Technical Committee on Health Care and Medical Systems

The globally unfolding COVID-19 pandemic has drastically changed our private and professional lives. Working from home, social distancing, and online teaching have become the new normal. The pandemic has also brought about unprecedented challenges to the health-care system.

Reorganizing hospitals and medical assistance to face the rapid spread of infection and sudden influx of patients was one such challenge. The increased need for intensive care unit (ICU) beds and a shortage of qualified nurses highlighted the need for automation.

Shortages of sedation drugs such as propofol, used to place COVID-19 patients on mechanical ventilation, were reported worldwide. At the same time, the use of fewer drugs to maintain the same depth of anesthesia as when manually administered is a common argument in favor of closed-loop anesthesia. This technology has been rapidly developing over the last 15 years, with active participation from control professionals, including members of the IEEE Control Systems Society (CSS) Technical Committee on Healthcare and Medical Systems (TC-HMS).

Containing the spread of an infectious disease is definitely a control problem. To pose and solve it as such, a mathematical model capturing its underlying dynamics is necessary, and its parameters must be estimated from available data. A realistic model describing a virus's spread in a population should capture the dynamics of a highly complex process involving human interaction, the mechanisms of virus transfer, entry into the host, the establishment of infection, and spread in the host. At the same time, such a model would be most useful at the beginning of an outbreak, when knowledge about the virus and epidemiological data are scarce. Many theoretical and implementational challenges must be overcome before the automatic (or even automated) control of epidemic and pandemic diseases becomes a reality. Examples of projects initiated to address COVID-19 pandemic management by members of TC-HMS are provided further in this article.

Many theoretical and implementational challenges must be overcome before the automatic (or even automated) control of epidemic and pandemic diseases becomes a reality.

The TC-HMS membership has grown steadily in recent years, reaching 67 in 2020. We are not a small TC anymore, even though we have existed for fewer than seven years. New TC membership averages from five to eight each year. This is a clear sign of the control community embracing the possibilities of medical technology and health-care systems as an important and rewarding application field of high societal value.

ACTIVITIES

The organization of invited sessions and workshops is a time-consuming activity within the committee that gathers together interested researchers and helps create new collaborations as well as extends professional networks.

Three invited sessions were organized by TC-HMS members at the 2019 American Control Conference (ACC) in Philadelphia. Two of them addressed the intersection of control and neuroscience under the title of "Analysis, Design, and Control of Systems in Neuroscience," (S. Pequito, A. Medvedev, F. Pasqualetti, W. Dixon). The third invited session, "Modeling, Analysis, and Control of Biomedical Systems," was organized by J.-O. Hahn and covered a broader scope of biomedical applications.

All of the biomedical systems exhibit nonlinear phenomena, which pose numerous modeling and design challenges in medical technology. Control theory is expected to meet the demand for engineering-level nonlinear tools, and the IEEE Conference on Decision and Control (CDC) is a known outlet for rapid publications in this direction. Therefore, an invited session, "Nonlinear Modeling and Estimation in Nonlinear Systems," was organized by S. Knorn and A. Medvedev at CDC 2019 in Nice, France,

Digital Object Identifier 10.1109/MCS.2020.3033105
Date of current version: 18 January 2021

to cover state-of-the-art data-driven technologies with relevant novel and established applications.

Wearables is a fast-expanding area of medical and lifestyle devices. Hahn organized the special session "Wearable Sensor Informatics for Cardiopulmonary Monitoring" at the IEEE Biomedical Health Informatics Conference in Chicago in 2019. Medical robotics was covered in the "Advances in Robotics" (X. Liu) at the ASME Dynamic Systems and Control Conference in Park City, Utah, in 2019.

Compared to conference technical sessions, workshops offer a better format for presenting longer talks with tutorial value that invite discussion. Preconference workshops organized in connection with major control conferences are popular with participants and well attended. Two such workshops were organized by Pequito: one at CDC 2019, "Neuroscience and Control: The Emerging Intersection" (together with Medvedev), and the other, "Deciphering the Brain: From Mathematical Models to Computing Platforms for Cyber-Human Autonomy Symbiosis" at Embedded Systems Week in New York City.

A. Borri and P. Palumbo organized the international workshop "Mathematical Modeling and Control for Healthcare and Biomedical Systems," sponsored by the Italian National Research Council in Rome, Italy.

The sustained progress in hybrid systems theory calls for applications and fits well with the topic of continuous-discrete mathematical models in life sciences. Continuous processes impacted by discrete events appear often when the mechanisms underlying biological function on cellular, organ, and organismal levels are described. A special session, "Hybrid Systems in Biology and Medicine," at CDC 2020, on Jeju Island, Republic of Korea, was organized by Borri, A. Singh, and Palumbo. It featured contributions devoted to systems biology as well as the optimization of a cancer treatment and the estimation of multipeak pharmacokinetic models.

Compared to conference technical sessions, workshops offer a better format for presenting longer talks with tutorial value that invite discussion.

A tangible trend in the activities of the TC is an increased collaboration with a similar committee of the International Federation of Automatic Control (IFAC) Committee 8.2 on Biological and Medical Systems. An invited session, "Modeling and Control in Biomedicine and Healthcare," was organized by Medvedev, together with colleagues from IFAC at the 2020 European Control Conference in St. Petersburg, Russia.

The IFAC 2020 World Congress is a premium triennial event that has become the first Virtual IFAC World Congress, along with being the 21st IFAC World Congress, Berlin, Germany. TC-HMS members coorganized two open invited tracks: "Physiological Control Systems in Medicine" (L. Kovacs and Medvedev) and "Control, Mechatronics, and Imaging for Medical Devices and Systems in Medicine" (C. Ionescu and Medvedev). The open-track format allows for inviting an unlimited number of papers that pertain to a certain research topic or area. At the event, a tutorial session on social influence networks was coorganized by A. Proskurnikov.

To highlight the role of the control community in understanding, monitoring, and containing the spread of COVID-19, a special session, "Systems and Control Response to the COVID-19 Pandemic," was proposed by Proskurnikov and Medvedev for inclusion in the program of the third IFAC Workshop on Cyber-Physical & Human Systems in Shanghai, China, in December 2020. This invited session offered an overview of the research projects that have been initiated in India, Sweden, Russia, New Zealand, the United States, and China to address the challenges of the ongoing pandemic.

RECOGNITION

Hahn (Rensselaer Polytechnic Institute) was elected fellow of the American Institute of Chemical Engineers (AIChE). From 2019 to 2021, he served as the director of the AIChE Computing and Systems Technology Division. He is the new deputy editor-in-chief of *Journal of Process Control* and serves as the section editor (biological/biomedical systems) for *Processes* as well as associate editor/editorial board member for *Control Engineering Practice*.

Proskurnikov (Politecnico di Torino) was awarded the Annual Reviews in Control Paper Prize for a paper he coauthored with R. Tempo, "A Tutorial on Modeling and Analysis of Dynamic Social Networks, Part I." Since January 2020, he has served as the associate editor of *IEEE Transactions on Automatic Control*. Proskurnikov was also a guest coeditor for a special issue of *International Journal of Control* (vol. 93, no. 2, 2020), which was dedicated to Alexander Fradkov's 70th anniversary.

T. Menara (University of California, Riverside) won the Best Student Paper Award at ACC 2019 for "Exact and Approximate Stability Conditions for Cluster Synchronization of Kuramoto Oscillators" (T. Menara, G. Baggio, D.S. Bassett, F. Pasqualetti). Menara also received the IEEE CSS Roberto Tempo Best CDC Paper Award for "A Framework to Control Functional Connectivity in the Human Brain," (T. Menara, G. Baggio, D.S. Bassett, F. Pasqualetti)

published in the proceedings of CDC 2019 in Nice.

COVID-19 PROJECT EXAMPLES

C. Scoglio (Kansas State University) runs the National Science Foundation-funded project "Understanding COVID-19 Transmission With Non-Markovian Models." This project investigates the consequences of the assumption that the transition times of individuals between different disease states (that is, susceptible, exposed, infected, and recovered) are exponential. Interestingly, recent observations of COVID-19 data highlight nonexponential distributions for some critical transition times, such as its infectious period (see Figure 1). With this in mind, the goals of the project are to 1) develop network-based compartmental metapopulation models that accept arbitrary distributions for the transition times of the individual between different compartments, 2) develop rigorous methodologies to estimate unknown parameters of the model

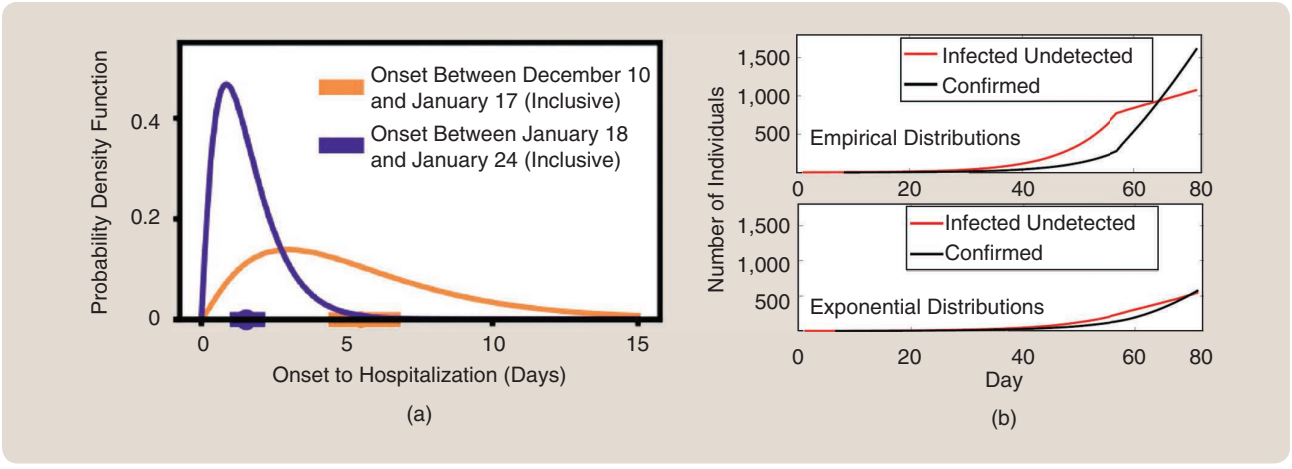

FIGURE 1 (a) Empirical distributions of the infectious period. These curves are nonexponential. (b) Simulations of the COVID-19 spreading process, with the lognormal distributions depicted in the upper plot and the exponential distribution in the lower plot. Even though the distributions share the same mean, they have different quantitative behaviors.

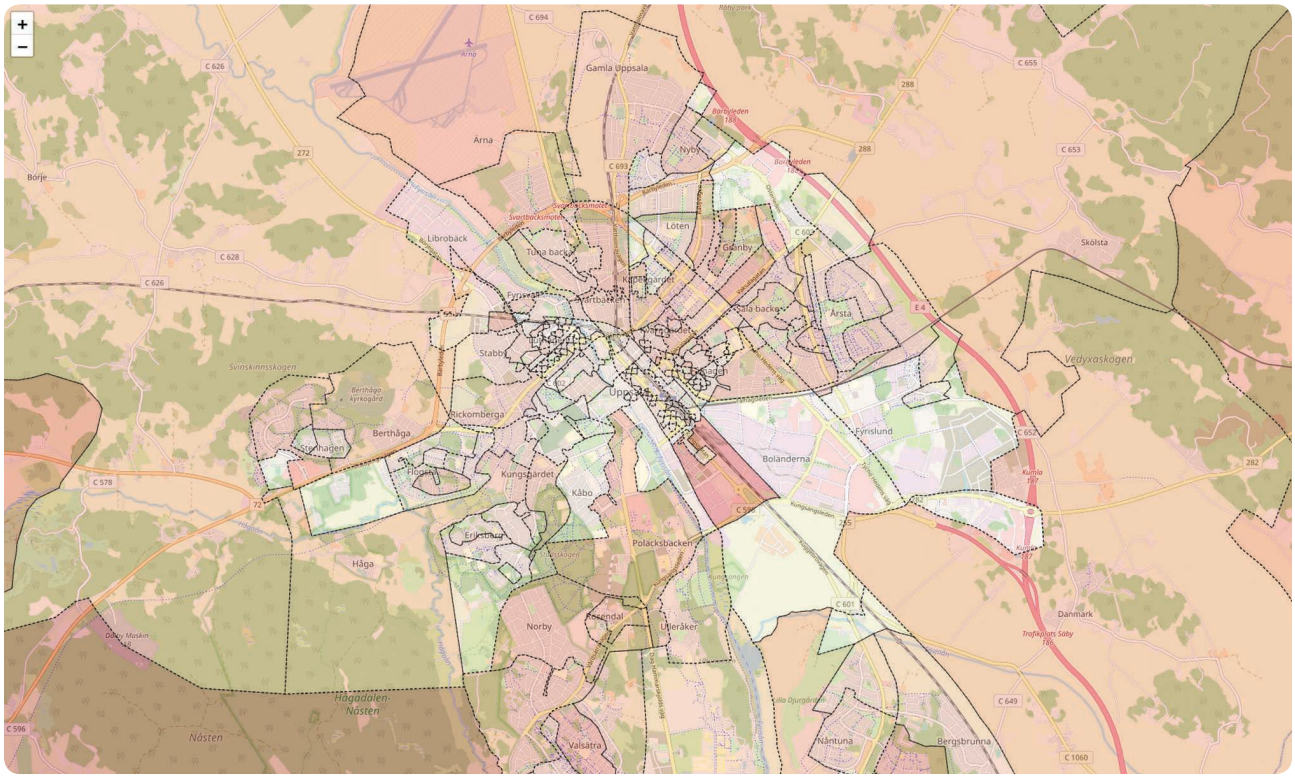

FIGURE 2 A color map of COVID-19 incidence in areas of Uppsala City, Sweden. Uppsala City is the fourth-largest city in the country.

using stochastic optimization methods, and 3) determine contact networks tailored for regions receiving lower attention, such as rural areas.

Italy is one of the nations that was worst hit by the global COVID-19 pandemic. A project from C. Novaro at Politecnico di Torino contributes to the understanding of the infection spread. The parameters of a model corresponding to the contagion as well as the recovery and death rates are estimated by solving a nonconvex identification problem (along with the initial number of susceptible individuals). Using time-varying parameters, the model captures possible changes in the epidemic's characteristics due to, for instance, interventions by authorities or virus mutation.

Another heavily impacted COVID-19 country is Mexico. A study that I. Paschalidis (Boston University) took part in evaluated national data for approximately 91,000 patients. The data for each patient include demographics, prior medical conditions, SARS-CoV-2 test results, hospitalization, mortality, and whether a patient developed pneumonia or not. Personalized models were developed and achieved a prediction accuracy of 72% for hospitalization, 89% for the ICU, and 90% for a ventilator.

Sweden has taken a low-key approach to the pandemic that has been perceived by many as controversial. During the fall and winter, a cluster spread of COVID-19 was expected in the metropolitan areas of the country. Anticipating a second wave of the disease, Uppsala County initiated a study where COVID-19 incidence estimates for the different residential areas of Uppsala (see Figure 2) were obtained by the model-based fusion of relevant information sources such as hospital data, direct testing, symptoms app, and sewage water analysis. The area-specific maps assisted health-care authorities in directing targeted epidemiological interventions in the county. The study was conducted in cooperation with a cross-disciplinary research team at Uppsala University, and Medvedev is a part of it.

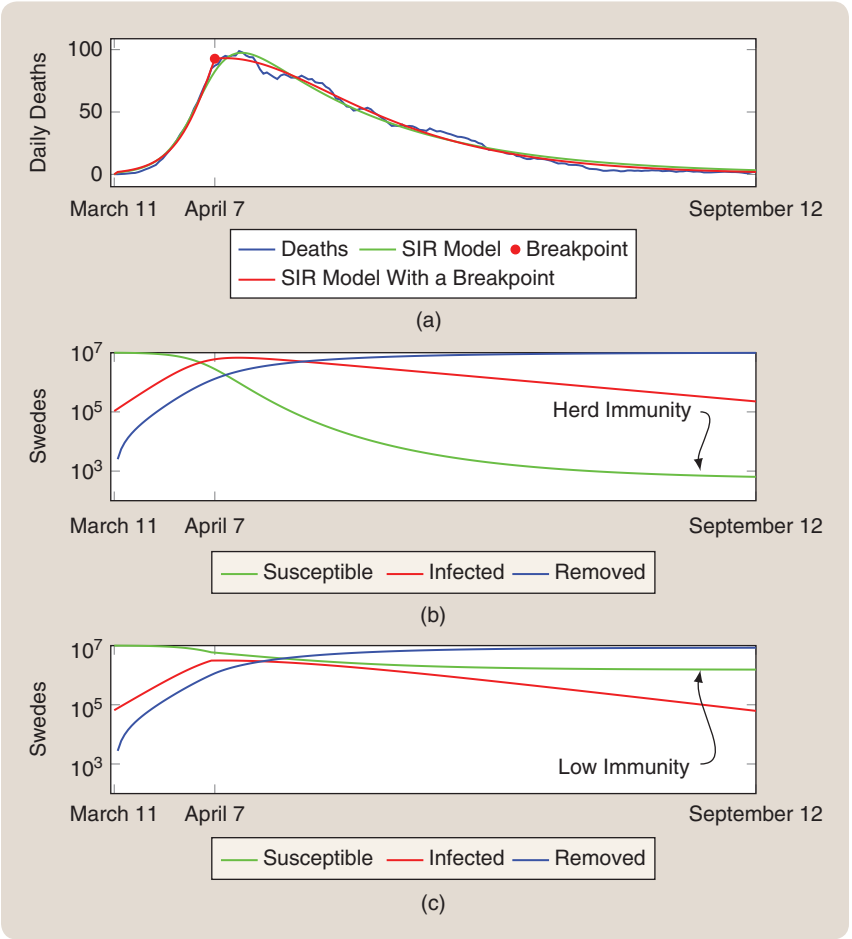

FIGURE 3 (a) The Swedish daily death data from the national Public Health Agency (blue) identified a susceptible, infected, and recovered (SIR) model (green) and an SIR model with a breakpoint, at which parameters are allowed to change (red) to model a nonpharmaceutical intervention (NPI). Using these simple models, a single NPI causes overfitting: (b) The pure SIR model implies herd immunity, while (c) the one with breakpoints implies low immunity. (a) Model fit, (b) SIR model state, and (c) breakpoint model state.

Another project in Sweden coordinated by K. Soltesz (Lund University) brought together researchers in automatic control, statistical signal processing, and public health to map fundamental limitations in the estimation and prediction of COVID-19 spread parameters, as imposed by available data (see Figure 3). The main goal of the project is to improve hospital demand predictions through bias reduction in testing and the use of low-latency signals such as telephone nursing calls.

TC-HMS maintains a webpage at http://healthcare-and-medical-systems.ieeecss.org, which includes the committee roster. Affiliation, contact, and research interest details are available under the Member tab. Broader participation is highly encouraged. One can get involved by participating in TC meetings during the ACC and the CDC (which are open to all who are interested) or by emailing me at alexander.medvedev@it.uu.se.

Alexander Medvedev