Multi-Phase Dynamics of COVID-19 and Data-Driven Forecasts

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Abstract. As COVID-19 has spread across the world, drastic measures for transmission containment have been taken sequentially in different regions of the globe. With the aim of understanding the disease spreading dynamics, an enhanced compartment model is proposed based on the Susceptible-Exposed-Infected-Quarantined-Recovered (SEIQR) system. To include the containment effects of different measures, such as lockdown and reopening, the multi-phase nature of the dynamics is considered and the infection rate is modeled as a time-varying input in the enhanced model. Besides, variability in individual responses to infection is also considered and distributed delays are introduced to capture this aspect. Hence, the constructed enhanced model is a non-autonomous, nonlinear system with distributed time delays. To solve the inverse dynamics problem presented by the unknown parameters, unknown input, and unknown initial conditions, data-driven approaches are utilized based on a nonlinear regression algorithm. Case study applications are carried out in three countries: South Korea, Spain, and the USA. From the input identification results, it is revealed that two-phase, three-phase, and four-phase descriptions are required for the COVID-19 dynamics in South Korea, Spain, and the USA, respectively. The number of phases is also indicative of how well the containment measures have worked in the associated region. Reproduction numbers in each phase are also compared amongst these three countries to get a sense of the effectiveness of the chosen containment measures. Short-term forecasts based on data-driven dynamics are provided for understanding the evolution of the COVID-19 infection dynamics, the best- and worst-case possibilities, and information for policy makers.

Introduction, Results, and Discussion

COVID-19 is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It was first identified in December 2019 in Wuhan, Hubei, China, and has swept over this globe and caused almost 20 million confirmed infections at the time of writing this abstract in early August. A number of epidemiological models and analyses, including the SIR & SEIR models, machine learning-based models, and statistical regression analysis, have been pursued by different researchers. However, since the unknown parameters and unknown inputs introduce challenges to the system, satisfactory solutions have not been found yet for this inverse dynamics problem. This is to be addressed here, following on the recent work of the first and third authors [1]. Primary aspects of this work are as follows:

(1) To capture the containment effects during different stages, the multi-phase nature of the infection rate is taken into consideration. The infection rate is regarded as an unknown input, as shown in Figure 1(a).

(2) Variability in individual responses to infection is considered and distributed delays are introduced. This helps improve the response of the dynamical system and makes it more realistic.

(3) The number of parameters is kept as few as possible. With no more than 9 parameters, this architecture is not as parameter dense as machine learning models [2], which have hundreds of parameters and are prone to overfitting.

(4) Data-driven approaches are used for system identification and the identified system is used for forecasts. For the case studies of South Korea, Spain, and the USA, the proposed model prediction is found to show excellent convergence, and this is encouraging for capturing multiple waves of COVID-19, as shown in Figure 1(b).

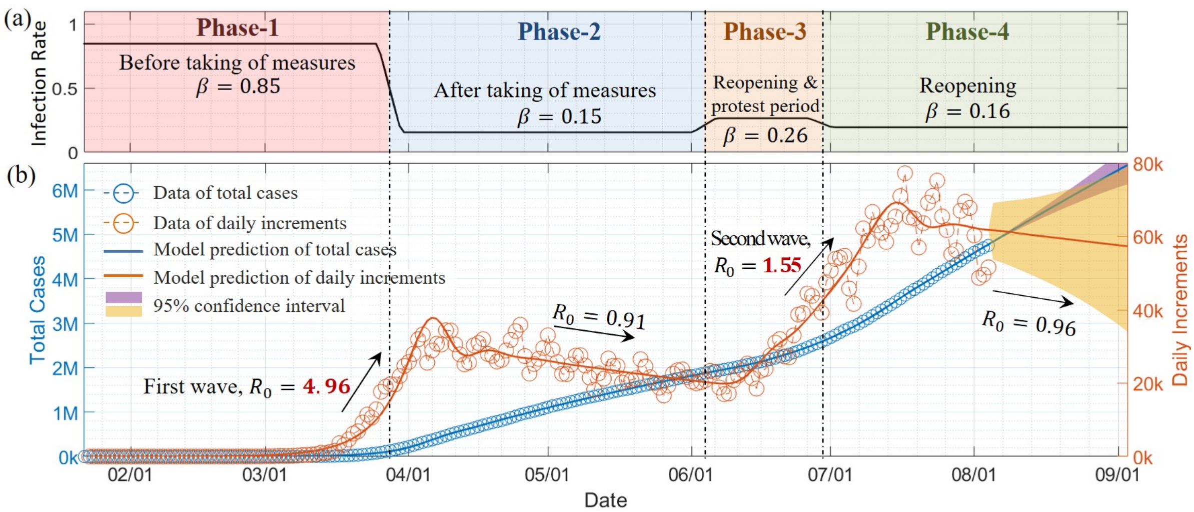

Figure 1: COVID-19 Dynamics in USA: (a) identified infection rate with four-phase description and (b) infection dynamics.

References

[1] Liu X., Zheng X., Balachandran B. (2020) COVID-19: Data-Driven Dynamics, Statistical and Distributed-Delay Models, and Observations, Nonlinear Dynamics.

[2] COVID-19 Projections Using Machine Learning, website **https://covid19-projections.com**.