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Dynamic analysis of a fractional-order delayed SIQR epidemic model for COVID-19 pandemic

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Abstract. In this paper, we build a fractional-order delayed SIQR epidemic model for COVID-19 pandemic. By leveraging the linearization method and the Laplace transform, the characteristic equation of the linearized system corresponding to the model is derived. The relationship between time delay and the stability of the positive equilibrium point is then explored through the examination of the roots of the characteristic equation and the cross-sectional conditions. Furthermore, a formula for calculating the critical value of time delay for the Hopf bifurcation is derived. Finally, suitable system parameters are chosen for numerical simulation to validate the soundness of the theoretical analysis.

Keywords: Fractional calculus; COVID-19 model; Stability; Hopf bifurcation; Delay

References

[1] Luo X.F., Feng S., Yang J., et al. Nonpharmaceutical interventions contribute to the control of COVID-19 in China based on a pairwise model. Infectious Disease Modelling, 2021, 6: 643-663.

[2] Tang X., Wu C., Li X., et al. On the origin and continuing evolution of SARS-CoV-2. National science review, 2020, 7(6): 1012-1023.

[3] Chinazzi M., Davis J.T., Ajelli M., et al. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. Science. 2020, 368(6489): 395-400.

[4] Peeri N.C., Shrestha N., Rahman M.S., et al. The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: what lessons have we learned? International Journal of Epidemiology. 2020, 49(3): 717-726.

[5] Hiroshi N.,Tetsuro K., Takeshi M., et al. Estimation of the asymptomatic ratio of novel coronavirus infections (COVID-19). International Journal of Infenctious Diseases. 2020, 94(2): 154-155.

[6] Li Q., Xiao Y.N., Wu J.H., Tang S.Y., Modelling COVID-19 epidemic with time delay and analyzing the strategy of confirmed cases-driven contact tracting following by quarantine (in Chinese), Acta Mathematicae Applicatae Sinica, 2020, 43(2):238-250.

[7] Peter O.J., Panigoro H.S., Abidemi A., et al. Mathematical model of COVID-19 pandemic with double dose vaccination. Acta biotheoretica, 2023, 71(2): 9.

[8] Gao S, Binod P, Chukwu C W, et al. A mathematical model to assess the impact of testing and isolation compliance on the transmission of COVID-19. Infectious Disease Modelling, 2023, 8(2): 427-444.

[9] Danane J., Hammouch Z., Allali K., et al. A fractional-order model of coronavirus disease 2019 (COVID-19) with governmental action and individual reaction. Mathematical Methods in the Applied Sciences, 2023, 46(7): 8275-8288.

[10] Butt A.I.K., Imran M., Chamaleen D.B.D., et al. Optimal control strategies for the reliable and competitive mathematical analysis of Covid-19 pandemic model. Mathematical Methods in the Applied Sciences, 2023, 46(2): 1528-1555.

[11] Sokolov A.V., Sokolova L.A. COVID-19 dynamic model: balanced identification of general biological and country specific features. Procedia computer science, 2020, 178: 301-310.

[12] Lazzizzera, I. An analytic approximate solution of the SIR model. Applied Mathematics, 2021, 12: 58-73.

[13] Podlubny I., Fractional Differential Equations, Academic Press, New York, 1999.

[14] Dai Y., Wei Y., Hu Y., et al. Modulating function-based identification for fractional order systems. Neurocomputing, 2016, 173: 1959-1966.

[15] Wei Y., Tse P.W., Yao Z., et al. Adaptive backstepping output feedback control for a class of nonlinear fractional order systems. Nonlinear Dynamics, 2016, 86: 1047-1056.

[16] Zarin R., Khan A., Yusuf A., et al. Analysis of fractional COVID-19 epidemic model under Caputo operator. Mathematical Methods in the Applied Sciences, 2023, 46(7): 7944-7964.

[17] Arshad S., Siddique I., Nawaz F., et al. Dynamics of a fractional order mathematical model for COVID-19 epidemic transmission. Physica A: Statistical Mechanics and its Applications, 2023, 609: 128383.

[18] Ruan S., Wang W.. Dynamical behavior of an epidemic model with a nonlinear incidence rate. Journal of differential equations, 2003, 188(1): 135-163.

[19] Xiao D., Ruan S.. Global analysis of an epidemic model with nonmonotone incidence rate. Mathematical biosciences, 2007, 208(2): 419-429.

[20] Tchuenche J.M., Nwagwo A., Levins R., Global behaviour of an SIR epidemic model with time delay. Mathematical methods in the applied sciences, 2007, 30(6): 733-749.

[21] Wang W., Global behavior of an SEIRS epidemic model with time delays. Applied Mathematics Letters, 2002, 15(4): 423-428.

[22] Liu L., A delayed SIR model with general nonlinear incidence rate. Advances in Difference Equations, 2015, 2015(1): 1-11.

[23] Vinitsky S.I., Gusev A.A., Derbov V.L., et al. Reduced SIR model of COVID-19 pandemic. Computational Mathematics and Mathematical Physics, 2021, 61(3): 376-387.

[24] Pen'kov F.M., Derbov V.L., Chuluunbaatar G., et al. Approximate Solutions of the RSIR Model of COVID-19 Pandemic. A. Byrski et al. (Eds.): ANTICOVID 2021, IFIP AICT 2021; 616: 53-64.

[25] Li C.P., Zhao Z.G., Asymptotical stability analysis of linear fractional diferential systems, Journal of Shanghai University (English Edition), 2009, 13(3): 197-206.

[26] Deng W.H., Li C.P., Lü J.H., Stability analysis of linear fractional diferential system with multiple time delays, Nonlinear Dynamics, 2007, 48(4): 409-416.

[27] Li H.L., Zhang L., Hu C., Jiang Y.L., Teng Z.D., Dynamical analysis of a fractional-order predator-prey model incorporating a prey refuge, Journal of Applied Mathematics and Computing, 2017, 54(1-2): 435-449.

[28] Odibat Z.M., Shawagfeh N.T., Generalized Taylors formula, Applied Mathematics and Computation, 2007, 186: 286-293.

[29] Boukhouima A., Hattaf K., Yousfi N., Dynamics of a fractional order HIV infection model with specific functional response and cure rate, International Journal of Differential Equations, 2017, 2017: 8372140.

[30] van den Driessche P., Watmough J., Reproduction numbers and sub-Threshold endemic equilibria for compartmental models of disease transmission, Mathematical Biosciences, 2007, 180: 29-48.