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Editorial

First special section on systems and control research efforts against COVID-19 and future pandemics

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The world is currently impacted by the Coronavirus Disease 2019 (COVID-19) pandemic, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This pandemic has paralyzed society, leading to prolonged self-isolation and quarantine. COVID-19 is a major threat to humans, with alarming levels of spread and mortality rates among the elderly. COVID-19 is a global threat, and tackling the pandemic requires a global effort involving all countries, and especially the scientific community, across all fields and disciplines (Fig. 1).

This first special section includes nine articles that develop “Fast Solutions” to respond to COVID-19 using control systems methods. Seven papers discuss high-level aspects of contagion and viral transmission within the population, investigating contagion evolution, confinement strategies, transport effects, as well as decentralized strategies to better track the pandemic spreading. Two papers include the development of modelling foundations at the within-host level, which can be used to support the design of future therapies against SARS-CoV-2. These contributions include theoretical analysis conducted with system-theoretic and control-theoretic methods, as well as, critically, actual data sets, conveying epidemiological or clinical information about countries severely affected by COVID-19, such as Italy, France, USA, India, and Brazil. The results in this special section may help to devise novel strategies for the mitigation of the current COVID-19 pandemic, at all stages, and may aid the prevention of future outbreaks of SARS-CoV-2 or other viruses.

The first article is a review entitled **“Modelling, Estimation, and Analysis of Epidemics over Networks: An Overview”** by Philip E. Paré, Carolyn L. Beck, and Tamer Başar. This review illustrates the variety of SIR-like mathematical models proposed to capture the dynamics of epidemics, discussing both group models and networked models. The focus is on the study of networked models, capturing the scenario where numerous groups or individuals are interconnected via a contact graph or a more general interconnection network. Network models better match the contact tracing data typically collected in pandemic response, and thus match the model to data. The authors present stability results for several group and networked models, both in continuous-time and in discrete-time. The authors conclude the paper by illustrating how ignoring the underlying graph structure can lead to a poor prediction of the epidemic evolution, which was certainly seen in many news reports and early pandemic responses, thus supporting the need for networked models.

The second article, authored by Giuseppe C. Calafiore, Carlo Novara, and Corrado Possieri, is entitled **“A Time-Varying SIRD Model for the COVID-19 Contagion in Italy”**. The authors contribute to the understanding of the contagion in Italy, one of the first Western countries significantly hit by SARS-CoV-2. A time-varying Susceptible-Infected-Recovered-Deceased (SIRD) model for the contagion is proposed and real pandemic data are used to identify the model parameters. A non-convex identification problem is solved employing a nested approach, consisting of a one-dimensional grid search in the outer loop, and a Lasso optimization problem in the inner step. The proposed time-varying epidemic models can help describe different phases of the contagion and the approach can be generalized to similar models and/or data.

Also focused on the Italian case is the third paper, entitled **“Model predictive control to mitigate the COVID-19 outbreak in a multi-region scenario”** by Raffaele Carli, Graziana Cavone, Nicola Epicoco, Paolo Scarabaggio, and Mariagrazia Dotoli. This paper proposes an optimal control approach to support governments in defining the most effective strategies to be adopted during post-lockdown mitigation phases in a multi-region scenario. A non-linear Model Predictive Control scheme and a modified Susceptible-Infected-Recovered-based (SIR-based) epidemiological model, namely as the SIRQTHE (Susceptible, Infected, Removed, Quarantined, Threatened, Healed, and Extinct) model, with data related to the network of Italian regions is used to minimize the cost of non-pharmaceutical interventions while ensuring the capacity of the network of regional healthcare systems is not exceeded.

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The fourth paper is entitled **"Transport effect of COVID-19 pandemic in France"** by Lina Guan, Christophe Prieur, Liguo Zhang, Clementine Prieur, Didier Georges, and Pascal Bellemain. The authors discuss a range of relevant aspects of transport between regions and cities in France that could have contributed to the COVID-19 pandemic. To this end, a network model of the pandemic transport between regions in France is built based on the regional extended model. Numerical results highlight how transportation played a key role during the COVID-19 pandemic, which needs to be considered when developing deconfinement strategies, as well as providing key information for early action in future similar pandemics.

The fifth article is entitled **"From the hospital scale to nationwide: observability and identification of models for the COVID-19 epidemic waves"** by Emeric Scharbarg, Claude H. Moog, Nicolas Mauduit, Claudia Califano. The authors suggest taking advantage of the availability and agility of local hospital data, rather than merging them into centralized information systems. Interconnected models can be used to represent the transfer of COVID-19 patients from a hospital to another, as was done to distribute the pressure on healthcare when local peaks of infection occurred. The proposed approach suggests relevant fast, agile, and decentralized actions can be taken at a local level both to predict a new wave of the pandemic and to assess the real-time efficacy of treatments or health policies. Such decentralized actions can significantly mitigate issues in pandemic response, as they are easier to take quickly, and show the value of specific local actions separate from larger coordinated responses.

The sixth article is entitled **"An Optimal Predictive Control Strategy for COVID-19 (SARS-CoV-2) Social Distancing Policies in Brazil"** by Marcelo M. Morato, Saulo B. Bastos, Daniel O. Cajueiro, Julio E. Normey-Rico. The authors propose a Model Predictive Control (MPC) policy to mitigate COVID-19 contagion in Brazil, which is designed as an optimal On-Off social isolation strategy. Simulations point out social distancing should not have been relaxed before mid-August 2020 in Brazil. If confinement relaxation is necessary, it should not be too early, and should always be for small periods, no longer than 25 days. The results also indicate a possible second peak of infections that may occur around the beginning of October. This new peak can be reduced if the periods of days with relaxed social isolation measures are shortened.

The seventh paper is entitled **"Modelling a Pandemic with Asymptomatic Patients, Impact of Lockdown and Herd Immunity, With Applications to COVID-19"** by Santosh Ansumali, Shaury Kaushal, Aloke Kumar, Meher K. Prakash, M. Vidyasagar. The authors employ Lyapunov theory to assess the global asymptotic stability of SAIR (Susceptible, Asymptomatic, Infected, Removed) models. Then, they use compartmental SAIR models to account for the migration of population across different countries, and once again establish global asymptotic stability. The results show "herd immunity" could be achieved when the total of infected people is as low as 25% of the population.

The eighth paper is **"In-host Mathematical Modelling of COVID-19 in Humans"** by Esteban A. Hernandez-Vargas and Jorge X. Velasco-Hernandez. The authors propose mathematical models to represent SARS-CoV-2 dynamics in infected patients, providing insight into the SARS-CoV-2 replication cycle, interactions with the immune system, and drug effects at the within-host level. The best model in comparison to data includes immune cell response, suggesting a slow immune response peaking between 5 to 10 days post-onset of symptoms. Specifically, simulations predict that SARS-CoV-2 may replicate very slowly in the first days after infection, and the viral load could be below detection levels during the first 4 days post-infection, which matches increasing numbers of observations and 7-14 day quarantine periods being imposed around the globe.

The ninth paper is authored by Pablo Abuin, Alejandro Anderson, Antonio Ferramosca, Esteban A. Hernandez-Vargas, and Alejandro H. Gonzalez with the title **"Characterization of SARS-CoV-2 Dynamics in the Host"**. The authors develop a complete analysis of the host dynamic characteristic based on the reproduction number. The equilibrium regions of the system are fully characterized, and their stability is formally established. The analysis highlights critical conditions to monotonically decrease SARS-CoV-2 in the host, which are relevant to tailor future antiviral treatments.

The guest editors would like to thank all the authors for their excellent contributions, and all the reviewers who evaluated the manuscripts submitted to the special issue for their valuable comments and suggestions that significantly improved the quality of the contributions. We hope that this special section could be a step forward in the understanding of COVID-19 with systems-and-control approaches and could stimulate further research to gain insight into the evolution of pandemics and how to control them.

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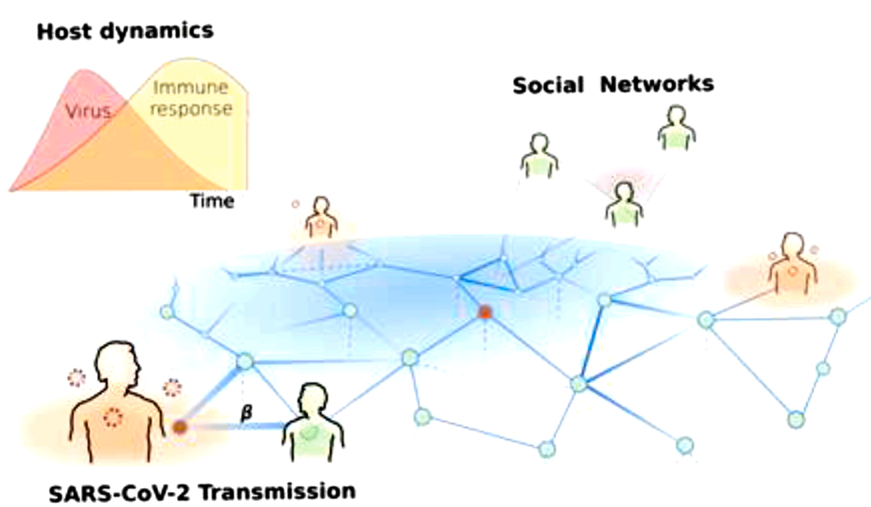

Fig. 1. Modelling and control of pandemic response and treatment approaches at multiscale levels.