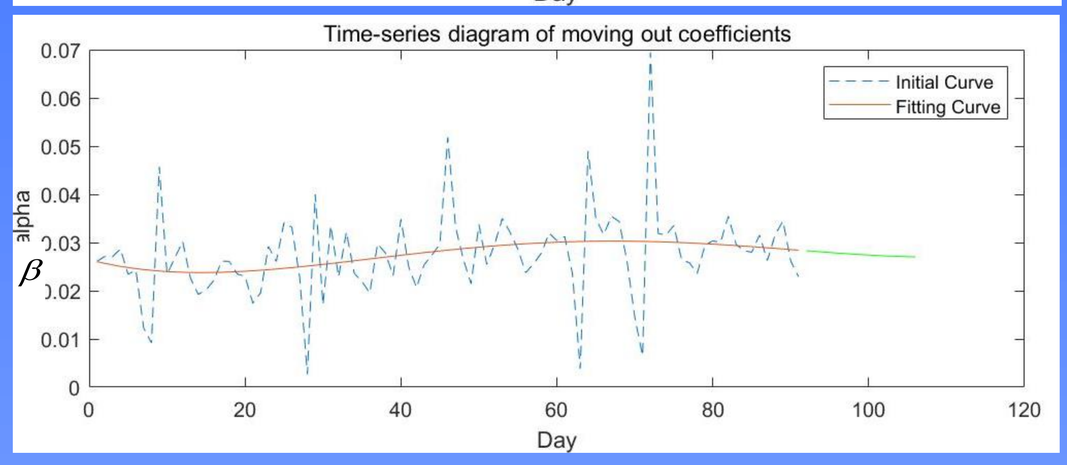
Since January 2020, the daily number of new confirmed cases in the United States is shown in the following figure



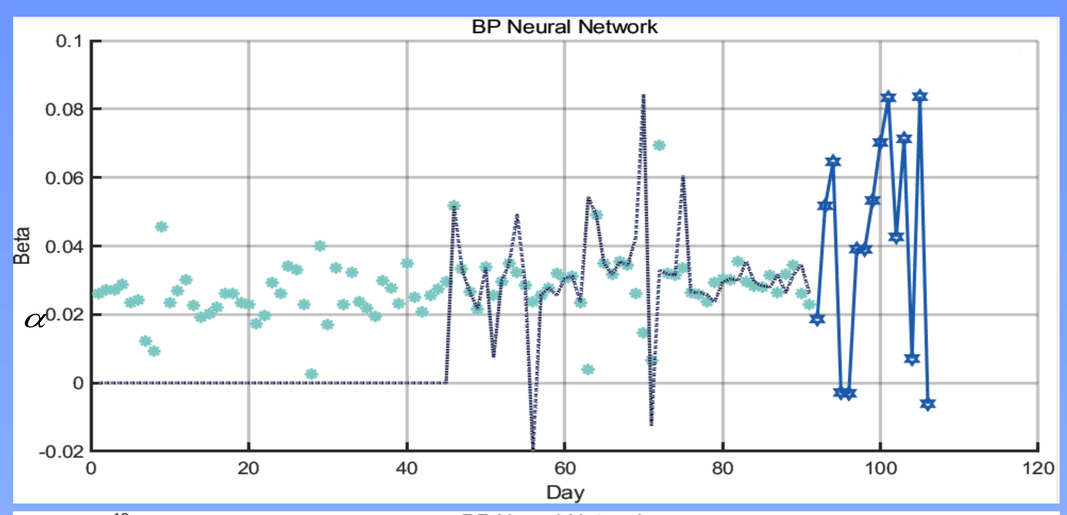
➢ Parameter fitting

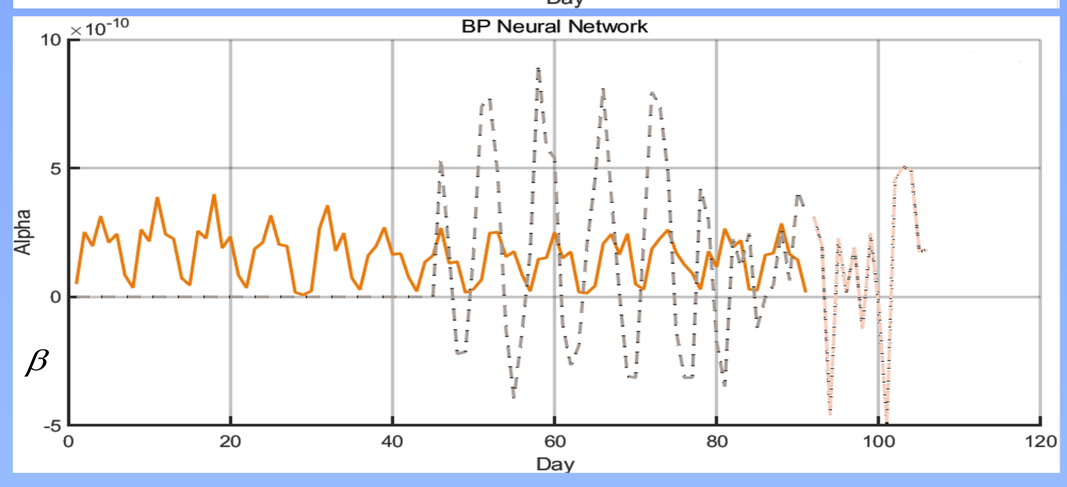
Polynomial regression: Infection factor α and move out factor β





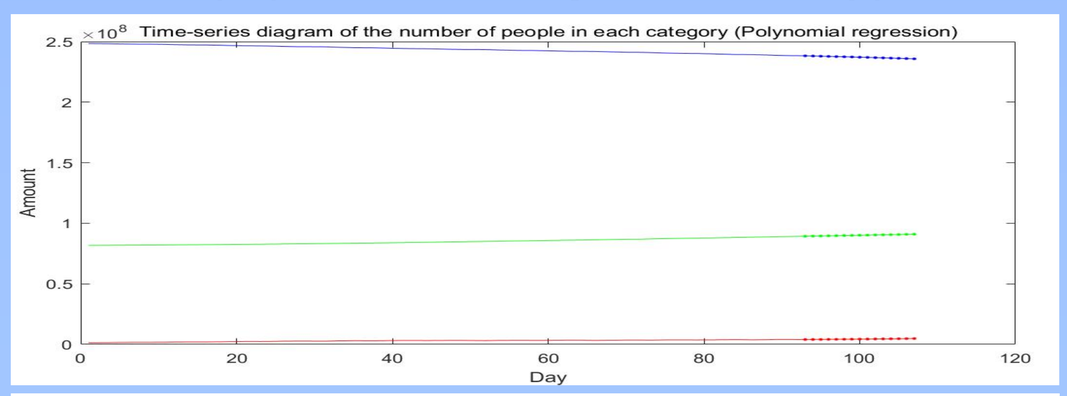
BP neural network: Infection factor α and move out factor β

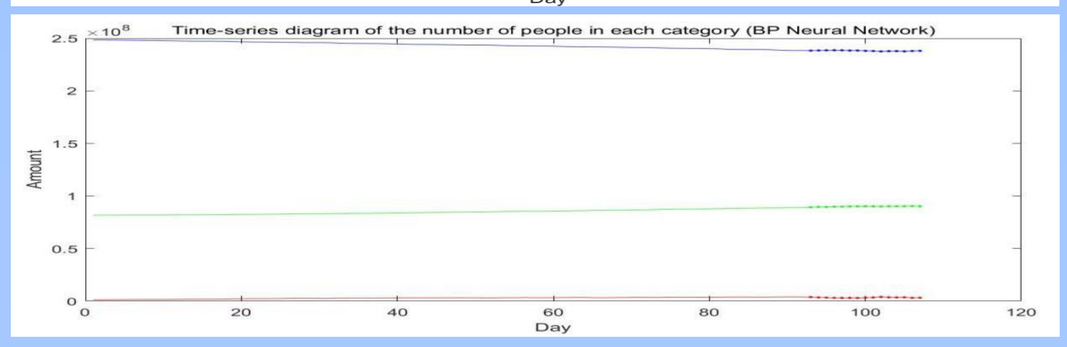




➢ Conclusion

Both the classical susceptible-infected-recovered model and differential recursion method are used to simulate the epidemic situation and extrapolate the data from the total volume. By using polynomial regression and BP neural network to dynamically track the infection coefficient and displacement coefficient, the variation tendency over time for all kinds of people in the control stage can be accurately predicted.





➢ References

[1] Vega R, Flores L, Greiner R. SIMLR: Machine Learning inside the SIR model for COVID-19 Forecasting[J]. Forecasting, 2022, 4(1): 72-94. https://doi.org/10.3390/forecast4010005

[2] Chen X, Li J, Xiao C, et al. Numerical solution and parameter estimation for uncertain SIR model with application to COVID-19[J]. Fuzzy optimization and decision making, 2021, 20(2): 189-208. https://doi.org/10.1007/s10700-020-09342-9

[3] Bai Y, Jin Z. Prediction of SARS epidemic by BP neural networks with online prediction strategy[J]. Chaos, Solitons & Fractals, 2005, 26(2): 559-569. https://doi.org/10.1016/j.chaos.2005.01.064.