Delayed dynamics of SIR model for COVID-19 spread forecasting

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Abstract

Background

The global spread of the COVID-19 pandemic has been one of the most challenging tasks the world has faced since the last pandemic outbreak of 1918. Early on countries felt the strength and persistence of the virus infections spreading with no means of estimating the dispersion rates. Officials in infected countries followed several guidelines set by the World Health Organization (WHO) to try and flatten the infection curve and maintain a low number of infectives. Nonetheless, the virus kept on spreading with impunity and all predictions of how containments or peak detections have been a fail so far. Therefore, a need for a more accurate model to predict the peaking of infections and help guide officials on what best to enact as a measure of public health safety from a multitude of choices outlined by the WHO. Earlier studies of compartmental model of Susceptible-Infected-Recovered (SIR) did not predict the peaking of a hot spots flairs of viral infections and a new model needed to provide a more realistic results to serve public officials battling the pandemic worldwide

Methods

A new modified SIR model which incorporates appropriate delay parameters leading to a more precise prediction of COVID-19 real time data. The predictions of the new model are compared to real data obtained from four countries, namely Germany, Italy, Kuwait, and Oman. Two included delay periods for incubation and recovery within the SIR model produces a sensible and more accurate representation of the real time data. The reproductive number R_0 is defined for the model for values of recovery time delay τ_2 of the infective case.

Results

Incorporating two delay periods that corresponds to the duration of the incubational and recovery periods measured for COVID-19 gives a more accurate prediction of the peak pandemic infections per geographical area. The parameter variations in the model $\beta, \gamma, \alpha, \tau_1, \text{ and } \tau_2$ makeup different cases corresponding to different situations. The variations are estimated a priori based on what is being observed and collected data of an infected region to give officials better guidelines on what health policies should be enacted in the future.

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Conclusions

The empirical data provided by WHO show that the proposed new SIR model gives a better more accurate prediction of COVID-19 pandemic spreading curve. The model is shown to closely fit real time data for four countries. Simulation results are consistent with data and generated curves are well constrained. The parameters can be varied and adjusted for producing and/or reproduction of numbers within the range of each country

Full Text

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Figures

Figure 1

Schematic diagram of the Basic SIR model. Boxes represent compartment, and arrows indicates the rate of transfer between compartments.

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Figure 2

Top: Germany's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.17, \gamma=0.03, \alpha=0.01, R_0=4.25, \tau_1=3, \text{ and } \tau_2=9$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 2

Top: Germany's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.17, \gamma=0.03, \alpha=0.01, R_0=4.25, \tau_1=3, \text{ and } \tau_2=9$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 3

Top: Italy's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.18, \gamma=0.03, \alpha=0.05, R_0=2.25, \tau_1=3, \text{ and } \tau_2=8$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 3

Top: Italy's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.18, \gamma=0.03, \alpha=0.05, R_0=2.25, \tau_1=3, \text{ and } \tau_2=8$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 4

Top: Kuwait's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.208, \gamma=0.02, \alpha=0.01, R_0=1.8, \tau_1=3, \text{ and } \tau_2=10$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 4

Top: Kuwait's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.208, \gamma=0.02, \alpha=0.01, R_0=1.8, \tau_1=3, \text{ and } \tau_2=10$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 5

Top: Oman's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.255, \gamma=0.05, \alpha=0.09, R_0=1.82, \tau_1=3, \text{ and } \tau_2=9$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 5

Top: Oman's SIR curve compared with the modified time-delayed SIR model estimates with $\beta=0.255, \gamma=0.05, \alpha=0.09, R_0=1.82, \tau_1=3, \text{ and } \tau_2=9$ vs. lower curve representing basic SIR model with $\tau_1=\tau_2=0$.

Figure 6

The delayed SIR model undergoes: a) damping oscillation with a parameter $\beta=0.6, \gamma=.05, \alpha=.08, \tau_1=3, \tau_2=37$, and b) Hopf bifurcation with a parameter $\beta=0.255, \gamma=0.05, \alpha=0.01, \tau_1=3, \tau_2=37$.

Figure 6

The delayed SIR model undergoes: a) damping oscillation with a parameter $\beta=0.6, \gamma=.05, \alpha=.08, \tau_1=3, \tau_2=37$, and b) Hopf bifurcation with a parameter $\beta=0.255, \gamma=0.05, \alpha=0.01, \tau_1=3, \tau_2=37$.