Control for Climate Change Adaptation and Mitigation

Organizers:
Aranya Chakrabortty, US National Science Foundation
Pramod Khargonekar, University of California, Irvine
Tariq Samad, University of Minnesota

Motivation and Objectives

Climate change is the existential threat facing humanity today, its genesis being human activities resulting in high greenhouse gas emissions, starting after the industrial revolution and inexorably trending upwards since then. Given that the control science and engineering community has the foremost repository of expertise in modeling and managing complex dynamical systems, in this workshop our goal is to start a dialogue between researchers from various avenues of control systems, optimization, and climate science, to discuss how control theory can contribute to the advancement of ideas on climate change adaptation and mitigation as we strive to remedy excesses of the past, to create a future that is more ecologically benign, and to realize a livable planet for our future generations.

The workshop will feature eight research talks from an esteemed group of researchers, covering a broad range of topics on sectoral targets for research and innovation for the controls community, including infrastructure systems, wildfire awareness, renewables and electric power grids, clean transportation, smart buildings, and smart water systems. The urgency, criticality, and human impacts of climate change will be highlighted in all the talks. Special attention will be paid to the important role that data, machine learning, and artificial intelligence can play in enabling these different system and control methods of interest.

The first four talks will be presented in the morning session, followed by the remaining four talks in the afternoon, with a lunch break in between. Each session will have a short coffee break to facilitate casual interactions between the attendees and the speakers. A one-hour panel session will be held at the end of the workshop. In this session, program directors from the US National Science Foundation (NSF) will summarize current NSF research initiatives and funding opportunities on climate change and related control research, followed by a question and answer session in which the attendees can engage with the speakers. The goals of the panel session will be: (1) to summarize the ideas reflected in the presentations and receive feedback from the audience, (2) to discuss how academics can access climate-related datasets from companies and government labs, (3) to discuss mechanisms for broadening participation and education in climate change, as well as for promoting trans-disciplinary collaborations on this topic, and (4) to highlight leadership roles that federal agencies such as NSF can play in advancing knowledge in this field. Graduate students and postdocs in the audience will be particularly encouraged to voice their thoughts and opinions on how the controls community can address this grand challenge of the 21st century from both academic and industrial perspectives.
Structure of the Workshop

This will be a full-day workshop, starting at 8.20 am and going till 5 pm. The agenda will consist of eight talks, each of 45 minutes, including 5 minutes for Q&A. There will be one coffee break in the middle of each session for fifteen minutes. A 45-minute panel session will be held at the end to facilitate audience participation, summarize the lessons learnt, and discuss the next steps. The goal will be to generate a publicly available report based on the outcomes of the workshop, and share it with funding agencies such as NSF and professional organizations such as the IEEE Control Systems Society to foster research advancements in this area. The speakers and the titles for the eight talks are as follows:

1. Opening Remarks by Aranya Chakrabortty, 8.20 am - 8.30 am

2. Climate Change Mitigation and Adaptation: Role for Systems and Control, 8.30 am - 9.15 am
   Pramod Khargonekar, *University of California Irvine*
   Tariq Samad, *University of Minnesota*

3. Kernel Flows for Learning Dynamical Systems from Data with Application to Climate Modeling, 9.15 am - 10 am
   Boumediene Hamzi, *California Institute of Technology*
   Houman Owhadi, *California Institute of Technology*
   Romit Maulik, *Argonne National Laboratory*

4. Coffee Break, 10 am - 10.15 am

   Joe H. Chow, *Rensselaer Polytechnic Institute*
   Koushik Kar, *Rensselaer Polytechnic Institute*
   Rahul Chakraborty, *North Carolina State University*

6. Sensor-enabled Wildfire Awareness and Risk Management for Electric Power Infrastructure, 11 am - 11.45 am
   Anamitra Pal, *Arizona State University*
   Umit Ogras, *University of Wisconsin Madison*

7. Lunch Break, 11.45 am - 1 pm

8. Multiagent Learning and Coordination for Resilience in Cyber Physical Systems, 1 pm - 1.45 pm
   Srinivas Shakkotai, *Texas A&M University*
   Vijay Subramanian, *University of Michigan Ann Arbor*
   Subhonmesh Bose, *University of Illinois Urbana-Champaign*
9. The Role of Intelligent Water Systems in Climate Change Control Solutions, 1.45 pm - 2.30 pm
Jason Ren, Princeton University
Nalini Venkatasubramanian, University of California Irvine
Amro Farid, Dartmouth College

10. Coffee Break, 2.30 pm - 2.45 pm

11. Cataloging Climate Solutions on the Coasts: Problem framing to find place-based points of criticality and leverage AI for action, 2.45 pm - 3.30 pm
Suzzane Pierce, University of Texas Austin
Kasey Faust, University of Texas Austin

12. Climate Control in Buildings as a Renewable Energy Market Player, 3.30 pm - 4.15 pm
Iven Mareels, IBM Australia
Arun Vishwanath, IBM Australia
Ram Kolluri, IBM Australia
Hendrik Hamann, IBM USA

8. Panel Discussion 4.15 pm - 5 pm
Moderators: Aranya Chakrabortty, Eyad Abed, other program directors from NSF, and the speakers
- Workshop summary and report writing
- Q&A between panelists and audience
- Discussing next steps

We strongly envision that this workshop will initiate coherent thinking along these new lines of research, and carry these ideas forward for further defining and addressing the emerging technical challenges at the interface of climate science, machine learning, and control theory. We will especially encourage participation from graduate students, postdocs, and junior professors who may be looking for new topics for their research. Attendees from industry and national labs will also be encouraged to participate in the discussions.

Abstracts of the Talks

Climate Change Mitigation and Adaptation: Role for Systems and Control
Pramod P. Khargonekar and Tariq Samad

Abstract: In this talk, we will begin with an overview of the global warming, climate change, and associated impacts. A major focus will be on the global energy system both from the generation and consumption viewpoints. We will discuss the key trends in energy consumption
growth due to population growth and economic growth setting the stage for understanding challenges in decarbonization of the energy system. Next, we will discuss the major technological pathways for their decarbonization of the key energy sectors, e.g., electricity, transportation, manufacturing, etc. We will describe the critical and difficult technological problems where systems and control community can make important contributions to the decarbonization of the energy system. In the final part of the presentation, we will discuss adaptation and resilience strategies to deal with the impacts of climate change already underway.

Kernel Flows for Learning Dynamical Systems from Data with Application to Climate Modeling
Boumediene Hamzi, Houman Owhadi, Romit Maulik

Abstract: Regressing the vector field of a dynamical system from a finite number of observed states is a natural way to learn surrogate models for such systems. We present variants of the method of Kernel Flows, a variant of cross-validation, based on Maximum Mean Discrepancy and Lyapunov exponents as simple approaches for learning the kernel that appear in the emulators we use in our work. When trained on geophysical observational data, for example, the weekly averaged global sea-surface temperature, considerable gains are also observed by the proposed technique in comparison to classical partial differential equation-based models in terms of forecast computational cost and accuracy. When trained on publicly available re-analysis data for the daily temperature of the North-American continent, we see significant improvements over classical baselines such as climatology and persistence-based forecast techniques. Although our experiments concern specific examples, the proposed approach is general, and our results support the viability of kernel methods (with learned kernels) for interpretable and computationally efficient geophysical forecasting for a large diversity of processes.

Control-theoretic Designs for Power Systems with Renewables: Markets, Risks, and Stability,
Joe H. Chow, Koushik Kar, Rahul Chakraborty

Abstract: We will present new results on developing market mechanisms and control solutions for cost-effective and risk-informed integration of renewable energy resources in the electric power grid. As more renewables get integrated in the transmission system to reduce carbon emissions, risk-segmentation mechanisms for renewable generation assets (bulk wind and spatially aggregated solar) are becoming increasingly important for operators to bid into day-ahead and real-time markets competitively. This talk will present a new approach by which markets can allow renewable generators to bid in multiple risk segments (referred to as “tranches”) that are scored dynamically for their riskiness based on advanced forecasting models and system reliability metrics. We will show how instability risks in real-time operations due to fluctuations in the renewable resources can be integrated into the market mechanisms as well as in the control solutions. This includes developing stability-constrained unit-commitment solutions, refining optimal power flow solutions to improve transient stability, and adequate provision of reserves for contingency. Data-driven validation of the
methods for TX and NY grids under different generation scenarios and grid conditions will also be presented.

**Sensor-enabled Wildfire Awareness and Risk Management for Electric Power Infrastructure**  
Anamitra Pal, Umit Ogras

Abstract: The electric grid is susceptible to increasing wildfire risks, particularly in forested and rural areas. The wildfire risks are aggravated primarily due to a lack of risk awareness in remote locations, which interferes with response management. This talk focuses on designing and testing a Wildfire Awareness and Risk Management (WARM) system. It will first overview an Internet of Things (IoT) framework composed of self-powered wireless sensors that monitor the environment around remote electric power infrastructures. Then, we will discuss how this framework can support resilient grid operation during high wildfire risk periods. The goal is to bring transformative changes to how power utilities, regulatory agencies, and municipal managers react to wildfire threats by raising their real-time situational awareness and developing methods and strategies that increase their options for successful prevention and rapid response.

**Multiagent Learning and Coordination for Resilience in Cyber Physical Systems**  
Srinivas Shakkotai, Vijay Subramanian, Subhonmesh Bose

Abstract: As the world moves towards goals such as carbon neutrality and increased efficiency of infrastructure systems, their operating points are shifting towards unreliable behavior that is kept in check through the operation of cyber-physical multi-agent algorithms operating over distributed communication and compute resources. Increasing volatility in the system, engendered by events such as more frequent hurricanes, implies these algorithms are becoming ever more critical. Our goal in this talk is to explore the theory and platforms for analysis and instantiation of these multi-agent algorithms, both from the perspective of ensuring everyday resilient operation and of preventing catastrophic failure. We will begin with the design of multi-agent markets for the integration of dynamic distributed resources, and constrained reinforcement learning that forms the basis for such agents, focusing on convergence rates and samples needed to enable learning of safe policies that can prevent catastrophic failures. We will then present several illustrative scenarios on smart grid resilience using our platform called OpenGridGym. Finally, we will present details of a prototype resilient information network operable over unreliable communication and compute nodes designed to support a variety of cyber-physical systems.

**The Role of Intelligent Water Systems in Climate Change Control Solutions**  
Jason Ren, Nalini Venkatasubramanian, Amro Farid

Abstract: As global climate change charges forward, there is an immediate and pressing need to develop mitigation and adaptation measures across the spectrum of anthropogenic economic activities. Water infrastructure is perhaps amongst the most important of these. Not only must it provide potable water to our ever growing populations and remove wastewater
to keep them healthy, but it is amongst the first to be vulnerable to the devastation of climate change through droughts, floods, hurricanes, and ultimately sea level rise. Meanwhile much of existing water infrastructure was built decades ago using 100-year planning assumptions that are not likely to suffice in the coming years. Rather than relying on traditional and often static methods, water infrastructure must evolve greater intelligence to be adaptable and ready for the variable and unknown conditions of the future. This talk will discuss the role of intelligent water systems in climate change control solutions. The first speaker, Prof. Jason Ren will highlight why today’s water quantity and quality challenges are dynamic and require control solutions at a variety of relevant time scales. The second speaker, Prof. Nalini Venkatasubramanian will highlight the role of data-driven solutions where machine learning can be used to characterize poorly understood dynamic water system phenomena and predict their behavior into the future. Finally, Prof. Amro Farid will discuss how control techniques like model-predictive control can be used to not only manage water sector objectives but also find environmental and economic synergies with other infrastructure through the energy-water nexus.

Cataloging Climate Solutions on the Coasts: Problem framing to find place-based points of criticality and leverage AI for action
Suzzane Pierce, Kasey Faust

Abstract: As climate shifts, coasts around the globe are on the frontlines of impact. Coastal resilience faces multi-faceted, wicked problems across natural and built environments with effects on economic systems that drive changes in livelihood and tilt towards inequitable results. This talk will present results from transdisciplinary research underway at coastal sites on the Gulf of Mexico that is advancing human-in-the-loop approaches to fuse process models with stakeholders’ lived experiences to formulate tractable decision problems. The aim is to identify issues that matter to communities and develop well-posed formulations and integrated models to facilitate model-informed dialogue for decision-making. A case study in the Rio Grande Valley of Texas will be shown to illustrate the integration of coastal surge and flooding models with models of infectious disease spread and hazard vulnerability maps generated with machine learning approaches, highlighting our ability to integrate cross-domain models and data with participatory methods and AI approaches to construct a catalog of resilient solutions. Some examples that we hope to explore with the workshop participants include - (1) System identification approaches to connect sparse, unstructured data with response models, (2) Create machine-readable datasets to benchmark coastal system behaviors, (3) Address the need to incorporate evaluation of cognitive and psychological models for group learning and model-based reasoning for complex climate challenges.

Climate Control in Buildings as a Renewable Energy Market Player
Iven Mareels, Arun Vishwanath, Ram Kolluri, Hendrik Hamann

Abstract: The decarbonisation of the energy market is one of the key goals the world has to accomplish by 2050. It is becoming clear that en route towards this objective the world will need to adopt locally available wind and solar energy and buffer the mismatch between instantaneous power supply and power demand through storage technologies. In this talk we
will present results on one type of storage technology, namely, discretionary power demand in buildings. Building climate control presents itself as a very useful storage technology in a renewable market, where the thermal capacity of the building is used as a leaky energy store, while preserving the required quality of service levels in the building. We will first consider a simplistic case to argue the case for control and mechanical systems co-design under climate change, demonstrating that the incorporation of heat storage makes a significant difference over the life time of the building. The co-design problem is posed as a stochastic (risk based) optimization problem where the risk envelope is determined by the climate change trajectory, small-scale stochasticity by the weather and the operational limits by the mechanical design, whereas the operational considerations depend on weather and daily control actions. We will also demonstrate how the interaction between building dynamics, occupancy and weather can be controlled to great advantage for the overall market whilst meeting the climate comfort levels of the building. An adaptive (learning the building dynamics including occupancy) receding horizon control informed by how the weather impacts on the building will be shown for this purpose, followed by data from a case study that will support the efficacy of the adaptive control approach, showing significant economic savings whilst facilitating the increased penetration of renewable energy sources in the market.