

Jake Welde

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RESEARCH FOCUS

My work develops geometric abstractions that enable efficient and explainable algorithms for the control of complex robotic systems. Using applied mathematics, optimization, and machine learning, I exploit structural characteristics like symmetry, compositionality, and mechanical structure to design and rigorously certify algorithms that scale gracefully with system complexity. Such methods transcend individual robot morphologies and inform mechanism and controller design for real-world systems, leading towards a future with robots that more faithfully echo the incredible example of Nature.

EDUCATION

PhD in Mechanical Engineering and Applied Mechanics 2019 - 2025 (expected)
University of Pennsylvania, GRASP Laboratory Philadelphia, PA
Thesis (working title): “Efficient Geometric Methods for the Control of Underactuated Robotic Systems”
Advisor: Vijay Kumar **Committee:** Daniel Koditschek, Michael Posa, Muruhan Rathinam, and Jim Ostrowski
My thesis work leverages Lie group theory, Riemannian geometry, and dynamical systems theory to design and rigorously characterize efficient algorithms (both analytical and learning-based) for the control of complex mechanical systems, such as aerial and space robots.

Master of Science in Engineering, Robotics 2020
University of Pennsylvania Philadelphia, PA

Bachelor of Science in Engineering, Mechanical Engineering and Applied Mechanics, magna cum laude 2019
University of Pennsylvania Philadelphia, PA
Minor in French and Francophone Studies

HONORS AND AWARDS

RSS Pioneers Cohort Member, Robotics: Science and Systems 2024
Selected as 1 of 30 of the “world’s top early-career researchers” in robotics for an intensive career workshop (15% acceptance rate).

John A. Goff Prize, Mechanical Engineering and Applied Mechanics, University of Pennsylvania 2024
This prize is “awarded annually to a graduate student in the Department of Mechanical Engineering and Applied Mechanics who has been selected by the faculty on the basis of criteria of scholarship, resourcefulness, and leadership” (1-2 PhD students per year).

Best Contribution, Neuroscience & Interpretability Track, NeurReps Workshop @ NeurIPS 2024 2024
Winner of a best paper award (3/58 contributions) at the Workshop on Symmetry and Geometry in Neural Representations @ NeurIPS.

Student Travel Support Award, IEEE Conference on Decision and Control (CDC) 2024

Outstanding Teaching Assistant Award, Mechanical Engineering and Applied Mechanics, University of Pennsylvania 2021
“This award is given to the Mechanical Engineering graduate student whose teaching assistant service has been exemplary... because of their initiative, reliability, commitment to the students, and their overall contribution to the teaching mission” (1-2 TA’s per semester).

Finalist for Best Paper in Unmanned Aerial Vehicles, IEEE International Conference on Robotics and Automation (ICRA) 2021

National Science Foundation Graduate Research Fellowship (three years of research funding, totaling \$138,000) 2019

Second Place, School of Engineering Senior Design Competition, University of Pennsylvania 2019

Couloucoundis Prize for Best Presentation, Mechanical Engineering Senior Design, University of Pennsylvania 2019

Student Travel Grant Award, IEEE International Conference on Intelligent Robots and Systems (IROS) 2017

PUBLICATIONS

JOURNAL ARTICLES

1. “Almost Global Asymptotic Trajectory Tracking for Fully-Actuated Mechanical Systems on Homogeneous Riemannian Manifolds”,
Jake Welde and Vijay Kumar.
IEEE Control Systems Letters, 2024.
2. “A Compositional Approach to Certifying Almost Global Asymptotic Stability of Cascade Systems”,
Jake Welde, Matthew D. Kvalheim, and Vijay Kumar.
IEEE Control Systems Letters, 2023.
3. “Dynamically Feasible Task Space Planning for Underactuated Aerial Manipulators”,
Jake Welde, James Paulos, and Vijay Kumar.
IEEE Robotics and Automation Letters, 2021.
Finalist for “Best Paper in Unmanned Aerial Vehicles” at ICRA 2021.
4. “Autonomous Flight for Detection, Localization, and Tracking of Moving Targets With a Small Quadrotor”,
Justin Thomas, Jake Welde, Giuseppe Loianno, Kostas Daniilidis, and Vijay Kumar.
IEEE Robotics and Automation Letters, 2017.

REFEREED CONFERENCE PROCEEDINGS

1. “The Role of Symmetry in Constructing Geometric Flat Outputs for Free-Flying Robotic Systems”,
Jake Welde, Matthew D. Kvalheim, and Vijay Kumar.
IEEE International Conference on Robotics and Automation, 2023.
2. “Trajectory Planning for the Bidirectional Quadrotor as a Differentially Flat Hybrid System”,
Katherine Mao, Jake Welde, M. Ani Hsieh, and Vijay Kumar.
IEEE International Conference on Robotics and Automation, 2023.
3. “Coordinate-Free Dynamics and Differential Flatness of a Class of 6DOF Aerial Manipulators”,
Jake Welde and Vijay Kumar.
IEEE International Conference on Robotics and Automation, 2020.

PREPRINTS

1. “Leveraging Symmetry to Accelerate Learning of Trajectory Tracking Controllers for Free-Flying Robotic Systems”,
Jake Welde*, Nishanth Rao*, Pratik Kunapuli*, Dinesh Jayaraman, and Vijay Kumar, 2024.
*Submitted the IEEE International Conference on Robotics and Automation. *equal contribution.*

PRESENTATIONS

TALKS

1. “Almost Global Asymptotic Trajectory Tracking for Mechanical Systems on Homogeneous Spaces”,
Vijay Kumar and Jake Welde (speaker).
Contributed Talk, *Joint Mathematics Meetings*, 2025.
2. “Geometric Abstractions for Efficient and Explainable Control of Complex Robotic Systems”,
Jake Welde.
Invited Talk, *Safe Autonomous Systems Lab (Sylvia Herbert)*, UC San Diego, 2025.
3. “Lie Group Symmetries and Continuous MDP Homomorphisms in Optimal Tracking Control Problems”,
Vijay Kumar, Pratik Kunapuli*, Nishanth Rao*, and Jake Welde* (speaker).
Contributed Talk, *Joint Mathematics Meetings*, 2025.
4. “Differential Flatness and Geometric Hierarchy in Underactuated Mechanical Systems with Symmetry”,
Vijay Kumar, Matthew D. Kvalheim, and Jake Welde (speaker).
Invited Talk, *Joint Mathematics Meetings*, 2024.

5. **“Geometric Tracking Control on Homogeneous Riemannian Manifolds”**,
Jake Welde and Vijay Kumar.
Contributed Talk, *Northeast Systems and Controls Workshop*, 2024.
6. **“Plenty of Room in the Middle: Towards Efficient and Explainable Control of Complex Robotic Systems via Symmetry, Abstraction, and Learning”**,
Jake Welde.
Invited Talk, *Robotics and Optimization for Analysis of Human Motion Lab (Ram Vasudevan)*, University of Michigan, 2024.
7. **“A Compositional Approach to Certifying Almost Global Asymptotic Stability of Cascade Systems”**,
Jake Welde, Matthew D. Kvalheim, and Vijay Kumar.
Contributed Talk, *Compositional Robotics Workshop*, International Conference on Robotics and Automation, 2023.
8. **“A Geometric Perspective on Differential Flatness of Mechanical Systems with Symmetry”**,
Jake Welde, Matthew D. Kvalheim, and Vijay Kumar.
Contributed Lecture, *SLAM Conference on Control and Its Applications*, 2023.
9. **“A Principal Bundle Perspective on Differential Flatness in Complex Robotic and Biological Systems”**,
Jake Welde, Matthew D. Kvalheim, and Vijay Kumar.
Contributed Talk, *Robophysics Focus Session*, APS March Meeting, 2023.
10. **“Geometric Control of Underactuated Robotic Systems: Flatness, Hierarchy, and Control-Aware Design”**,
Jake Welde.
Invited Talk, *Nikolai Matni Group*, University of Pennsylvania, 2023.
11. **“Hierarchical Methods for Geometric Control of Underactuated, Free-Flying Robotic Systems”**,
Jake Welde.
Departmental Research Seminar, *Mechanical Engineering and Applied Mechanics*, University of Pennsylvania, 2023.
12. **“The Role of Symmetry in Constructing Geometric Flat Outputs for Free-Flying Robotic Systems”**,
Jake Welde, Matthew D. Kvalheim, and Vijay Kumar.
Invited Talk, *Kostas Daniilidis Group*, University of Pennsylvania, 2022.

POSTERS

1. **“Geometric Methods of Systematic Controller Synthesis for Underactuated Robotic Systems”**,
Jake Welde.
RSS Pioneers Workshop, Robotics: Science and Systems, 2024.
2. **“Integrated Hardware and Software Codesign for Controlling Underactuated Aerial Robots”**,
Jack Campanella (presenter), Jake Welde, and Vijay Kumar.
Northeast Systems and Control Workshop, 2024.
3. **“Leveraging Symmetry to Accelerate Learning of Trajectory Tracking Controllers for Free-Flying Robotic Systems”**,
Jake Welde*, Nishanth Rao* (presenter), Pratik Kunapuli* (presenter), Dinesh Jayaraman, and Vijay Kumar.
Symmetry and Geometry in Neural Representations Workshop, Conference on Neural Information Processing Systems, 2024.
Oral Presentation (9/58 \approx 16%). “Best Contribution, Neuroscience & Interpretability Track”. *equal contribution.
4. **“Towards a Lightweight Fully-Actuated Aerial Vehicle: Thrust Vectoring and Control Allocation Under Redundancy”**,
Saibernard Yogendran (presenter), Jake Welde, and Vijay Kumar.
Northeast Systems and Control Workshop, 2024.
5. **“Towards Automatic Identification of Globally Valid Geometric Flat Outputs via Numerical Optimization”**,
Jake Welde and Vijay Kumar.
Geometric Representations Workshop, International Conference on Robotics and Automation, 2023.
6. **“Some Aerial Manipulators Can Exactly Track Arbitrary Smooth End-Effector Trajectories in 6 Degrees of Freedom”**,
Jake Welde and Vijay Kumar.
Northeast Robotics Colloquium, 2019.

MEDIA

“MEAM 520 Class Breakdown”, <i>GRASP Lab Presents</i>	2022
“Virtual Robots: Taking Risks in an Online Classroom”, <i>Penn Engineering Today</i>	2021
“Game of Drones”, <i>National Geographic’s “Breakthrough”</i>	2017
“Penn Students Create Gingerbread Replica of Fisher Fine Arts Library”, <i>34th Street Magazine</i>	2017

TECHNICAL EXPERIENCE

SharpShooter: an Invisible Tripod via Reaction Wheels	2018 - 2019
<i>Senior Design Project, Mechanical Engineering at the University of Pennsylvania</i>	<i>Philadelphia, PA</i>

Development of a novel reaction wheel stabilizer for ergonomic, handheld long-exposure still photography with team of five peers

- Developed nonlinear system identification pipeline to enable precise application of corrective torques at any motor velocity
- Implemented gyroscope bias observer to enable accurate and precise attitude estimation during exposures
- Quantitative stabilization performance exceeded all other commercially-available handheld stabilizers

Exyn Technologies	Summer 2018
<i>Robotics: Software and Algorithms Intern</i>	<i>Philadelphia, PA</i>

Software engineering at aerial robotics startup delivering trustworthy autonomy in challenging environments

- Evaluated and integrated range of technologies for barcode decoding and localization for autonomous warehouse inventory
- Contributed mission-critical modules to integrate low-level sensors with high-level flight software stack
- Developed and implemented novel algorithm for extrinsic calibration of any number of rigidly connected inertial measurement units, cameras, and LIDARs using only a single physical calibration target accomodating all sensing modalities

TEACHING

PEDAGOGICAL TRAINING

Certificate in College and University Teaching , Center for Teaching and Learning	2023
<i>Multipart teaching preparation and credential for university instruction</i>	<i>University of Pennsylvania</i>

Preparation consists of participation in teaching seminars held by current faculty, expert observation of a teaching demonstration, and exploration and development of personal teaching philosophy through interaction with expert teachers and scholars.

Course in College Teaching , Center for Teaching and Learning	Fall 2022
<i>Semester-long seminar covering course design, active learning, and engaging teaching practices</i>	<i>University of Pennsylvania</i>

Inclusive and Equitable Teaching Mini-Course , Center for Teaching and Learning	Spring 2023
<i>One-month seminar on scholarly research and primary sources in inclusive and equitable instruction</i>	<i>University of Pennsylvania</i>

INSTRUCTIONAL EXPERIENCE

MEAM 520 / CIT 520: Introduction to Robotics	Fall 2020 / Spring 2021 / Fall 2021
<i>Head Teaching Assistant for Professors Cynthia Sung, Vijay Kumar, and M. Ani Hsieh</i>	<i>University of Pennsylvania</i>

Led development of written and laboratory assignments to achieve key pedagogical objectives across theory and practice, covering forward and inverse kinematics, motion planning, rigorous testing, and simulation-to-reality workflow. Worked closely with students in office hours, recitations, and hands-on lab sessions. Led the creation and introduction of a final capstone competition in which students implement a complete manipulation solution on industrial robot hardware. Recognized with the **Outstanding TA Award**.

MEAM 211: Engineering Mechanics, Dynamics	Spring 2021
<i>Head Teaching Assistant for Professor Michael Posa</i>	<i>University of Pennsylvania</i>

Conducted interactive problem-solving recitations with undergraduates. Developed new computational assignments for the course, in which students implement a multibody dynamics simulator via step-by-step weekly modules, putting concepts into practice.

MENTORING

I have been either a close mentor or a direct supervisor to each of the following students during their work on the indicated project.

DOCTORAL STUDENTS

- Pratik Kunapuli, University of Pennsylvania, Computer and Information Science 2024
“Benchmarking Controllers for Agile Aerial Manipulators”
- Katie Mao, University of Pennsylvania, Mechanical Engineering 2022
“Trajectory Planning for the Bidirectional Quadrotor as a Differentially Flat Hybrid System”

MASTERS STUDENTS

- Nishanth Rao, University of Pennsylvania, Robotics 2024 - present
“Exploring Symmetries and Equivariance in Robot Learning” (in-progress Masters thesis)
- Jack Campanella, University of Pennsylvania, Robotics 2023 - present
“Integrated Hardware and Software Codesign for Controlling Underactuated Aerial Robots” (in-progress Masters thesis)
- Saibernard Yogendran, University of Pennsylvania, Robotics (now at ASML) 2022 - 2024
“Towards a Lightweight Fully-Actuated Aerial Vehicle: Thrust Vectoring and Control Allocation Under Redundancy”

UNDERGRADUATE STUDENTS

- Eshan Singhal, University of Pennsylvania, Computer Engineering and Physics 2024 - present
“Control of an Agile Quadrotor Aerial Vehicle with Articulated Propellers”
- Nicole Luna, Cal Poly Pomona, Mechanical Engineering and Physics (now a PhD Student at CU Boulder) Summer 2021
“Aerial Manipulator Mechanical Design”
- Natasha Dilamani, University of Pennsylvania, Mechanical Engineering (now at Millenium) Summer 2020
“Dynamic Modeling of the Sphero, a Highly Nonholonomic System”

SERVICE

PUBLIC OUTREACH

Science Olympiad at the University of Pennsylvania 2017 - present

- **Event Supervisor**, *Penn Invitational Tournament*. Coordinating a team of student volunteers to run a yearly engineering challenge for high school students, with over 100 students competing.
- **Placement Leader**, *Urban Initiative*. Site supervisor for several student volunteers in affiliated outreach and mentoring program. Making weekly visits to a Philadelphia public high school to work directly with students exploring science and engineering topics.

“Fun with Robots” Outreach Programming, *Roxborough Library, Free Library of Philadelphia* 2024

- Ran workshop for elementary, middle, and high school students, exploring basic concepts in control and stability for robotics

DEPARTMENTAL SERVICE

GRASP “Students, Faculty, and Industry” Seminar, Organizing Committee Member 2023 - present

Curating, inviting, and hosting speakers from peer institutions and industry connections to visit the GRASP research community.

Mechanical Engineering Graduate Association, Treasurer 2020 - 2021

Managed finances while planning and executing programming to support the professional, social, engagement, and inclusion needs of the graduate student community in our department.

SERVICE TO THE PROFESSION

RSS Pioneers Workshop, Robotics: Science and Systems (to occur), Faculty Chair 2025

I will serve as one of three Faculty Chairs for the next iteration of RSS Pioneers (an intensive workshop for early-career researchers).

Equivariant Robotics Workshop, International Conference on Intelligent Robots and Systems, Lead Organizer 2024

Led team of organizers across several institutions to run an interdisciplinary conference workshop at IROS 2024. This event explored the role of the natural symmetries enjoyed by robotic systems in solving diverse problems across estimation, perception, and control.

Review Activities for International Journals and Conferences

• IFAC Automatica	2024
• IEEE/ASME Transactions on Mechatronics	2024
• IEEE Control Systems Letters	2023 - 2024
• Springer Autonomous Robots	2023
• IEEE Robotics and Automation Letters	2021 - 2023
• ASME Journal of Dynamic Systems, Measurement and Control	2022 - 2023
• IEEE International Conference on Robotics and Automation	2022 - 2023
• IEEE Transactions on Robotics	2021 - 2023
• Robotics: Science and Systems	2022
• IEEE Transactions on Automatic Control	2022
• IEEE International Conference on Intelligent Robots and Systems	2020 - 2021
• IEEE International Conference on Automation Science and Engineering	2020

F U N F A C T S

My Erdős number is at most 3 (Jake Welde ↔ Kostas Daniilidis ↔ Pavel Valtr ↔ Paul Erdős).

In my free time, I love spending time in Nature, cooking spicy food, and playing fetch with my very energetic dog Sprout.

REFERENCES

VIJAY KUMAR

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