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Google Scholar (link)
Robust Autonomy Lab (link)

David M. Rosen

Assistant Professor

Research interests

I am broadly interested in the **mathematical and algorithmic foundations of trustworthy autonomy**. My research applies analytical and computational tools from nonlinear optimization, differential geometry and topology, abstract algebra, and probability and statistics to design *principled*, *computationally efficient*, and ***provably robust*** **algorithms for machine learning, perception, and control**.

Education

2016 **Sc.D. Computer Science**, *Massachusetts Institute of Technology*
Thesis: *Certifiably Correct SLAM*
Advisor: John J. Leonard
Minor concentration: Brain and Cognitive Science

2010 **M.A. Mathematics**, *University of Texas at Austin*
Concentration: Geometric Mechanics
Advisors: Raphael de la Llave, Alan Reid

2008 **B.S. Mathematics**, *California Institute of Technology*
Graduated with Honors
Advisors: David Wales, David Ben McReynolds
Minor concentration: Control and Dynamical Systems
Advisors: Jerrold E. Marsden, Richard M. Murray, Joel Burdick

Honors, awards, and fellowships

2021	**Honorable Mention, King-Sun Fu Memorial Best Paper Award**, *IEEE Transactions on Robotics* (T-RO)
2020	**Best Student Paper Award**[*], Robotics: Science and Systems (RSS)
2019	**RSS Pioneer**, Robotics: Science and Systems (RSS)
2016	**Best Paper Award**, International Workshop on the Algorithmic Foundations of Robotics (WAFR)
2011	MIT Intelligence Initiative Fellowship
2010 – 2011	MIT Energy Initiative Fellowship
2008 – 2009	NSF Research Training Groups in the Mathematical Sciences (RTG) Fellowship (UT Austin, Topology)
2004 – 2008	Leon L. Granoff Merit Scholarship (full scholarship)

Experience

Northeastern University, Boston, MA

2021 – present **Assistant Professor**, *Departments of Electrical & Computer Engineering (ECE) and Mathematics, Khoury College of Computer Sciences (by courtesy), Core Faculty Member, Institute for Experiential Robotics and Institute for Experiential AI*
My research advances the algorithmic foundations of robotics through the design of *computationally efficient* and *provably robust* algorithms for **machine learning, perception, and control**. A major focus of my work is the design of practical estimation and control algorithms for nonlinear systems that provide **explicit performance guarantees** in real-world operation. I am particularly interested in exploring *convex relaxation* as a general strategy for recovering provably-good approximate solutions to hard computational problems in artificial intelligence.

[*]Mentoring students Valentin Peretroukhin, Matthew Giamou, and W. Nicholas Greene.

Massachusetts Institute of Technology, Cambridge, MA

2020 – 2021 **Postdoctoral associate**, *Department of Aeronautics and Astronautics, Aerospace Controls Laboratory*
My work in the Aerospace Controls Laboratory addressed the design of robust estimation methods for multi-agent robotic systems, including the development of the **first *fully decentralized* certifiable perception algorithms for cooperative SLAM and rotation averaging** [W6, J3].

2018 – 2021 **Postdoctoral associate**, *Laboratory for Information and Decision Systems*
My research in LIDS explored general design approaches, and associated computational tools, for synthesizing practical robust estimation and learning methods, with a particular emphasis on the application of **semialgebraic methods and semidefinite optimization** to problems in machine perception [W6, J4, J11, C11, C9, W5].

2010 – 2016 **Doctoral candidate**, *Computer Science and Artificial Intelligence Laboratory, Marine Robotics Group*
My doctoral research addressed the development of computationally efficient and provably robust algorithms for robot perception, with a particular focus on the fundamental problem of *simultaneous localization and mapping* (SLAM). This work culminated in **SE-Sync, the first certifiably correct SLAM algorithm**; this is the first practical method that is **provably capable of recovering correct (globally optimal) SLAM solutions** [J2, W4, TR1, C7].

Oculus Research/Facebook Reality Labs, Redmond, WA

2016 – 2018 **Research scientist**, *Surreal Vision Group*
Developed large-scale distributed mapping and localization algorithms as part of the LiveMaps project to enable intelligent, always-on augmented- and mixed-reality devices.

Google, Mountain View, CA

2015 **Software engineering intern**, *Google Robotics*
Proposed a novel feature-based continuous-time modeling framework (and associated inference algorithms) to describe the temporal evolution of semi-static environments as an aid to long-duration robotic autonomy [C6, W2].

2014 **Software engineering intern**, *Google Research*
Designed and implemented robust mapping and localization systems to support persistent autonomous operation of teams of indoor ground robots. As part of this project, proposed a novel formulation of pose-graph SLAM as a quadratically-constrained quadratic program, and an associated convex relaxation for efficiently recovering high-quality solutions of this problem *without* the need for good initial estimates [C5].

University of Texas, Austin, TX

2009 – 2010 **Graduate research assistant**, *Applied Research Laboratories, Advanced Sonar Division*
Developed sonar image processing algorithms for deployment on autonomous underwater vehicles.

Publications

*Denotes equal contribution

†Denotes a student author

Preprints

[P3] Owen Howell†, Haoen Huang†, and **David M. Rosen**. *Multi-Irreducible Spectral Synchronization for Robust Rotation Averaging*. 2023.

[P2] Pushyami Kaveti, Matthew Giamou, Hanumant Singh, and **David M. Rosen**. *OASIS: Optimal Arrangements for Sensing in SLAM*. Under review at *IEEE International Conference on Robotics and Automation*. 2023.

[P1] Alan Papalia†, Andrew Fishberg†, Brendan W. O'Neill†, Jonathan P. How, **David M. Rosen**, and John J. Leonard. *Certifiably Correct Range-Aided SLAM*. Under review at *IEEE Transactions on Robotics*. 2023.

Journal articles

[J7] Qiangqiang Huang[†], Can Pu[†], Kasra Khosoussi, **David M. Rosen**, Dehann Fourie, Jonathan P. How, and John J. Leonard. “Incremental Non-Gaussian Inference for SLAM using Normalizing Flows”. In: *IEEE Transactions on Robotics* 39.2 (Apr. 2023), pp. 1458–1475. DOI: 10.1109/TRO.2022.3216498.

[J6] **David M. Rosen**. “Accelerating Certifiable Estimation with Preconditioned Eigensolvers”. In: *IEEE Robotics and Automation Letters* 7.4 (Oct. 2022), pp. 12507–12514. DOI: 10.1109/LRA.2022.3220154.

[J5] Matthew Giamou[*†], Filip Marić[*†], **David M. Rosen**, Valentin Peretroukhin, Nicholas Roy, Ivan Petrović, and Jonathan Kelly. “Convex Iteration for Distance-Geometric Inverse Kinematics”. In: *IEEE Robotics and Automation Letters* 7.2 (Apr. 2022), pp. 1952–1959. DOI: 10.1109/LRA.2022.3141763.

[J4] **David M. Rosen**, Kevin J. Doherty[†], Antonio Terán Espinoza[†], and John J. Leonard. “Advances in Inference and Representation for Simultaneous Localization and Mapping”. In: *Annual Review of Control, Robotics, and Autonomous Systems* 4 (May 2021), pp. 215–242. DOI: 10.1146/annurev-control-072720-082553. Invited article.

[J3] Yulun Tian[†], Kasra Khosoussi, **David M. Rosen**, and Jonathan P. How. “Distributed Certifiably Correct Pose-Graph Optimization”. In: *IEEE Transactions on Robotics* 37.6 (Dec. 2021), pp. 2137–2156. DOI: 10.1109/TRO.2021.3072346. Honorable Mention, King-Sun Fu Memorial Best Paper Award.

[J2] **David M. Rosen**, Luca Carlone, Afonso S. Bandeira, and John J. Leonard. “SE-Sync: A Certifiably Correct Algorithm for Synchronization over the Special Euclidean Group”. In: *International Journal of Robotics Research* 38.2–3 (Mar. 2019), pp. 95–125. DOI: 10.1177/0278364918784361. Invited article (WAFR 2016 special issue).

[J1] **David M. Rosen**, Michael Kaess, and John J. Leonard. “RISE: An Incremental Trust-Region Method for Robust Online Sparse Least-Squares Estimation”. In: *IEEE Transactions on Robotics* 30.5 (Oct. 2014), pp. 1091–1108. DOI: 10.1109/TRO.2014.2321852.

Peer-reviewed conference proceedings

[C15] Alan Papalia[†], Joseph Morales[†], Kevin J. Doherty[†], **David M. Rosen**, and John J. Leonard. “SCORE: A Second-Order Conic Initialization for Range-Aided SLAM”. In: *IEEE International Conference on Robotics and Automation*. London, UK, May 2023, pp. 10637–10644. DOI: 10.1109/ICRA48891.2023.10160787.

[C14] Kevin J. Doherty[†], **David M. Rosen**, and John J. Leonard. “Performance Guarantees for Spectral Initialization in Rotation Averaging and Pose-Graph SLAM”. In: *IEEE International Conference on Robotics and Automation*. Philadelphia, PA, May 2022, pp. 5608–5614. DOI: 10.1109/ICRA46639.2022.9811788.

[C13] Kevin J. Doherty[†], **David M. Rosen**, and John J. Leonard. “Spectral Measurement Sparsification for Pose-Graph SLAM”. In: *IEEE/RSJ International Conference on Intelligent Robots and Systems*. Kyoto, Japan, Oct. 2022, pp. 6412–6419. DOI: 10.1109/IROS47612.2022.9981584.

[C12] Yulun Tian[†], Amrit Singh Bedi, Alec Koppel, Miguel Calvo-Fullana, **David M. Rosen**, and Jonathan P. How. “Distributed Riemannian Optimization with Lazy Communication for Collaborative Geometric Estimation”. In: *IEEE/RSJ International Conference on Intelligent Robots and Systems*. Kyoto, Japan, Oct. 2022, pp. 4391–4398. DOI: 10.1109/IROS47612.2022.9981256.

[C11] **David M. Rosen**. “Scalable Low-Rank Semidefinite Programming for Certifiably Correct Machine Perception”. In: *International Workshop on the Algorithmic Foundations of Robotics*. June 2020. DOI: 10.1007/978-3-030-66723-8_33.

[C10] Irit Chelly[†], Vlad Winter[†], Dor Litvak[†], **David M. Rosen**, and Oren Freifeld. “JA-POLS: A Moving-Camera Background Model via Joint Alignment and Partially-Overlapping Local Subspaces”. In: *IEEE/CVF Conference on Computer Vision and Pattern Recognition*. Seattle, WA, June 2020, pp. 12585–12594. DOI: 10.1109/CVPR42600.2020.01260.

[C9] Frank Dellaert*, **David M. Rosen***, Jing Wu†, Robert Mahony, and Luca Carlone. “Shonan Rotation Averaging: Global Optimality by Surfing $SO(p)^n$”. In: *European Conference on Computer Vision*. Glasgow, UK, Aug. 2020, pp. 292–308. DOI: 10.1007/978-3-030-58539-6_18. Spotlight talk (top 5%).

[C8] Valentin Peretroukhin†, Matthew Giamou†, **David M. Rosen**, W. Nicholas Greene†, Nicholas Roy, and Jonathan Kelly. “A Smooth Representation of Belief over SO(3) for Deep Rotation Learning with Uncertainty”. In: *Robotics: Science and Systems*. Corvallis, OR, July 2020. Link. Best Student Paper Award.

[C7] **David M. Rosen**, Luca Carlone, Afonso S. Bandeira, and John J. Leonard. “A Certifiably Correct Algorithm for Synchronization over the Special Euclidean Group”. In: *International Workshop on the Algorithmic Foundations of Robotics*. San Francisco, CA, Dec. 2016. DOI: 10.1007/978-3-030-43089-4_5. Best Paper Award.

[C6] **David M. Rosen**, Julian Mason, and John J. Leonard. “Towards Lifelong Feature-Based Mapping in Semi-Static Environments”. In: *IEEE International Conference on Robotics and Automation*. Stockholm, Sweden, May 2016, pp. 1063–1070. DOI: 10.1109/ICRA.2016.7487237.

[C5] **David M. Rosen**, Charles DuHadway, and John J. Leonard. “A Convex Relaxation for Approximate Global Optimization in Simultaneous Localization and Mapping”. In: *IEEE International Conference on Robotics and Automation*. Seattle, WA, May 2015, pp. 5822–5829. DOI: 10.1109/ICRA.2015.7140014.

[C4] Luca Carlone, **David M. Rosen**, Giuseppe Calafiore, John J. Leonard, and Frank Dellaert. “Lagrangian Duality in 3D SLAM: Verification Techniques and Optimal Solutions”. In: *IEEE/RSJ International Conference on Intelligent Robots and Systems*. Hamburg, Germany, Sept. 2015. DOI: 10.1109/IROS.2015.7353364.

[C3] **David M. Rosen**, Guoquan Huang, and John J. Leonard. “Inference Over Heterogeneous Finite-/Infinite-Dimensional Systems Using Factor Graphs and Gaussian Processes”. In: *IEEE International Conference on Robotics and Automation*. Hong Kong, China, June 2014, pp. 1261–1268. DOI: 10.1109/ICRA.2014.6907015.

[C2] **David M. Rosen**, Michael Kaess, and John J. Leonard. “Robust Incremental Online Inference Over Sparse Factor Graphs: Beyond the Gaussian Case”. In: *IEEE International Conference on Robotics and Automation*. Karlsruhe, Germany, May 2013, pp. 1017–1024. DOI: 10.1109/ICRA.2013.6630699.

[C1] **David M. Rosen**, Michael Kaess, and John J. Leonard. “An Incremental Trust-Region Method for Robust Online Sparse Least-Squares Estimation”. In: *IEEE International Conference on Robotics and Automation*. St. Paul, MN, May 2012, pp. 1262–1269. DOI: 10.1109/ICRA.2012.6224646.

Workshop papers

[W8] Owen Howell†, Haoen Huang†, and **David M. Rosen**. “Multi-Irreducible Spectral Synchronization for Robust Rotation Averaging”. Presented at the New England Computer Vision Workshop. Hanover, NH, USA, Dec. 2023.

[W7] Tarik Kelestemur†, Taskin Padir, Robert Platt, and **David M. Rosen**. “Learning Prior Mean Functions for Gaussian Process Implicit Surfaces”. Presented at the International Conference on Robotics and Automation in the workshop "Motion Planning with Implicit Neural Representations of Geometry". Philadelphia, PA, USA, May 2022.

[W6] **David M. Rosen**. “The Riemannian Geometry of Synchronization Problems”. Presented at Robotics: Science and Systems in the workshop "Geometry and Topology in Robotics: Learning, Optimization, Planning, and Control". Virtual, July 2021.

[W5] **David M. Rosen**. “Towards Provably Robust Machine Perception”. Presented at Robotics: Science and Systems in the workshop "RSS Pioneers". Freiburg, Germany, June 2019.

[W4] **David M. Rosen** and Luca Carlone. “Computational Enhancements for Certifiably Correct SLAM”. Presented at the International Conference on Intelligent Robots and Systems in the workshop “Introspective Methods for Reliable Autonomy". Vancouver, Canada, Sept. 2017. Link.

[W3] **David M. Rosen** and Luca Carlone. “A Certifiably Exact Algorithm for Large-Scale SE(3) Synchronization”. Presented at the International Conference on Machine Learning in the workshop “Gimli: Geometry in Machine Learning". New York, NY, USA, June 2016.

[W2] **David M. Rosen**, Julian Mason, and John J. Leonard. “Towards Lifelong Feature-Based Mapping in Semi-Static Environments”. Presented at Robotics: Science and Systems in the workshop “The Problem of Mobile Sensors”. Rome, Italy, July 2015.

[W1] Roberto Tron, **David M. Rosen**, and Luca Carlone. “On the Inclusion of Determinant Constraints in Lagrangian Duality for 3D SLAM”. Presented at Robotics: Science and Systems in the workshop “The Problem of Mobile Sensors”. Rome, Italy, July 2015. Link.

Technical reports

[TR1] **David M. Rosen**, Luca Carlone, Afonso S. Bandeira, and John J. Leonard. *SE-Sync: A Certifiably Correct Algorithm for Synchronization over the Special Euclidean Group*. Tech. rep. MIT-CSAIL-TR-2017-002. Cambridge, MA 02139, USA: Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Feb. 2017. Link.

Selected talks

Invited keynotes

2022 **Certifiably Correct Machine Perception**: Workshop on Safe and Certifiable Navigation and Control for Intelligent Vehicles in Complex Urban Scenarios, IEEE International Conference on Intelligent Transportation Systems (ITSC). Macau, China. October 8.

2018 **Certifiably Correct SLAM**: Workshop on Geometry in Machine Learning, International Conference on Machine Learning (ICML), Stockholm, Sweden. July 15.

2017 **Building Spatially-Aware Systems for Fun and Profit**: Cairo Maker Faire. Cairo, Egypt. April 8.

Invited seminars

2023 **Building Blocks for Trustworthy Autonomy**: MIT Lincoln Laboratory, Space Systems and Technology Group. Lexington, MA, USA. February 22.

2022 **Certifiably Correct Machine Perception**: WPI Data Science Colloquium. Worcester, MA, USA. April 13.

2021 **Certifiably Correct Machine Perception**: Hong Kong Polytechnic University. Hong Kong, China. December 10.

2021 **Certifiably Correct Machine Perception**: Technion (Israel Institute of Technology). Haifa, Israel. May 5.

2020 **Certifiably Correct SLAM**: University of Toronto Robotics Institute. Toronto, Canada. December 7.

2017 **The Future of Mixed Reality**: UC Berkeley Institute of Design. Berkeley, CA, USA. December 12.

2016 **Towards Certifiably Robust Robotic Mapping**: Oculus Research. Redmond, WA, USA. February 19.

2015 **Robust Spatial Perception for Robotics: Progress and Challenges**: UC Berkeley Robot Learning and AUTOLAB groups. Berkeley, CA, USA. August 18.

2014 **Everything You Always Wanted to Know About Robotic Mapping, But Were Afraid to Ask**: Google Replicant. Palo Alto, CA, USA. August 13.

Invited conference presentations

2023 **Practical Algorithms for Globally Optimal Geometric Machine Perception**: Allerton Conference on Communication, Control, and Computing. Monticello, IL, USA. Sep 28.

2023 **Relaxation, Reparameterization, and Global Optimization in Geometric Machine Perception**: Minisymposium on Parameterizations and Nonconvex Landscapes, SIAM Conference on Optimization. Seattle, WA, USA. May 31.

Guest lectures

2021 **Certifiably Correct SLAM**: University of Michigan AEROSP 740 (Visual Navigation for Autonomous Aerial Vehicles)

2019–2020 **Certifiably Correct SLAM**: MIT AeroAstro 16.485 (Visual Navigation for Autonomous Vehicles)

2019 **Scalable Semidefinite Optimization**: MIT AeroAstro 16.S498 (Risk-Aware & Robust Nonlinear Planning)

Teaching

Mobile Robotics (EECE 5550), *Northeastern University, Boston*
An introduction to the scientific and engineering discipline of robotics through the lens of mobile autonomy, covering both the mathematical and algorithmic foundations of the major subdisciplines of the field (perception, planning, and control), as well as the practicalities of constructing and deploying complex autonomous systems using standard tools such as Linux, Git, NumPy/SciPy and ROS.
Semesters taught: Fall 2023, Fall 2022, Fall 2021

Computer Vision (EECE 5639), *Northeastern University, Boston*
An introduction to the exciting field of computer vision, which aims to make useful decisions about real physical objects and scenes based on sensed images. This course covers foundational topics such as image formation, segmentation, feature extraction, matching, shape recovery, dynamic scene analysis, and object recognition, building on disciplines such as signal processing, statistics, pattern recognition, control theory, system identification, physics, geometry, computer graphics, and learning theory.
Semesters taught: Spring 2024

Riemannian Optimization (Math 7223), *Northeastern University, Boston*
A self-contained introduction to optimization on smooth manifolds, covering both theoretical foundations and practical computation. The first half introduces the theory of smooth manifolds and Riemannian geometry, with an emphasis on those elements that are most relevant for optimization (tensor fields, metrics, connections, geodesics, retractions, and transporters). The second half applies this geometric machinery to develop first- and second-order smooth optimization methods on generic Riemannian manifolds. A primary focus of the course is the development of practical computational techniques, with applications to robotics, computer vision, and machine learning.
Semesters taught: Spring 2023

Spring 2020 **Kaufman Teaching Certification (recipient)**, *Massachusetts Institute of Technology*
MIT's Kaufman Teaching Certificate Program (KTCP) is a practice-based workshop series for graduate students and postdocs that imparts evidence-based best practices for effective teaching. Topics covered include course design, lesson planning, strategies for student assessment and feedback, and creating an effective classroom environment.

Spring 2018 **Instructor, Computer Vision (CSE P576)**, *University of Washington, Seattle*
Served as one of four instructors (together with Matthew Brown, Robert Gens, and Richard Newcombe) for the University of Washington's professional master's course in computer vision. Responsibilities included determining course scope and content, developing and delivering weekly lectures, and designing lab assignments.

Fall 2013 **Graduate teaching assistant, Machine Learning (EECS 6.867)**, *Massachusetts Institute of Technology*
Served as one of three graduate student teaching assistants for the MIT Electrical Engineering and Computer Science department's doctoral qualifying examination course in Machine Learning, taught by Prof. Tommi Jaakkola. Responsibilities included leading weekly recitation/tutorial sections, holding weekly office hours, and assisting in the composition and grading of weekly problem sets, the midterm and final exams, and final projects.

Service

Professional service

Associate editor
IJRR: International Journal of Robotics Research (2023–)
IROS: IEEE/RSJ International Conference on Intelligent Robots and Systems (2022)

Journal reviewer

T-RO: IEEE Transactions on Robotics (2014, 2015, 2019–2022)
IJRR: International Journal of Robotics Research (2016, 2017, 2019)
RA-L: IEEE Robotics and Automation Letters (2016 – 2022)
L-CSS: IEEE Control System Letters (2020)
SPL: IEEE Signal Processing Letters (2017, 2020–2021)
JMIV: Journal of Mathematical Imaging and Vision (2021)
SIOPT: SIAM Journal on Optimization (2023)

Conference reviewer

RSS: Robotics: Science and Systems (2014 – 2019)
ICRA: IEEE International Conference on Robotics and Automation (2015 – 2024)
IROS: IEEE/RSJ International Conference on Intelligent Robots and Systems (2012, 2014 – 2019, 2022–)
WAFR: International Workshop on the Algorithmic Foundations of Robotics (2018)
ISRR: International Symposium on Robotics Research (2019)
IJCAI: International Joint Conference on Artificial Intelligence (2020–2021)
CoRL: Conference on Robot Learning (2021–2022)

Organizer

Robotic Perception and Mapping: Frontier Vision and Learning Techniques: The International Conference on Intelligent Robots and Systems (IROS), October 2023.

Spectral Graph-Theoretic Methods for Estimation and Control: Robotics: Science and Systems (RSS), July 2023.

RSS Pioneers: Robotics: Science and Systems (RSS), July 2020.

Departmental service

2022–2023 **Member, Mathematics Faculty Search Committee** (Mathematics and computational modeling)

2022–2023 **Member, Northeastern ECE Distinguished Seminar Series organizing committee**

2019 **Postdoctoral representative, MIT EECS Visiting Committee**: Prepared and presented a report outlining recommendations for improving the postdoctoral experience to the biennial meeting of the MIT Department of Electrical Engineering and Computer Science's Visiting Committee (April 2019).

2019–2020 **MIT EECS Graduate Admissions Committee application reviewer**: Reviewed applications for admission to MIT's doctoral program in Electrical Engineering and Computer Science as part of the 2019–2020 cycle (January 2020).

Software

My research has been implemented in high-quality software libraries that are regularly used in both academia and industry:

- **SE-Sync**: C++, Python, and MATLAB implementations of the SE-Sync algorithm [J2, C7] for certifiably correct pose-graph SLAM are provided in the SE-Sync library.
- **DC2-PGO**: The DC2-PGO algorithm [J3] for distributed certifiably correct pose-graph optimization is implemented in the dpgo library. This algorithm is used as the distributed pose-graph optimization backend in Kimera.
- **MAC**: The MAC library implements efficient algorithms for sparsifying (possibly weighted) graphs by *maximizing algebraic connectivity* [C13]. In the context of robotics, this is useful for performing model compression by subselecting measurements in pose-graph SLAM.
- **Shonan Averaging**: The Shonan Averaging algorithm [C9] for certifiably correct rotation averaging is implemented in the Georgia Tech Smoothing and Mapping (GTSAM) library.

- **RISE**: The RISE online nonlinear least-squares optimization algorithm [J1, C1] is one of the core optimization methods used in the Georgia Tech Smoothing and Mapping (GTSAM) library, where it appears as the `DoglegOptimizer`.
- **CIDGIK**: The CIDGIK algorithm [J5] for inverse kinematics is one of the core algorithms implemented in the GraphIK library.