1. Type and Duration

Full-day workshop

2. Title

Safe Robot Control with Learned Motion and Environment Models

3. Organizers

Shumon Koga

Postdoctoral Researcher
Affiliation: Jacobs School of Engineering, University of California San Diego
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Phone: 716-220-8719
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URL: https://shumon0423.github.io

Bio: Shumon Koga received the B.S. degree in Applied Physics from Keio University (Japan) in 2014, and the M.S. and Ph.D. degrees in Mechanical and Aerospace Engineering from the University of California, San Diego (USA) in 2016 and 2020, respectively. He is currently a Postdoctoral Researcher at Existential Robotics Laboratory in Electrical and Computer Engineering at the University of California, San Diego. He received the Robert E. Skelton Systems and Control Dissertation Award from the UC San Diego Center for Control Systems and Dynamics in 2020. In 2019, he earned the O. Hugo Schuck Best Paper Award from American Automatic Control Council. Dr. Koga works on optimization and machine learning techniques for robotics, particularly, simultaneous localization and mapping (SLAM) and motion planning for safety-critical systems. His past research interests have included distributed parameter systems and optimization by extremum seeking and their applications to additive manufacturing, battery management, thermal management in buildings, transportation systems, and global climate systems.

Vikas Dhiman

Postdoctoral Researcher
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Bio: Vikas Dhiman is a Postdoctoral Researcher with Prof. Henrik Christensen and Prof. Nikolay Atanasov at the University of California, San Diego. His work focuses on robot localization, mapping, and safe-control algorithms. He completed his Ph.D. in 2019 under the mentorship of Prof. Jason Corso at the University of Michigan, Ann Arbor.

Nikolay Atanasov

Assistant Professor
Affiliation: University of California, San Diego - Dept. of Electrical and Computer Engineering
Address: 9500 Gilman Drive MC 0436, Atkinson Hall, Room 6127, La Jolla, CA 92093
Phone: 858-534-4105
Email: natanasov@ucsd.edu
URL: https://natanaso.github.io
Bio: Nikolay Atanasov is an Assistant Professor of Electrical and Computer Engineering at the University of California San Diego. His research focuses on robotics, control theory, and machine learning, applied to active sensing using ground and aerial robots. His contributions include probabilistic representations that unify geometry, semantics, and data association in robot localization and mapping as well as optimal control and reinforcement learning algorithms for active minimization of uncertainty in these models. Dr. Atanasov's work has been recognized by the Joseph and Rosaline Wolf award for the best Ph.D. dissertation in Electrical and Systems Engineering at the University of Pennsylvania in 2015 and the best conference paper award at the International Conference on Robotics and Automation in 2017.

4. URL

The workshop website is: https://vikasdhiman.info/safe-control-icra21/

5. Abstract

Guaranteeing safety is crucial for the effective deployment of robots. Control theory research has established techniques with theoretical safety and stability guarantees based on model predictive control, reference governor design, Hamilton-Jacobi reachability, control Lyapunov and barrier functions, and contraction theory. Existing techniques, however, predominantly assume that the robot motion dynamics and safety constraints are precisely known in advance. This assumption cannot be satisfied in the unstructured and dynamic real-world conditions. For example, an aerial vehicle aiding in disaster response must operate in an unpredictable environment subject to extreme disturbances. Similarly, a walking robot providing last-mile delivery has to traverse changing terrain while negotiating pedestrian traffic.

Recent progress in machine learning allows learning robot dynamics and environment models from sensory data. For example, Gaussian Process regression and Koopman operator theory have shown promise in learning dynamics models. Similarly, deep neural network models have enabled impressive results in 3D reconstruction from visual data. Despite their empirical success, these works usually do not provide theoretical guarantees for safety and stability.

This workshop will bring together experts from two communities -- control theory and machine learning -- to address challenges in safe and stable robot control with learned motion and environment models.

6. Content

The workshop will aim to bring forward cutting-edge research at the intersection of safe and stable robot control and machine learning of dynamics and environment models. We plan to explore the latest research in this area and, through interaction and discussion, foster new ideas and research directions.
This goal is motivated by the following observations. State-of-the-art control techniques for joint safety and stability have not extensively considered the effect of approximation in the system dynamics and safety constraints. Specifically, there is no formal approach for incorporating worst-case or probabilistic error estimates, originating from the approximations, in proving safety and stability. At the same time, there is significant progress in machine learning in approximating robot dynamics models and estimating safety constraints, e.g., based on implicit or explicit models of 3-D geometric surfaces of obstacles in navigation. However, these learned models have not been considered in the context of safe and stable control. Moreover, some very successful techniques, based on deep learning, provide maximum likelihood estimates but do not consider worst-case or Bayesian error quantification. Promoting work at the intersection of data-driven modeling and constrained control of dynamical systems will not only expand the capabilities of current autonomous systems but also **increase the confidence in deploying these systems in safety-critical applications.**

To achieve our goals, the workshop will include three main components:

1. **Invited Talks**: We invited both established and junior researchers to present and discuss the latest advances at the intersection of safe control and model learning. Our speakers will cover a broad spectrum of techniques for enforcing safety in control theory (Ames, Panagou, Tomlin, Zellinger) as well as cutting-edge research on physics- and cognitive-science-guided machine learning (Sukhatme, Allen, Yu, Levine). The specific research interests of each speaker are provided in the schedule below. Each invited talk will be 20 minutes, leaving enough time for 10 min interactive sessions to encourage interaction (Sec. 9).
2. **Contributed papers, posters, spotlight and demo videos:** We will solicit contributed papers in ICRA format, which will be peer-reviewed by a program committee. The program committee will be assembled if our workshop proposal is successful. Spotlight and demo videos, answering key questions related to the workshop goals will be solicited as supplementary material (see Sec. 7). The accepted papers will be featured in two poster sessions and through the spotlight videos. We will invite submissions from a broad range of topics that investigate the formal safety of robots while dealing with uncertainties introduced when the robot dynamics are learned or the environment state is estimated. Priority will be given to papers that bridge the gap between the two areas to provide safety and stability guarantees for systems with learned motion and environment dynamics.
3. **Discussion**: To foster new ideas and research questions, we will have short interactive sessions after each talk as well as a longer discussion at the end of the workshop. In our experience from prior workshops, having multiple short discussions increases interaction. We will prepare several key questions related to the workshop for each invited speaker. We also plan to solicit questions and discussion topics before and during the workshop via Twitter and Google forms (see Sec 9).

We have read and pledge to abide by the RAS guidelines for workshops.

Tentative Schedule

Time	Topic
08:45-09:00 AM	Registration, welcome, and opening remarks
09:00-09:30 AM	Invited talk: Aaron Ames, California Institute of Technology. Research interest: safe control using control barrier functions.
09:30-10:00 AM	Invited talk: Dimitra Panagou, University of Michigan. Research interest: safe control under adversarial attacks.
10:00-10:30 AM	Poster session[1]
10:30-11:00 AM	Coffee break
11:00-11:30 AM	Poster session[1]
11:30-12:00 PM	Invited talk: Claire J. Tomlin, UC Berkeley. Research interest: safe control using reachability analysis.
12:00-12:30 PM	Invited talk: Melanie N. Zeilinger, ETH Zurich. Research interest: safe control using model predictive control.
12:30-02:00 PM	Lunch break
02:00-02:30 PM	Invited talk: Gaurav Sukhatme, University of Southern California. Research interest: robust multi-robot team coordination using machine learning.
02:30-03:00 PM	Invited talk: Kelsey Allen, Massachusetts Institute of Technology. Research interest: human-inspired physics-based control.
03:00-03:30 PM	Coffee break and Poster session
03:30-04:00 PM	Poster session[1]
04:00-04:30 PM	Invited talk: Qi (Rose) Yu, UC San Diego. Research interest: physics-guided deep learning.
04:30-05:00 PM	Invited talk: Sergey Levine, UC Berkeley. Research interest: machine learning for robot autonomy.
05:00-05:30 PM	Discussion and closing remarks

1. In the event that an in-person poster session is not possible, the contributed papers will be highlighted with spotlight presentations.

7. Physical demo and videos

We will request that each contributed paper is accompanied by a **spotlight video submission** that provides a demo of the proposed approach and answers four key questions related to our workshop:

- What is your approach for **estimating** robot dynamics or environment models?
- How are the estimation errors quantified and used in **verifying safety** or stability?

- What is the key **contribution** of this approach?
- What is a key research problem that the community should address in **future work** and whose resolution will significantly impact your work?

The spotlight videos will be presented during the time allocated for the poster session. In the demo part of the video, the authors will be encouraged to demonstrate the operation of their system (either real or simulated) in a safety critical scenario.

Additionally, we will **record presentation and discussion videos** of the invited speaker presentations, each followed by a 10-minute Q&A session. The organizers will bring up the same four questions during the Q&A sessions to encourage discussion and interaction among junior and senior researchers and identify key directions for future research.

8. Plan to solicit participation

The confluence of recent impressive progress in fields related to robot control in unstructured environments --- control theory, cognitive science, and machine learning --- provides an exciting opportunity to share ideas across the three disciplines, discuss open problems, and establish a research direction in robotics aimed at enabling safety guarantees for robots operating with learned models. We will use a variety of ways to attract participation from researchers and practitioners in these areas. First, we will utilize traditional workshop announcements, including an abstract and call for contributions, on relevant **mailing lists** in robotics (robotics-worldwide; euRobotics), computer vision (the Multimodal Robot Perception group on Facebook), machine learning (the machine learning List: http://cll.stanford.edu/mllist/, Uncertainty in AI), and cognitive science (Connectionists, EUCog). Second, the workshop will be advertised in collaboration with the IEEE Robotics and Automation Society technical committee on **Verification of Autonomous Systems** (see Sec. 12). Third, we will send **personal invitations to top research groups**, working in the targeted fields. Based on experience from previous workshop organization, personal invitations to prominent researchers and collaborators are a particularly effective method for soliciting broad participation and high-quality contributions. Lastly, we will advertise the workshop on our and our invited speakers' **personal websites and social media accounts**. In particular, we will announce the workshop and call for papers on the Twitter account of UCSD Engineering. We expect these efforts to encourage researchers traditionally outside the robotics community to contribute to our workshop.

The proposers have previously organized several successful conceptually-related workshops:

- RSS'16 Workshop on "Robot-Environment Interaction for Perception and Manipulation: Interactive Perception Meets Reinforcement Learning and Optimal Control"
    - URL: http://rss16ip-rl-oc.robotics.usc.edu/
    - Organizers: K. Hausman, H. van Hoof, **N. Atanasov**, R. Martin Martin, O. Brock
    - Estimated number of participants: 70
- RSS'17 Workshop on "Learning Perception and Control for Autonomous Flight: Safety, Memory, and Efficiency"
    - URL: http://www.ece.ucr.edu/~kkarydis/rss17/
    - Organizers: K. Karydis, **N. Atanasov**, S. Levine, N. Roy, C. Tomlin, V. Kumar

    - Estimated number of participants: 120
- ICRA’18 Workshop on "Representing a Complex World: Perception, Inference, and Learning for Joint Semantic, Geometric, and Physical Understanding"
    - URL: https://natanaso.github.io/rcw-icra18
    - Organizers: **N. Atanasov**, L. Carlone
    - Estimated number of participants: 150

Our goal is to use these efforts as a starting point to promote a discussion on how learned environment representations (ICRA’18 workshop) and dynamics models (RSS’16 and RSS’17 workshops) can be integrated into control theoretic techniques without violating the safety and stability guarantees. Based on previous years' attendance, we anticipate more than **100 participants**.

9. Plan to encourage interaction among participants

We propose the following strategies to promote active discussion among the participants from different communities (robotics, control theory, cognitive science, and machine learning). First, we will coordinate and lead **10-minutes Q&A interactive sessions** at the end of each talk. We believe these sessions will be effective in clarifying technical questions related to the talks as well as encouraging continuous audience engagement. Second, we will solicit **early questions and discussion topics** from the participants (e.g. a list of essential pros and cons of the current approaches for enforcing safety constraints with learned models), through Twitter prior to the workshop and through a Google form shared on the website during the workshop. Third, we will have a longer **discussion section** at the end of the workshop that will encourage the participants to summarize the takeaways of the workshop, foster new ideas and think about important open problems in these areas. Lastly, the Q&A and discussion during the **poster sessions** will promote interaction of early-career and established researchers. We hope that these strategies will encourage interaction among participants from different communities and different levels in the career.

10. Dissemination

The workshop outcomes will include **presentation and discussion videos** from the invited talks and interactive sessions, **invited talk slides**, **contributed papers and posters**, and **spotlight and demo videos** from the contributed papers. We also plan to record an **outro video** summarizing the key observations made during the presentations, poster sessions, and discussion sessions and highlighting potential avenues for future research. These materials will be disseminated through two platforms: the **workshop website** and an **online video platform** (e.g., YouTube) approved by ICRA. All videos will be uploaded to both platforms and links to the workshop website will be provided on the video platform. The presentation slides and contributed papers and posters will be published on the workshop website and will be compiled into a single PDF file to serve as the **workshop proceedings**. The invited speakers, contributing authors, and participants will receive a copy of the proceedings via email.

11. Equipment

The workshop will include oral presentations from the invited speakers, spotlight videos and two poster sessions with contributed content, and 8 short interactive sessions after each invited presentation, followed by a long closing discussion. In the event of an in-person workshop, we

expect the following equipment to be sufficient:

- Presentation equipment: projector, laser pointer, screen, VGA/HDMI adapters
- Poster equipment: 10-20 poster stands/easels and tape in case of traditional posters, or monitors for digital poster presentation
- Discussion equipment: flip chart and markers
- Recording equipment: to allow recording the invited talks in real time and disseminating them on an online video platform (e.g., YouTube) and on the workshop website.

In the event of a remote workshop, we will rely on:

- Zoom or a similar video conferencing software, approved by ICRA, for the invented talks, poster spotlight presentations, and interactive sessions,
- Slack or a similar IRC-style communication platform, provided by ICRA, to solicit additional questions and discussion for the final long interactive session as well as to provide announcements and advertisement for the workshop contents before, during, and after the event.

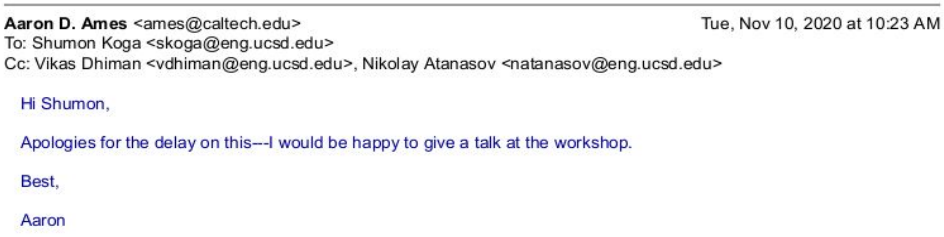
12. Support of an IEEE RAS Technical Committee

The workshop is endorsed by the IEEE RAS Technical Committee for Verification of Autonomous Systems (**please refer to the attached support letter**). We plan to solicit participation in the workshop in collaboration with the technical committee by announcing the workshop on their website and sending the call for papers to their mailing list.

13. Appendix

Acceptance emails from invited speakers:

1. Prof. Aron Ames



Aaron D. Ames <ames@caltech.edu> Tue, Nov 10, 2020 at 10:23 AM
To: Shumon Koga <skoga@eng.ucsd.edu>
Cc: Vikas Dhiman <vdhiman@eng.ucsd.edu>, Nikolay Atanasov <natanasov@eng.ucsd.edu>

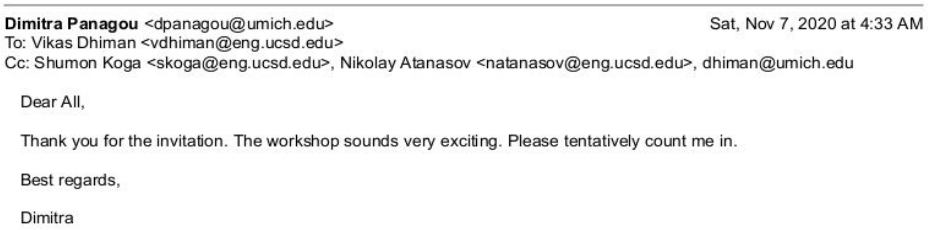
Hi Shumon,

Apologies for the delay on this---I would be happy to give a talk at the workshop.

Best,

Aaron

2. Prof. Dimitra Panagou



Dimitra Panagou <dpanagou@umich.edu> Sat, Nov 7, 2020 at 4:33 AM
To: Vikas Dhiman <vdhiman@eng.ucsd.edu>
Cc: Shumon Koga <skoga@eng.ucsd.edu>, Nikolay Atanasov <natanasov@eng.ucsd.edu>, dhiman@umich.edu

Dear All,

Thank you for the invitation. The workshop sounds very exciting. Please tentatively count me in.

Best regards,

Dimitra

3. Prof. Claire Tomlin

Claire Tomlin <tomlin@eecs.berkeley.edu> Fri, Nov 13, 2020 at 10:10 AM
Reply-To: tomlin@eecs.berkeley.edu
To: Vikas Dhiman <vdhiman@eng.ucsd.edu>
Cc: Nikolay Atanasov <natanasov@eng.ucsd.edu>, Shumon Koga <skoga@eng.ucsd.edu>

Dear Vikas and all --
I'd be happy to participate, though I've already indicated my willingness to participate in another related workshop. I think
it should be OK to do both, but I'm not sure how that works if both get accepted.
Thanks for the invitation,
cheers
Claire

4. Prof. Melanie Zeilinger

Melanie Zeilinger <mzeilinger@ethz.ch> Fri, Nov 6, 2020 at 12:02 AM
To: Vikas Dhiman <vdhiman@eng.ucsd.edu>
Cc: Nikolay Atanasov <natanasov@eng.ucsd.edu>, Shumon Koga <skoga@eng.ucsd.edu>

Dear Organizers,

Thank you very much for the invitation to speak at the workshop!
The workshop sounds very interesting.
I would indeed have difficulty committing to the presentation at this point. While I would be generally happy to give a talk, I will not be able to travel to China for ICRA'21. I could however give a virtual talk if that is an option that you are considering.
I understand if you can similarly not decide on this right now, but if it might be an option please consider this as a tentative yes.

Best regards
Melanie

5. Prof. Gaurav Sukhatme

Gaurav Sukhatme <gaurav@usc.edu> Mon, Nov 9, 2020 at 9:08 AM
To: Shumon Koga <skoga@eng.ucsd.edu>
Cc: Vikas Dhiman <vdhiman@eng.ucsd.edu>, Nikolay Atanasov <natanasov@eng.ucsd.edu>

Thanks so much for your kind invitation. I'd be happy to participate.
Best,

Gaurav

6. Kelsey Allen

Kelsey Allen <krallen@mit.edu> Mon, Nov 9, 2020 at 6:29 PM
To: Shumon Koga <skoga@eng.ucsd.edu>
Cc: Kelsey Allen <krallen@mit.edu>, Vikas Dhiman <vdhiman@eng.ucsd.edu>, Nikolay Atanasov <natanasov@eng.ucsd.edu>

Hi Shumon,

Thank you very much for the invitation! I would be very happy to speak at the workshop if it is accepted.

Best wishes,
Kelsey

7. Prof. Qi (Rose) Yu

Rose Yu <roseyu@eng.ucsd.edu> Sat, Nov 7, 2020 at 6:03 AM
To: Shumon Koga <skoga@eng.ucsd.edu>
Cc: Vikas Dhiman <vdhiman@eng.ucsd.edu>, Nikolay Atanasov <natanasov@eng.ucsd.edu>

Hi Shumon,

Thank you for the invitation. I'm happy to give a talk.

8. Prof. Sergey Levine

Sergey Levine <svlevine@eecs.berkeley.edu> Fri, Nov 6, 2020 at 9:39 AM
To: Vikas Dhiman <vdhiman@eng.ucsd.edu>
Cc: Shumon Koga <skoga@eng.ucsd.edu>, Nikolay Atanasov <natanasov@eng.ucsd.edu>

Dear organizers,

Thank you for the invitation. I would be happy to give a talk, though I do not think I can commit to in-person travel in May next year due to uncertainty regarding travel restrictions and the public health situation. But if you're OK with that kind of uncertainty, sure, I would be happy to tentatively agree.

SL