Modelling Time-Varying Epidemiological Parameters for COVID-19

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Daily estimates of parameters relating to epidemics can help public health experts to track the changes in the epidemic's dynamics and the effectiveness of public health policy changes.

It's approaching one year since COVID-19 first emerged: a year that is rich with stories of success and failure, contributed to by various factors. The heterogeneous temporal and spatial characteristics of data relating to the epidemic reflect various factors including government health policies, cultural differences between societies, public responses to epidemic control policies, and possibly mutations that affect the transmissibility of the virus. Temporal heterogeneity is particularly notable owing to the rather drastic changes in public policy over the time – such as lockdowns and reopening period during the summer. The delay in the response of the epidemic curve to public policy changes also reflects the response of society or how strictly the policies are enforced. Research groups around the world have modelled the spread of virus using classical compartmental models such as SIR and SEIR. Most of these works unfortunately assume fixed parameters for the epidemic models. The fixed parameter models fall short of describing the non-smooth curves demonstrated by epidemic's spread in almost every country.

The epidemic's parameters can give public health authorities important information regarding the changes in the transmissibility of the virus and the effect of changes in control policies. In particular, the parameters obtained from each city's local data can point to problems associated with implementing policies, such as the local lockdowns in regions in Italy. Fixed parameter models do not provide the temporal information needed to help public health officials to adjust or fine-tune policies. It is therefore vital to develop methods that can track epidemic's parameters daily.

This challenge was addressed by researchers from ISTI-CNR, China, and Data Science and Information Technology Center of Tsinghua-Berkeley Shenzhen Institute, China. We adopted a state-space formulation that relates temporal observations to hidden parameters of the epidemic. A statistical modelling approach was used, which aims to estimate the probability distributions of hidden variables, rather than just point estimates. This formulation also makes it possible to handle non-Gaussian distributions and nonlinear dynamics in data. Although the classical solution for this problem is provided by Kalman filtering, it necessarily makes the assumption of linearity of the system and Gaussianity of state and observation noise.

We have utilised the Unscented Kalman Filter for the solution of the state-space model which both deals with non-Gaussianity and nonlinearity, and offers computational simplicity. Despite its name, the Unscented Kalman Filter (UKF) has a different computing approach to the Kalman filter. It follows a sampling approach and avoids matrix calculations. The method is also faster

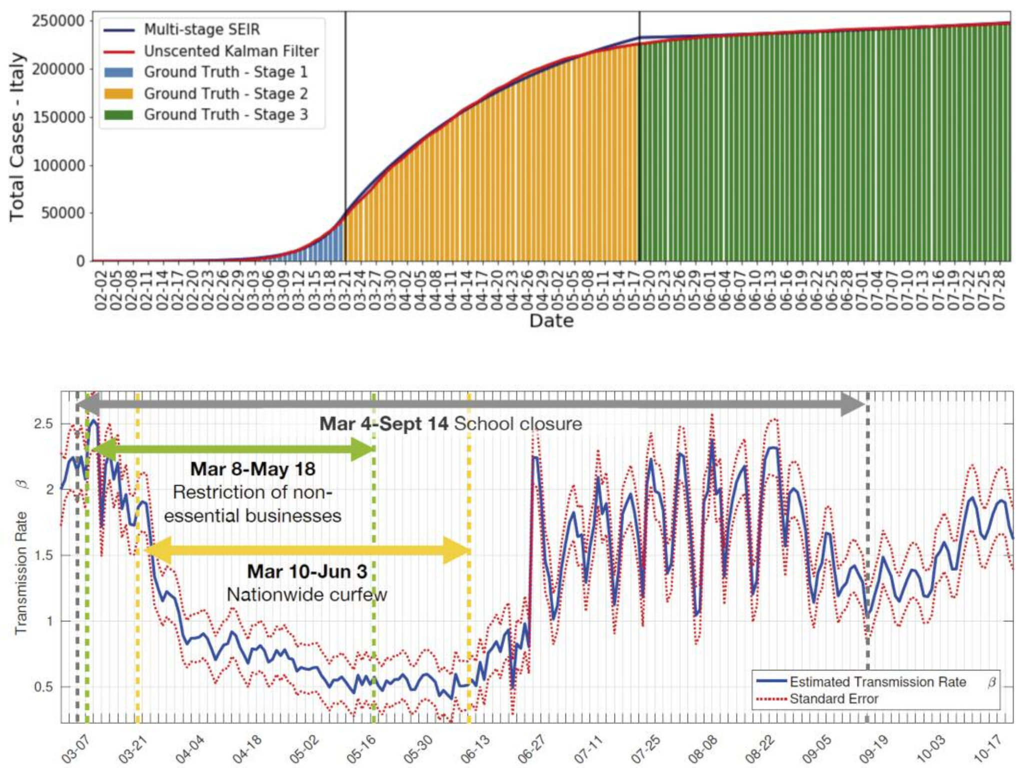

Figure 1:
a) Daily epidemic statistics for Italy and the fit to it by UKF (top);
b) The corresponding daily transmissibility index for Italy calculated by UKF (bottom).

when compared to other sampling-based approaches, such as sequential Monte Carlo.

We have applied this method, which provides daily estimates of transmissibility rate and error bounds, to daily epidemic data from the USA, UK, Italy and Turkey. It has demonstrated precise fits to the actual data: the methods were even capable of capturing daily changes in data from Italy during the summer period, showing the patterns of holiday-making during weekends. The method can also be used to make short-term predictions for the coming days. Figure 1a shows the daily statistics for Italy and the fit to it by UKF. In Figure 1b, we provide the corresponding daily transmissibility index for Italy calculated by UKF. This shows the drastic effect that occurred within a week of lockdown after 10 March 2020 and the rise of infected cases again within one week of normalisation (the removal of travel restrictions) on 3 June 2020.

As we continue this project, we will analyse the data from different regions of Italy and new factors will be introduced to the model first to take care of the period for immunity and also in anticipation of the arrival of a vaccine. We will also include the availability of healthcare resources as a parameter in our model and will simulate extreme case scenarios in which the health system has been stretched beyond capacity.

The software we have developed is available to public health officials upon request. We welcome experts on epidemics and health officials to contact us to collaborate.

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A Common Information Space for Pandemic Management

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Managing a global pandemic requires constant analysis of the current situation and corresponding responses. An open message bus can help organisations achieve a common operational picture across system boundaries, thus ensuring efficiency and effectiveness of their efforts.

In recent decades, many isolated information technology solutions have been developed within the field of crisis management (CM), which very specifically describe, interpret and present information for each organisation. The challenge is to share information about observations, resources and approaches between organisations such as first responders and local crisis management units.

Especially in complex situations like the ongoing COVID-19 pandemic, information from many different sources, like first responders, hospitals, laboratories and national crisis management centres, is needed to assess the current situation, develop strategies and coordinate their efforts [1].

Requirements

There is a clear need for a cross-organisational information exchange. Recent collaborative projects involving various stakeholders have identified some key requirements to achieve this:

- A decentralised platform for sharing information with one or multiple C2 systems, negating the need for a central data storage
- Lightweight standardised interfaces to reduce implementation efforts
- Logging of all activities in the system to fulfil documentation requirements
- The ability to join the platform later and receive previously sent objects on demand
- A resilient and secure design to ensure operation even in the case of (partial) failure.

Design of the Public Safety Hub

Based on these requirements, AIT has developed a communication backbone called Public Safety Hub (PSH) [L1]. The special technological architecture of the PSH enables secure and flexible data exchange between most diverse organisations without creating numerous dependencies and single points of failures. The data is exchanged in the form of protocol-agnostic messages through a lightweight REST interface, allowing the simple integration of systems without predefined protocols. Messages can be delivered to a specific recipient or through broadcast channels. These broadcast channels can be open or organised using a topological hierarchy of addresses, enabling a tailored information exchange for any organisational structure.

The PSH utilises an elastic federated design to ensure the resilience and division of responsibilities required by the CM and other public safety domains (see Figure 1). Each organisation has its own structure, workflow, and responsibility. Through the flexible design of the PSH, each federated instance can be fitted to the specific needs of an organisation. Moreover, its elastic design allows the PSH to scale to the size of the organisation, which increases performance and reliability. Federated instances of the PSH are independent and isolated. However, they can be interconnected in a mesh of federated instances, enabling information exchange on any organisational or pan-organisational structures, while keeping the internal information exchange isolated.

In order to gather a common operational picture, messages in the CM domain are often exchanged based on the EMSI (Emergency Management Shared Information) data model, as defined in the ISO Technical Report 22351. EMSI enables the peer-to-peer exchange of information on the same hierarchical level, as well as across the command structure. A simple PSH client can use an extension of the EMSI data model based on XML. To ensure the validity of the transmitted messages, all messages are