Open Call for Vision Statement
for
Control for Societal-Scale Challenges: Roadmap 2030

Virtual Workshop, June 4-5, 2021
Physical Workshop, Stockholm, June 2022

Organizers: A.M. Annaswamy, K. H. Johansson, and G.J. Pappas

The IEEE Control Systems Society would like to develop a scientific roadmap for the future of our discipline, *Control for Societal-Scale Challenges: Roadmap 2030.* The objectives of the roadmap are to lay out new societal areas where our discipline can have impact over the next decade, propose novel scientific challenges that the community should pursue, and investigate workforce education and training curricula in order to address these challenges. Our plan is also to ensure that the roadmap has a broad scope including new technological drivers, new infrastructures for control systems, and legal, organizational and regulatory factors that are prevalent in societal-scale systems.

In support of this effort, we will conduct a workshop in two parts, the first during June 4-5, 2021, in a virtual format, and the second during June 2022 in Stockholm, in an in-person format. The workshop discussions will be centered around six identified themes, with elements of real-time decision making, machine learning, autonomy, data-driven and physics-driven approaches, security and privacy, and big-data pervading all six themes. Short descriptions of all theme abstracts can be found in the appendix.

We would like to invite the broader control community to submit vision statements towards this roadmap, describing your personal view about the future of the discipline. Your written input can address any of the following issues: (a) Novel or existing domains where control systems can have a critical role, (b) scientific challenges or exciting scientific directions for the future, (c) innovative ideas about workforce development and control systems curriculum, (d) organizational, regulatory, economic or infrastructure challenges or drivers that we should be considering in the future, and (e) anything else you think is critical for the future of our discipline. Please note that all inputs should be forward looking, broad, and thematically linked to the objectives of the roadmap. We are not looking for specific approaches, technical solutions, or results, but rather future directions that our community should be exploring to solve grand societal challenges.

We would like your vision statement to be in the form of an abstract, not exceeding 300 words, and either in a doc or pdf format. All statements will be reviewed by the theme leaders (see appendix), and some may be chosen for presentation at the workshops, or invited for further articulation in the roadmap. Selected submissions will be included the final roadmap report, which will be posted on the IEEE CSS homepage and related websites.

Please email your abstracts to any of the three organizers listed above (aanna@Mit.edu, kallej@kth.se, pappasg@seas.upenn.edu) no later than March 15, 2021.

Appendix

Panel 1: Decision making with real-time and distributed data (Leads: Anders Rantzer and Na Li)

Recent radical evolution in distributed sensing, computation, communication, and actuation has revolutionized the way systems operate and fostered the emergence of real-time decision making with large and distributed data. Examples cut across a broad spectrum of engineering and societal fields such as energy systems, transportation systems, Internet, sensor networks, social networks, epidemics and many others. In most of applications, established models from one or more disciplines need to be combined with blackbox models built from data. A good example is in autonomous driving, where the existing extensive experience of control technology such as ABS braking, cruise control and ESP systems for vehicle stabilization needs to be combined with machine learning methods to analyse traffic situations and human behavior. To do this in a safe and robust manner, it is essential to understand how learning algorithms for sequential decision-making can interact with continuous physics based dynamics. Similarly, in power systems, well established control solutions are increasingly being combined with learning algorithms correlating consumer behavior with weather forecasts, to minimize costs and optimize efficiency. This panel will focus on the challenges related to learning in a real-time setting in combination with distributed data, with a focus on challenges that common to a variety of aforementioned applications. Examples include 1) how to develop physics-aided learning methods that exploit both the known-physics, historical data, and real-time data? 2) how to develop scalable solutions which could handle the large size of the system and the large amount of data generated from different locations? 3) how to balance the tradeoff between solution efficiency, computation speed, and communication quality for real-time operation by prioritizing the information and tasks? 4) how to ensure system safety while providing enough flexibility and robustness for running the system under various (nonstationary or even adversarial) environment?

Panel 2: Safety-critical autonomous systems with ML (Leads: Claire Tomlin and Angela Schoellig)

Advances in machine learning have accelerated the introduction of autonomy in our everyday lives. However, ensuring that these autonomous systems act safely is an immense challenge. Today, when self-driving vehicles, or collaborative robots, operate in real-world uncertain environments, it is impossible to guarantee safety at all times. The key challenge stems from the uncertainty of the environment itself, and the inability to predict all possible situations that could confront the system. Machine learning, and its potential ability to generalize, may be a solution. For example, a learning-based perception system for a self-driving vehicle, must be able to generalize beyond the scenes that it has observed in training. Yet today, these algorithms are producing solutions that are not easy to understand, are brittle to faults and possible cyber-attacks. The purpose of this Panel is to explore the scope of safe autonomy, to present the challenges, and to explore current research developments which help us move towards a solution.

Panel 3: Resilient infrastructure-systems with AI and IoT (Leads: Dan Work and Carlos Canudas de Wit)

Monitoring and control for large-scale critical infrastructure systems is accelerated by low cost sensing, communication, computation, and actuation technologies that underpin the internet of things. Enabled by the large volumes of data produced by these systems, a new generation of mobility, energy, water, and health networks are increasingly adopting artificial intelligence-enabled components that further increase the richness of these systems. As the scale and complexity of these systems continues to grow, so do the challenges to provide robustness and resilience. For example, attacks on the cyber infrastructure can lead to cascading failures that dramatically degrade or cripple the physical systems. Allowing pervasive sensing and guaranteeing privacy remains open in many application domains. This panel will establish the challenges to enable monitoring and control for infrastructure systems that are smart, resilient, secure, and privacy preserving.

Panel 4: Control in Human-automation, Health, and Networked Systems (Leads: Sandra Hirche and Aaron Ames)

Control has the unique ability to transform society across a spectrum of application domains that can positively impact quality of life. In many of these domains the interaction between the human and the automation system plays an important role and requires an in-depth understanding for the development of novel control technologies. This panel is devoted to future directions in control for human-automation systems, that can positively address societal-scale challenges at multiple levels, from direct physiological interaction, to human collaborations with robotic and autonomous systems, to networked population-wide interactions.

At the direct interaction level, the goal is to understand interactions with the human body and its processes, from neurocontrol to physiological control mechanisms. This can directly infuse control theory to positively improve human function, mitigate against disease, and augment performance. There is ever increasing interaction with humans and control systems via robotic and autonomous systems, and understanding this has important ramifications to everything from robotic assistive devices to ever increasing autonomous features in automotive systems. Finally, at the human population level, control can inform and drive the evolution of systems from local community to global scales. This includes traffic management, power and general infrastructure systems, economics and epidemics.

In all application domains and all levels of interaction, key challenges from a control theory perspective include understanding safety and uncertainty in the context of human decision making. Safety considerations are central due to the direction interactions with humans. Exploring notions of safety from a theoretic and dynamic point of view, and characterizations thereof, will be essential in deploying theoretic solutions into real-world applications. These notions of safety, and guarantees obtained via control theory more generally, will involve human models that may be difficult to ascertain. As such, methods that are robust to uncertainty will need to be developed--these likely could include data-driven approaches for mitigating this uncertainty that learn and adapt.

Panel 5: Systems and Control Opportunities for Climate Change Mitigation and Adaptation (Leads: Pramod Khargonekar and Tariq Samad)

There is international consensus that global warming and the resulting climate change represent an extremely important grand challenge for the next several decades. Experts in the field of systems and control can make valuable contributions to several key strategies for climate change mitigation and adaptation. Indeed, because of the large scope of this topic, this panel will only address a subset of possible directions. In fact, two topics will be of primary focus, although these are broad enough to incorporate numerous opportunities for impact.

The first is energy system decarbonization. In general, we will emphasize “system-level” aspects—large-scale renewable generation from diverse sources; integration of renewables and storage in transmission and distribution networks; microgrid optimization and control; and energy markets for products and services.

The second broad topic is adaptation to climate change: How can the control community contribute to ensuring a habitable planet if, as seems highly likely now, mitigation efforts are, at best, only partially successful? Adverse impacts will be manifold—including increasing frequencies of storms, dramatic sea-level rise, droughts and flooding, and deterioration of agricultural lands and yields. However, we will target a general problem that we believe the controls community is ideally suited to take a leadership role in: What novel methodologies can be developed for facilitating strategic decision making under deep uncertainty?

Our objective for the panel is to develop a set of recommendations for the controls community, its leadership, and funding agencies. These recommendations will include promising new opportunities for research, collaborations with other fields, new R&D programs at national and international levels, workshops and other events, and publications for motivating and promoting the role of control science and engineering in the defining grand challenge for the future of humanity and its ecosystem.

Panel 6: Education and Training (Leads: Christos Cassandras and Joao Hespanha)

The panel’s scope is designed to cover the following five areas:

1) Academic curriculum: Design the ideal undergraduate curriculum for Systems and Control over the next decade in terms of (i) material covered, (ii) blend of theory/applications, (iii) blend of paper-pencil exercises/simulation/experiments. Identify explicit changes with respect to a typical current curriculum: What should be eliminated/downplayed? What should be added?

2) Outreach: Identify opportunities (and create them if possible) to incorporate Systems and Control concepts in pre-college education. Specifically identify concepts, ideas, or grand challenges that can provide inspirational value to pre-college students.

3) Driving Areas: Identify the technical areas that should drive Systems and Control education. Differentiate between areas based on principles which transcend technological and societal changes and new areas that need to be introduced to Systems and Control education.

4) Industry: Explore the role that academic institutions could/should have in Industry training, as well as the role that Industry should have in academic education. Find ways to improve the interaction between universities and industry, in the educational and training context. Explore the role that internships or apprenticeships can play in bringing students closer to real industrial application problems.

5) Building bridges with other science/engineering fields: It has often been said that control is a “hidden technology” one that “enables” other technologies but does not stand out by itself. Discuss the accuracy (or not) of this statement. If the statement is true, explore how to best incorporate systems and control into a college curriculum (e.g., what department does it belong to?) If the statement is not true, find new ways to change this perception through education or outreach.