Technical Committee on Healthcare and Medical Systems

> **Relieving medical personnel of tedious and repetitive tasks through automation will not only reduce healthcare costs but also reduce the probability of human error.**

Healthcare costs are rising globally. In the United States (according to the Centers for Medicare and Medicaid Services), the annual cost is nearly US$11,000 per person and rose 4.6% in 2017. A similar trend (although probably at a lower spending level) can be observed in any developed country. A growing and aging population and increases in chronic illnesses are often named as the main drivers. What can a control engineer do about it?

Traditional methods of interpreting patient information rely on human input. Relieving medical personnel of tedious and repetitive tasks through automation will not only reduce healthcare costs but also reduce the probability of human error, thus improving patient safety. With objective symptom-quantification technology and mathematical modeling of the therapy effect, a therapeutic intervention can be cast as a formal feedback control problem and effectively automated. A major hurdle on that path is model uncertainty or variability. All humans are unique and respond differently to therapy under different circumstances. Another problem is that some symptoms are notoriously difficult to measure, such as pain.

The IEEE Control Systems Society (CSS) Technical Committee on Healthcare and Medical Systems (TC-HMS) was launched by Daniel Rivera (Arizona State University, Tempe) in 2013. TC-HMS currently has approximately 60 members, and the ranks are growing steadily. However, more than half of the members are from the Americas, with only two from Asia. TC-HMS members work on a wide range of challenging problems related to the diagnosis, treatment, and long-term management of diabetes, cancer, neurological diseases, and infections. Closed-loop drug delivery and drug regimen optimization and individualization are also popular topics within the committee.

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Two special sessions were sponsored by TC-HMS at the 2017 IEEE Conference on Decision and Control (CDC) in Melbourne, Australia. Alexander Medvedev (Uppsala University, Sweden) and Warren Dixon (University of Florida, Gainesville) organized the session "Dynamics in Neuroscience: Modeling, Estimation, and Control," which was well attended and well received. Several participants requested that control and estimation applications in neuroscience be covered by at least one regular or invited session at the CDC and the American Control Conference (ACC), given the broad interest from control theoreticians and engineers in this actively developing research area. The other session, "Individualization and Optimization of Therapies," was organized by Levente Kovacs (Obuda University, Hungary), Medvedev, and Pasquale Palumbo (IASI-CNR, Italy). It provided updates on the latest developments in the individualization and optimization of therapies in a number of medical fields.

Two special sessions under the common title "Analysis, Design, and Control of Systems in Neuroscience," proposed by Sergio Pequito (Rensselaer Polytechnic Institute, Troy, New York), Medvedev, Fabio Pasqualetti (University of California, Riverside), and Dixon (and sponsored by TC-HMS), were included in the technical program of ACC 2019. Palumbo and Alessandro Borri (both of IASI-CNR) co-organized the minisymposium "Recent Trends in the Modeling and Control of the Glucose-Insulin System" at the European Conference on Mathematical and Theoretical Biology, Lisbon, Portugal, in July 2018. B. Wayne Bequette (Rensselaer Polytechnic Institute) served as International Programming Committee chair at the ADCHEM 2018, Shenyang, China. Naira Hovakimyan (University of Illinois at Urbana-Champaign) co-organized (with Aram Galstyan, University of Southern California, Los Angeles) the U.S. National Science Foundation workshop "Machine Learning for Discovery Sciences" in Yerevan, Armenia, in 2017, which was cosponsored by the Foundation for Armenian Science and Technology. She also served as general cochair of the ICNPAA World Congress: Mathematical Problems in Engineering, Sciences and Aerospace, in Yerevan, Armenia, 2018. Juergen Hahn (Rensselaer Polytechnic Institute) was vice chair for invited sessions of ACC 2018 and conference chair for the 2018 Foundations of Systems Biology in Engineering Conference.

TC-HMS also enjoys active cooperation with the IFAC Biological and Medical Systems TC 8.2. For example, Medvedev organized an invited session, "System Identification and Data-Driven Modeling in Medicine," at the 18th IFAC Symposium on System Identification in Stockholm from July 9–11, 2018.

Mathematical modeling and parameter estimation are key areas of competence in biomedical systems. TC-HMS (in cooperation with the IEEE CSS TCs on Systems Biology and System Identification and Adaptive Control) has organized a special issue for *IEEE Transactions on Control Systems Technology*, "System Identification and Control in Biomedical Applications." To promote real-world projects, it was required that a manuscript for this special issue include applications to actual biological data rather than simulations. Altogether, 65 papers were submitted, and of those, 35 were accepted.

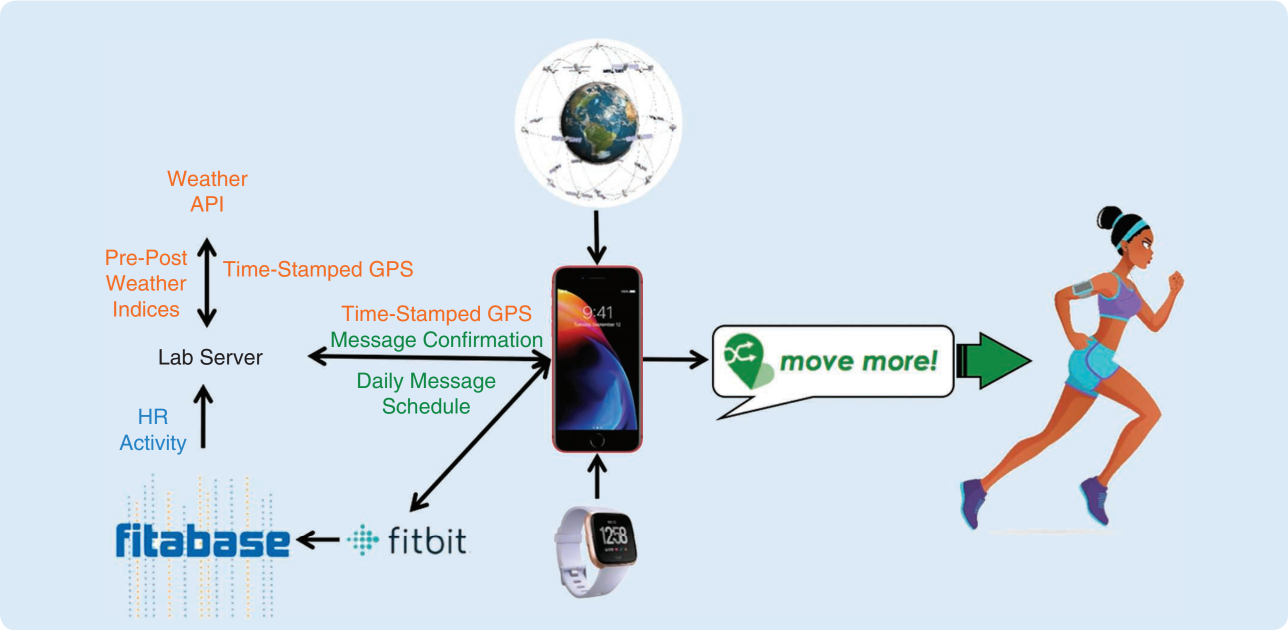

FIGURE 1 The AIM project by David Conroy and Constantino Lagoa at The Pennsylvania State University. The objective of this project is to improve light physical exercise through interventions personalized by means of system identification. API: application programming interface.

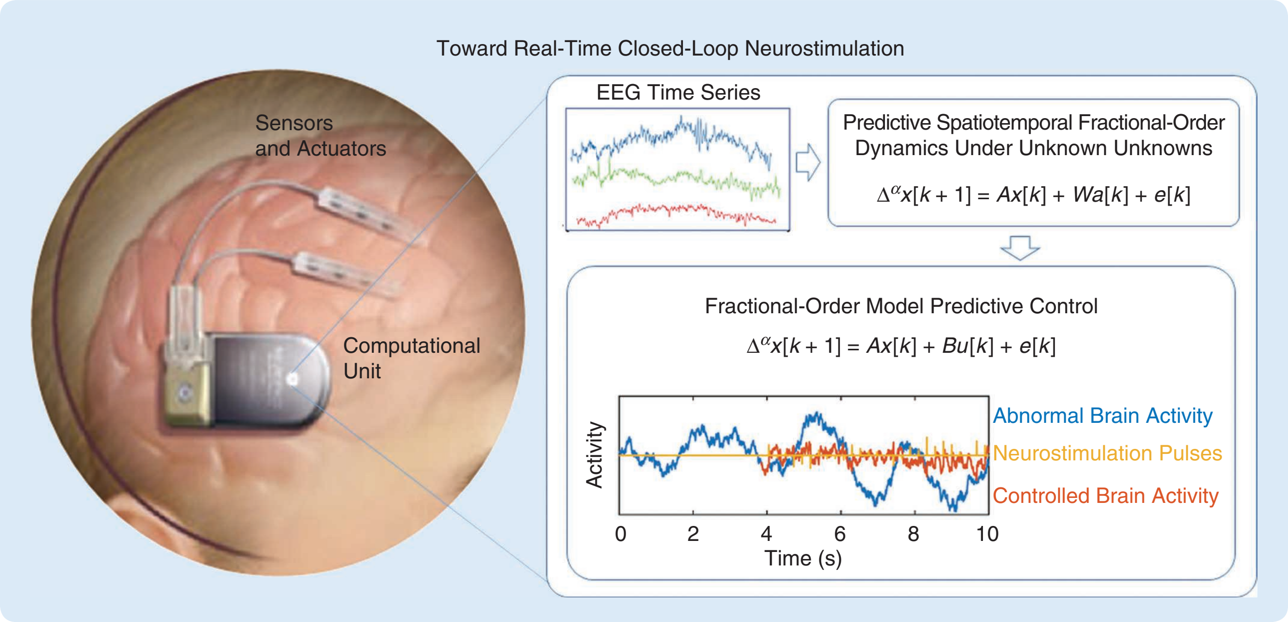

FIGURE 2 A model-based approach to neurostimulation proposed by Orlando Romero and Sergio Pequito at the Rensselaer Polytechnic Institute. Once a model is established, a model predictive control scheme is applied, the performance of which is illustrated in the figure. Activity without stimulation is depicted in blue, and the controlled brain activity obtained by deploying the fractional-order model predictive control is in red (begins at time 4 s). EEG: electroencephalogram.

EXAMPLE RESEARCH PROJECTS

Several examples of research projects performed by TC-HMS members are provided below and illustrated in the figures.

- » Sedentary lifestyle is one of the contributing factors to health problems. David Conroy and Constantino Lagoa (both of The Pennsylvania State University, University Park) have undertaken the AIM project to improve light physical exercise through interventions personalized by means of system identification. The intervention is composed of messages whose content and delivery time are chosen to maximize their effect and, at the same time, minimize burden. Individual physical activity response to messages is modeled as a switched linear dynamical system whose coefficients depend on, for example, the day of the week, location, and weather. Determination of the timing and type of message to be sent is accomplished using a model predictive controller, where the objective is to maximize the probability of increasing activity level (Figure 1) [1].
- » Electrical stimulation of brain structures is an established technology in treating neurological and mental diseases. Current neurostimulation devices implement event-triggered methodologies to quench epileptic seizures by delivering biphasic pulses with constant amplitude, frequency, and duration in an open loop. Orlando Romero and Pequito (both of the Rensselaer Polytechnic Institute) are at work on a closed-loop stimulation system based on spatiotemporal fractional-order dynamical models that consider both the spatial interactions and long-term memory in the brain. The proposed framework keeps the brain activity within low amplitude by deploying time-varying pulses that are crafted in response to the individual's needs (Figure 2).

With objective symptom-quantification technology and mathematical modeling of the therapy effect, a therapeutic intervention can be cast as a formal feedback control problem.

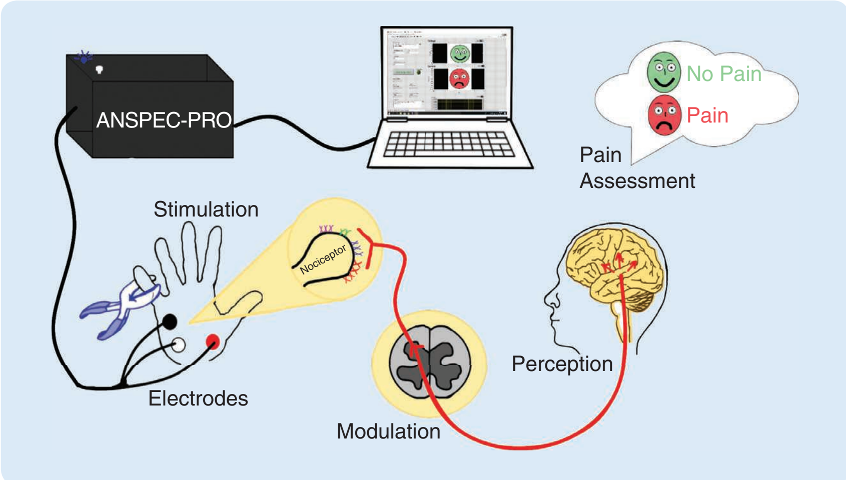

FIGURE 3 To measure is to know. The latest research of Clara Ionescu and Dana Copot at Ghent University in the area of pain measurements has resulted in a prototype device to evaluate pain via skin impedance that shows promise in clinical trials.

- » Pain is traditionally evaluated by medical staff on a scale from zero to 10, with the rating derived from observing the patient's reaction and self-reporting. Clara Ionescu and Dana Copot (both of Ghent University, Belgium) have developed a prototype device for measuring pain based on skin impedance that shows promise in clinical trials. The essential benefit of their ANSPEC-PRO device is that it allows a customizable input signal to the system under observation. With the development of the ANSPEC-PRO instrumentation and methodology, there is a great opportunity to push through state-of-the-art clinical technology for pain monitoring and related research. It is broadly accessible for performing measurements using a generic identification procedure and commercial electrodes (Figure 3).

  One important application of the novel technology is closed-loop dosing of anesthetic drugs.

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 CDC (which are open to all interested) or by emailing Alexander Medvedev at alexander.medvedev@it.uu.se.

Alexander Medvedev

REFERENCE

[1] D. E. Conroy, S. Hojjatinia, C. M. Lagoa, C.-H. Yang, S. T. Lanza, and J. M. Smyth, "Personalized models of physical activity responses to text message micro-interventions: A proof-of-concept application of control systems engineering methods," *Psychol. Sport Exercise*, vol. 41, pp. 172–180, 2019.