

Michael W. Otte

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Research Interests

My research is on the design and analysis of algorithms for autonomous vehicles and robotic systems. My major research thrusts involve: motion planning for single and multi-agent systems, and distributed algorithms that enable robotic teams and/or swarms to pool resources in order to solve their common problems. I am particularly interested in applications where the environment is hazardous and/or changing and communication is unreliable. My work involves elements of planning, control, robotics, multi-agent systems, distributed systems, graph theory, computational geometry, machine learning, artificial intelligence, emergent behavior, and stochastic processes.

Education

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| 2014 | Postdoctoral Studies
Massachusetts Institute of Technology , Cambridge, Massachusetts
Adviser: Emilio Frazzoli |
| 2011 | Ph.D., Computer Science
University of Colorado at Boulder , Boulder, Colorado
Adviser: Nikolaus Correll |
| 2007 | M.S., Computer Science
University of Colorado at Boulder , Boulder, Colorado
Advisers: Greg Grudic and Jane Mulligan |
| 2005 | B.S. (With Distinction), Aeronautical Engineering
Clarkson University , Potsdam, New York |
| 2005 | B.S. (With Distinction), Computer Science
Clarkson University , Potsdam, New York |

Research

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| 2016-Present | National Research Council RAP Postdoctoral Associate
U.S. Naval Research Laboratory , Washington, D.C.
Information Technology Division, Adviser: Don Sofge <ul style="list-style-type: none">• Co-Investigator on grant “Autonomous Multi-Agent Search and Rescue in Unpredictable Contested Environments” funded by ONR Science of Autonomy.• Ongoing Work to design, analyze, and implement algorithms for search and rescue in contested environments (including experiments on a team of quadrotor Pelican Robots). |
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2014-2015

Research Associate (in residence at AFRL)

University of Colorado at Boulder, Boulder, Colorado

Dept. of Aerospace Engineering Sciences,

In residence at The U.S. Air Force Research Laboratory, Ohio

The Control Science Center of Excellence.

- Designed a new algorithm for any-time path-planning in wind-fields that change over time (deployed on an unmanned aircraft using Dual Doppler Radar) [14] {Julia language, C++} .
- Ongoing work exploring emergent cognition in multi-robot systems (experiments with 300+ Kilobots) [13] {C, C++}.
- Ongoing work exploring applications of integer data structures to floating point motion planning problems [33,34].

2011-2014

Postdoctoral Associate

Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts

Laboratory for Information and Decision Systems, Adviser: Emilio Frazzoli

- Designed RRT^X a new algorithm for real-time motion replanning in dynamic environments [15].
- Proved time bounds on the information transfer time and the runtime complexity of building an n node graph for RRT^X, RRT[#], and RRT* [15].
- Collaborated on a team that designed/analyzed a new certificate-based algorithm for efficient collision checking in the context of sampling-based motion planning [20].
 - Designed/analyzed/implemented an extension to centralized multi-robot teams using symmetries [30] {Julia language}.
 - Designed/analyzed/implemented an “Any-Com” extension to decentralized multi-robot teams [16] {Julia language, C++}.
- Designed/analyzed a new algorithm that learns to sample uniformly at random from the obstacle-free portion of a configuration space (i.e., without rejection sampling), and thereby increases the computational efficiency of sampling based motion planning [18].
 - Extending the method to learn arbitrary distributions.
- Introduced the “navigation with random foraging” problem, and showed how to calculate/bound the resulting expected path length of an agent following the two nontrivial pure-strategy policies [19].
- Designed/implemented a game theoretic multi-robot navigation algorithm [17] {Julia language}.
- Designed/analyzed an algorithm for path planning in continuous space via interpolation over a multi-resolution grid, mentored a high-school student as they implemented the algorithm {C++}.
- Studied Any-Com algorithms for multi-agent intruder detection to be used for patrolling road network.
- Collaborating on a multidisciplinary team that is studying high-speed navigation through forests. In particular, evaluating human proficiency vs. theoretical limits.
- Collaborating with others to investigate how an artificial retina sensor can be used to enable high-speed motion planning and control.

2009-2011

Research Assistant

University of Colorado at Boulder, Boulder, Colorado

Correll Laboratory, Adviser: Nikolaus Correll

- Designed/analyzed/implemented a new parallelized shortest-path planning algorithm called “C-FOREST” that can achieve significant super-linear speedup in practice (e.g., a speedup of 350 using 64 computational nodes) [7], [37] {C++}.
- Coined the term “Any-Com” to describe a distributed algorithm that gracefully tolerates communication disruption between computational nodes. Designed/analyzed/implemented Any-Com algorithms for multi-robot path planning [21], [22], [37] {C, C++, ROS}.
 - Designed/analyzed/implemented an Any-Com algorithm for Multi-robot coordination [31] {C++, ROS}.
- Collaborated with a team to demonstrate that a robot could be remotely controlled and teleoperated using brain-waves via noninvasive electroencephalography (EEG). [28].
- Oversaw development of the CU “Prairiedog” robotic platform software by a team of students. Implemented modules for: planning, mapping, control, localization, operations control, and robot-robot communication. Prairiedog was used in much of the research described above [21], [22], [28], [37] . {C, C++, ROS}
 - Prairiedog was also used as a test-bed for a new programming language called “OIL” that was designed for use in self-organizing sensor/actuator networks [23] {C++, ROS, OIL}.

2006-2009

Research Assistant

University of Colorado at Boulder, Boulder, Colorado

Intelligence in Action Laboratory, Adviser: Greg Grudic

- Designed/implemented a new algorithm that enabled a robot to plan paths in image-space, demonstrated on the Learning Applied to Ground Robotics (LAGR) platform [8], [26], [35], [38] {C, C++, MATLAB}.
- Designed/implemented a new and better way to extract continuous paths from cost fields that are created via interpolation over a discrete graph [24] {C++}.
- Implemented modules for path-planning, mapping, and operations controls in CU’s software for the Learning Applied to Ground Robotics (LAGR) program {C, C++, MATLAB}.
 - Online learning of terrain type for navigation in unknown environments on the LAGR platform [25].
- Designed/implemented new techniques for supervised learning from non-invasive physiological metrics to predict hemodynamic decomposition {MATLAB}.

2006-2007

Independent Study

University of Colorado at Boulder, Boulder, Colorado

Mozer Laboratory, Adviser: Mike Mozer

- Studied unsupervised/semi-supervised learning of program execution temporal phase structure from hardware based runtime metrics. [32], [35].

2004-2005

Independent Study

Clarkson University, Potsdam, New York

Clarkson VR Laboratory, Adviser: Janice Searleman

- Implemented a virtual reality game with force feedback to teach children how to operate a motorized wheelchair {VRTools}.
- Implemented a virtual reality game with physiological input to assist with breathing therapy {VRTools}.

Publications

Journal Papers (Peer Reviewed)

- [1] **Michael Otte**. Collective cognition & sensing in robotic swarms via an emergent group-mind. In submission.
- [2] **Michael Otte** and Nikolaus Correll. Dynamic teams of robots as ad hoc distributed computers: Reducing the complexity of multi-robot motion planning via sub-space selection. In submission.
- [3] **Michael Otte**, Michael Kuhlman, and Donald Sofge. Communication symmetry and asymmetry in competitive two team target search game. *Autonomous Robots*, Conditionally accepted.
- [4] Michael Kuhlman, **Michael Otte**, Donald Sofge, and Satyandra K Gupta. Multipass target search in natural environments. *Sensors*, To appear.
- [5] Joshua Bialkowski, **Michael Otte**, Sertac Karaman, and Emilio Frazzoli. Efficient collision checking in sampling-based motion planning via safety certificates. *The International Journal of Robotics Research*, 35(7):767–796, 2016.
- [6] **Michael Otte** and Emilio Frazzoli. RRTX: Asymptotically optimal single-query sampling-based motion planning with quick replanning. *The International Journal of Robotics Research*, 35(7):797–822, 2016.
- [7] **Michael Otte** and Nikolaus Correll. C-FOREST: Parallel shortest-path planning with super linear speedup. *IEEE Transactions on Robotics*, 29:798–806, June 2013.
- [8] **Michael Otte**, Scott Richardson, Jane Mulligan, and Gregory Grudic. Path planning in image space for autonomous robot navigation in unstructured environments. *Journal of Field Robotics*, 26:212–240, 2009.

Conference Papers (Peer Reviewed) and Book Chapters (♠)

- [9] **Michael Otte**, Michael Kuhlman, and Donald Sofge. Multi-robot task allocation with auctions in harsh communication environments. In *International Symposium on Multi-Robot and Multi-Agent Systems (MRS)*, Los Angeles, 2017.
- [10] Rahul Rajan, **Michael Otte**, and Donald Sofge. Novel physicomimetic bio-inspired algorithm for search and rescue applications. In *IEEE Symposium on Series on Computational Intelligence (SSCI)*, Honolulu, 2017.
- [11] Michael Kuhlman, **Michael Otte**, Donald Sofge, and Satyandra K Gupta. Maximizing mutual information for multipass target search in changing environments. In *IEEE International Conference on Robotics and Automation (ICRA)*, Singapore, 2017.
- [12] **Michael Otte**, Michael Kuhlman, and Donald Sofge. Competitive two team target search game with communication symmetry and asymmetry. In *International Workshop on the Algorithmic Foundations of Robotics (WAFR)*, San Francisco, USA, 2016.
♠To appear as a book chapter in *Algorithmic Foundations of Robotics*, Springer Proceedings in Advanced Robotics, 2017.

- [13] **Michael Otte**. Collective cognition & sensing in robotic swarms via an emergent group-mind. In *International Symposium on Experimental Robotics (ISER)*, Tokyo, Japan, 2016.
♠Also appeared as a book chapter in, Springer Proceedings in Advanced Robotics, Vol 1, 2017.
- [14] **Michael Otte**, William Silva, and Eric Frew. Any-time path-planning: Time-varying wind field + moving obstacles. In *IEEE International Conference on Robotics and Automation*, Stockholm, Sweden, 2016.
- [15] **Michael Otte** and Emilio Frazzoli. RRT-X: Real-time motion planning/replanning for environments with unpredictable obstacles. In *International Workshop on the Algorithmic Foundations of Robotics (WAFR)*, Istanbul, Turkey, 2014.
♠Also appeared as a book chapter in *Algorithmic Foundations of Robotics XI*, Springer Tracts in Advanced Robotics, 107:461-478, 2015.
- [16] **Michael Otte**, Joshua Bialkowski, and Emilio Frazzoli. Any-com collision checking: Sharing certificates in decentralized multi-robot teams. In *IEEE International Conference on Robotics and Automation (ICRA)*, Hong Kong, China, 2014.
- [17] Minghui Zhu, **Michael Otte**, Pratik Chaudhari, and Emilio Frazzoli. Game theoretic controller synthesis for multi-robot motion planning part i: Trajectory based algorithms. In *IEEE International Conference on Robotics and Automation (ICRA)*, Hong Kong, China, 2014.
- [18] Joshua Bialkowski, **Michael Otte**, and Emilio Frazzoli. Free-configuration biased sampling for motion planning. In *IEEE International Conference on Intelligent Robots and Systems (IROS)*, Tokyo, Japan, 2013.
- [19] **Michael Otte**, Nikolaus Correll, and Emilio Frazzoli. Navigation with foraging. In *IEEE International Conference on Intelligent Robots and Systems (IROS)*, Tokyo, Japan, 2013.
- [20] Joshua Bialkowski, Sertac Karaman, **Michael Otte**, and Emilio Frazzoli. Efficient collision checking in sampling-based motion planning. In *International Workshop on the Algorithmic Foundations of Robotics (WAFR)*, Cambridge, Massachusetts, 2012.
♠Also appeared as a book chapter in *Algorithmic Foundations of Robotics X*, Springer Tracts in Advanced Robotics, 86:365-380, 2013.
- [21] **Michael Otte** and Nikolaus Correll. Any-Com multi-robot path-planning: Maximizing collaboration for variable bandwidth. In *International Symposium on Distributed Autonomous Robotics Systems (DARS)*, 2010.
♠Also appeared as a book chapter in *Distributed Autonomous Robotic Systems*, Springer Tracts in Advanced Robotics, 83:161-173, 2013.
- [22] **Michael Otte** and Nikolaus Correll. Any-Com multi-robot path-planning with dynamic teams: Multi-robot coordination under communication constraints. In *International Symposium on Experimental Robotics (ISER)*, 2010.
♠Also appeared as a book chapter in *Experimental Robotics*, Springer Tracts in Advanced Robotics, 79:743-757, 2014.
- [23] D. J. Sutton, Peter Klein, **Michael Otte**, and Nikolaus Correll. Object interaction language (oil): An intent-based language for programming self-organized sensor/actuator networks. In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2010.
- [24] **Michael Otte** and Gregory Grudic. extracting paths from fields built with linear interpolation. In *International Conference on Intelligent Robots and Systems (IROS)*, St. Louis, 2009.
- [25] Greg Grudic, Jane Mulligan, **Michael Otte**, and Adam Bates. Online learning of multiple perceptual models for navigation in unknown terrain. In *International Conference on Field and Service Robotics (FSR)*, Chamonix, France, 2007.

♠Also appeared as a book chapter in *Field and Service Robotics*, Springer Tracts in Advanced Robotics, 42:411-420, 2008.

- [26] **Michael Otte**, Scott Richardson, Jane Mulligan, and Gregory Grudic. Local path planning in image space for autonomous robot navigation in unstructured environments. In *International Conference on Intelligent Robots and Systems (IROS)*, San Diego, 2007.

Conference Extended Abstract/Video (Refereed)

- [27] **Michael Otte** and Nikolaus Correll. C-Forest: Parallel shortest-path planning with super linear speedup. In *International Conference on Automated Planning and Scheduling (Journal Track)*, Portsmouth, New Hampshire, 2014.
- [28] Aaron Cephers, Ilya Kushnir, **Michael Otte**, Clayton Lewis, and N Correll. Brain computer interfaces. In *AAAI Video Competition*, Atlanta, GA, USA, 2010.

Workshop Papers/Posters (Refereed)

- [29] Dmitry Yershov, **Michael Otte**, and Emilio Frazzoli. Sampling-based volumetric methods for optimal feedback planning. In *In IEEE International Conference on Robotics and Automation, Workshop on optimal robot motion planning (WORMP)*, 2015.
- [30] Joshua Bialkowski, **Michael Otte**, and Emilio Frazzoli. Fast collision checking: From single robots to multi-robot teams. In *IEEE International Conference on Robotics and Automation: Crossing the Reality Gap - From Single to Multi- to Many Robot Systems (ICRA-CRG)*, 2013.
- [31] **Michael Otte** and Nikolaus Correll. The any-com approach to multi-robot coordination. In *IEEE International Conference on Robotics and Automation: Network Science and Systems Issues in Multi-Robot Autonomy (ICRA-NETSS)*, 2010.
- [32] Scott Richardson, **Michael Otte**, Michael Mozer, Amer Diwan, and Dan Conners. Discovering the runtime structure of software with probabilistic generative models. In *Neural Information Processing Systems Conference: Workshop on Machine Learning for Systems Problems (NIPS-MLSP)*, Whistler, Canada, 2007.

Technical Reports

- [33] **Michael Otte**. On solving floating point SSSP using an integer priority queue. Technical report, University of Colorado, arXiv:1606.00726v1, 2016.
- [34] **Michael Otte**. Modifying dijkstra's algorithm to solve many instances of SSSP in linear time. Technical Report Spring-2015, University of Colorado at Boulder, 2015.
- [35] **Michael Otte**, Dan Knights, Joseph J. Pfeiffer III, Jane Mulligan, and Greg Grudic. New techniques for path planning in image space. Technical Report CU-CS-1052-09, University of Colorado at Boulder, 2009.
- [36] **Michael Otte** and Scott Richardson. An hmm applied to semi-online program phase analysis. Technical Report CU-CS-1034-07, University of Colorado at Boulder, 2007.

Theses

- [37] **Michael Otte**. *Any-Com Multi-Robot Path Planning*. PhD thesis, University of Colorado at Boulder, 2011.
- [38] **Michael Otte**. *Path Planning in Image Space for the Autonomous Navigation of Unmanned Vehicles in Unstructured Outdoor Environments*. Master's thesis, University of Colorado at Boulder, 2007.

Grants

- 2016 (ONGOING) *Autonomous Multi-Agent Search and Rescue in Unpredictable Contested Environments.* **ONR Science of Autonomy Program** Grant #N0001416WX01271. Don Sofge (PI), Michael Otte (Co-PI).
- 2010 *Travel Grant.* University of Colorado at Boulder, Graduate School.
- 2010 *Academic Travel Grant.* University of Colorado at Boulder, United Government of Graduate Students.
- 2010 *Travel Award.* University of Colorado at Boulder, Dept. Computer Science.
- 2009 *Graduate Student Research Community Development Awards.* University of Colorado at Boulder, Dept. Computer Science.

Invited Talks (excluding conference and workshops)

- 10/2016 *Collective Cognition & Sensing in Robotic Swarms Via an Emergent Group-Mind.* U.S. Naval Research Lab. Washington, D.C.
- 6/2016 *Any-Com Algorithms and Multi-agent Search and Rescue.* U.S. Naval Research Lab. Washington, D.C.
- 10/2015 *Path planning in wind with moving obstacles.* U.S. Air Force Research Lab. Wright-Patterson AFB, Ohio.
- 9/2015 *Creating a group mind neural network over a swarm of robots.* Self-Organizing Systems Research Group, Harvard University. Cambridge, Massachusetts.
- 5/2015 *Improving Dijkstra's Algorithm.* U.S. Air Force Research Lab. Wright-Patterson AFB, Ohio.
- 11/2014 *Robotic Motion Planning, Replanning, and Parallelization.* George Mason University. Fairfax, Virginia.
- 7/2014 *Sampling Based Motion Planning and Replanning.* Distributed Autonomous Systems Group, Naval Research Laboratory. Washington D.C.
- 2/2014 *Any-Com Algorithms for Multi-Agent Systems.* Self-Organizing Systems Research Group, Harvard University. Cambridge, Massachusetts.
- 11/2013 *Image-Space Control.* Russ Tedrake's Group, Massachusetts Institute of Technology. Cambridge, Massachusetts.
- 11/2013 *Improving motion planning via intelligent collision checking.* George Washington University. Washington D.C.
- 3/2013 *Robots.* The Pinhead Institute's Scholars in the Schools Program. 9 talks in 2 days: Naturita Elementary School (X2), Naturita, Colorado. Norwood Elementary School (X2), Norwood, Colorado. Telluride Mountain School, Telluride, Colorado. Telluride Intermediate School (X4), Telluride, Colorado.
- 2/2013 *Recent Breakthroughs in Robotic Motion Planning.* University of New Hampshire. Durham, New Hampshire.
- 5/2012 *Robots and Artificial Intelligence.* The Pinhead Institute's Scholars in the Schools Program. 5 talks in 2 days: Ouray High School, Ouray, Colorado. Ridgway Secondary School, Ridgway, Colorado. Telluride High School, Telluride, Colorado. Telluride Mountain School, Telluride, Colorado. Pinhead Institute Science Soiree, Telluride, Colorado.

- 3/2012 *Robots and Artificial Intelligence*. Art and Science. Cambridge, Massachusetts.
- 2/2012 *Robots and Artificial Intelligence*. Aspen Rotary Club. Aspen, Colorado.
- 2/2012 *Any-Com Multi-Robot Path Planning*. iRobot Corporation. Bedford, Massachusetts.

Teaching

Lecturer

- Spring 2017 Planning for Autonomous Robots. ENPM661.
University of Maryland. College Park, Maryland.

Assistant

- Fall 2009 Multi Robot Systems, CSCI-4830/7000
University of Colorado at Boulder. Boulder, Colorado.

Guest Lecturer

- Spring 2010 Introduction to robotics, CSCI-3302
University of Colorado at Boulder. Boulder, Colorado.
- Fall 2007 Introduction to Artificial Intelligence, CSCI-3302
University of Colorado at Boulder, Boulder, Colorado.

Mentoring

- Summer 2016 Co-mentoring ASEE Science and Engineering Apprenticeship Program intern from Thomas Jefferson High School (Alexandria, VA) at U.S. Naval Research Laboratory (Washington, D.C.)
- Summer 2016 Co-mentoring ASEE Naval Research Enterprise Internship Program intern from University of Maryland (College Park, Maryland) at U.S. Naval Research Laboratory (Washington, D.C.)
- Summer 2013 Mentored Pinhead Institute sponsored intern from Telluride High School (Telluride, CO) at Massachusetts Institute of Technology (Cambridge, MA) “Extracting paths from fields sampled at multiple resolutions”

Service

Workshop Organizing Committee Member

- 7/2017 Robot Communication in the Wild: Meeting the Challenges of Real-World Systems. At Robotics Science and Systems (RSS). Cambridge, Massachusetts.

Conference Program Committee Member

- 10/2016 International Symposium on Experimental Robotics (ISER). Tokyo, Japan.
- 6/2014 International Symposium on Experimental Robotics (ISER). Marrakech and Essaouira, Morocco.

- 6/2014 International Conference on Automated Planning and Scheduling (ICAPS).
Portsmouth, New Hampshire.
- 6/2013 International Conference on Automated Planning and Scheduling (ICAPS).
Rome, Italy.

Conference Session Chair/Co-Chair

- 6/2014 International Conference on Automated Planning and Scheduling (ICAPS)
Robotics. Portsmouth, New Hampshire.
- 11/2013 IEEE/RSJ International Conference on Intelligent Robots and Systems
(IROS). *Navigation II*. St. Louis, Missouri.
- 10/2009 IEEE/RSJ International Conference on Intelligent Robots and Systems
(IROS). *Navigation and Path Planning*. St. Louis, Missouri.
- 10/2007 IEEE/RSJ International Conference on Intelligent Robots and Systems
(IROS). *Navigation and Path Planning*. San Diego, California.

Reviewer for Journals and Conferences

- Ongoing
- The International Journal of Robotics Research
 - IEEE RAS Transactions on Robotics
 - The Journal of Field Robotics
 - Journal of Optimization Theory and Applications
 - Journal of Intelligent and Robotic Systems
 - Computers and Electrical Engineering
 - IEEE Transactions on Automation Science and Engineering
 - Advances in Mechanical Engineering
 - IEEE Robotics and Automation Letters
 - International Journal of Computer Engineering Research
 - International Journal of Advanced Robotic Systems
 - Robotics and Autonomous Systems
 - Robotics: Science and Systems Conference
 - IEEE International Conference on Robotics and Automation
 - IEEE International Conference on Intelligent Robots and Systems
 - International Workshop on the Algorithmic Foundations of Robotics
 - IEEE Conference on Decision and Control
 - American Control Conference
 - Research in Applied Computation Symposium

Grant Proposal Reviewer

- Ongoing
- U.S. National Science Foundation (NSF)
 - U.S. Office of Naval Research (ONR)

National Advisory Board

- Ongoing Pinhead Science Advisers. *Pinhead Institute*. Telluride, Colorado.

Related Professional Experience

- 2009 Consultant. Develosoft Corporation. Boulder, Colorado.
- Research and development of artificial intelligence and machine vision algorithms for a project funded by the US Navy.
- 2005 Certified as Intern Engineer. New York State.
- 2005 Passed the Fundamentals of Engineering (FE) Exam. New York State.