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Stochastic Epidemic Models with Partial Information : Dark Figure and Parameters Estimation

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Mathematical models of epidemics such as the current COVID-19 pandemics often use compartmental models dividing the population into several compartments. Based on a microscopic setting describing the temporal evolution of the subpopulation sizes in the compartments by stochastic counting processes one can derive macroscopic models for large populations describing the average behavior by associated ODEs such as the celebrated SIR model. Further, diffusion approximations allow to address fluctuations from the average and to describe the state dynamics also for smaller populations by stochastic differential equations (SDE).
Usually not all of the state variables are directly observable and we are facing the so-called "dark figure" problem addressing for example the unknown number of asymptomatic and non-detected infections. Such not directly observable states are problematic if it comes to the computation of characteristics of the epidemic such as the effective reproduction rate and the prevalence of the infection within the population. Further, the management and containment of epidemics relying on solutions of (stochastic) optimal control problems and the associated feedback controls need observations of the current state as input.
The estimation of unobservable states based on records of the observable states leads to a non-standard filtering problem for observable stochastic models. We adopt the extended Kalman filter approach coping with non-linearities in the state dynamics and the state-dependent diffusion coefficients in the SDEs. This allows to develop approximative solutions to that filtering problem.
The proposed model depends on a variety of parameters that can be time-dependent and have been calibrated to real-world data for COVID-19. There, we apply maximum-likelihood and Kalman filter methods. We illustrate our theoretical finding by numerical results.

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