

JOHN J. LEONARD

SAMUEL C. COLLINS PROFESSOR

DEPARTMENT OF MECHANICAL ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
jleonard@mit.edu

John J. Leonard is Samuel C. Collins Professor in the MIT Department of Mechanical Engineering and a member of the MIT Computer Science and Artificial Intelligence Laboratory. His research addresses the problems of navigation and mapping for autonomous mobile robots. Leonard was a pioneer in formulating the problem of Simultaneous Localization and Mapping (SLAM) in the mobile robotics research community. With his students and collaborators, he has developed several state-of-the-art robot navigation and mapping systems for robots operating in underwater and terrestrial environments. He has extensive experience deploying underwater robots systems for Navy missions such as mine-hunting and surveillance. He has lead several major initiatives for the Office of Naval Research, including a program to utilize SLAM for mine neutralization and a program for cooperative navigation of multiple autonomous underwater vehicles and gliders. He was team leader for MIT's DARPA Urban Challenge team, which was one of eleven teams to qualify for the Urban Challenge final event and one of six teams to complete the race.

Prof. Leonard served as Associate Department Head for Research in the MIT Department of Mechanical Engineering from 2013-2016. He currently serves as an Associate Director for Engineering for the MIT/WHOI Joint Program. He has served as an associate editor of the IEEE Journal of Oceanic Engineering from 1998-2006 and of the IEEE Transactions on Robotics and Automation from 2000-2003. He was one of three guest editors for the 2008 IEEE Transactions on Robotics Special Issue on Visual SLAM. He was an Area Chair for Robotics: Science and systems in 2005, 2014 and 2015. He is an advisory board member of the University of Michigan Department of Naval Architecture. He served on the Robotics: Science and Systems Foundation Board from 2005 to 2015. He is the recipient of a Thouron Award (1987), an NSF Career Award (1998), a Science Foundation Ireland E.T.S. Walton Visitor Award (2004), the Best Paper Award at ACM SenSys in 2004 (shared with D. Moore, D. Rus, and S. Teller), the King-Sun Fu Memorial Best Transactions on Robotics Paper Award in 2006 (shared with R. Eustice and H. Singh) and the WAFR 2016 Best Paper Award (shared with D. Rosen, L. Carlone, and A. F. Bandeira). He was a finalist for the Best Automation Paper Award at ICRA 2011, a finalist for the Best Paper Award for ICRA 2012, and a finalist for the Best Student Paper Award for ICRA 2013. He was elected an IEEE Fellow in 2014 and an AAAS Fellow in 2019.

Professor Leonard is a Technical Advisor for Human Interactive Driving at Toyota Research Institute.

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Education:

D.Phil., University of Oxford 1994
B.S.E.E., University of Pennsylvania 1987

Selected MIT Appointments and Service:

Joined the MIT Faculty 1996
Dean's Action Group, Social and Ethical Responsibilities of Computing 2020-2021
Member, MIT Task Force on Work of the Future 2018-2020
Chair, MechE Faculty Awards Committee 2019-present
Member, SoE Faculty Awards Committee 2019-present
Co-Chair, MechE General Faculty Search Committee 2018-present
Associate Director, MIT/Woods Hole Joint Program 2018-present
Associate Department Head for Research 2013-2016
Chair, MechE General Faculty Search Committee 2013-2017
MIT Faculty Postdoc Advisory Committee 2013-2016
Area Head, Ocean Science and Engineering 2008-2014
Faculty Director, Ford-MIT Alliance 2009-2013
MIT/Woods Hole Joint Committee for Applied Ocean Science and Engineering 2009-present
Sea Grant College Program Committee 2008-2015
MIT Museum Advisory Board 2006-2012
Chair, Faculty Search Committee for Ocean Engineering 2010-2011
MIT/Woods Hole Joint Program Strategic Planning Committee 2010-2011
ME/OE Merger Review Committee 2009-2010
Area Head, Control, Instrumentation and Robotics 2007-2008
Chair, Faculty Search Committee for Robotics 2007-2008
Chair, Faculty Search Committee for Ocean Engineering 2006-2007
ME Strategic Planning Committee 2004-2005
Department ABET Coordinator 2000-2002

Selected Honors and Awards:

General Motors Scholarship 1985
A. Atwater Kent Award, Moore School of Electrical Engineering, U. of Penn. 1987
Thouron Fellowship 1987-1989
Henry L. and Grace Doherty Assistant Professorship in Ocean Utilization 1996-1998
National Science Foundation CAREER Award 1998
E.T.S. Walton Visitor Award, Science Foundation Ireland 2004
Best Paper Award, ACM SenSys 2004 2004
Best Student Paper Award, IEEE ICRA 2005 2005
King-Sun Fu Memorial Best Transactions on Robotics Paper Award 2007

Finisher, DARPA Urban Challenge	2007
Honorary Professor, Dept. of Computer Science, National University of Ireland, Maynooth	2008
Finalist, Best Automation Paper Award, IEEE ICRA 2011	
Finalist, Best Paper Award, IEEE ICRA 2012	
Finalist, Best Student Paper Award, IEEE ICRA 2013	
Best Paper Award, Workshop on Algorithmic Foundations of Robotics	2016

Selected External Service:

Advisory Board, Department of Naval Architecture, University of Michigan	2011-present
Associate Editor, IEEE ICRA	2022
Area Chair, Robotics: Science and Systems	2005, 2014, 2015
Advisory Board, Robotics: Science and Systems	2009-2015
Guest Associate Editor, IEEE Trans. on Robotics, Special Issue on Visual SLAM	2007-2008
Associate Editor, IEEE Journal of Oceanic Engineering	1998-2006
Associate Editor, IEEE Transactions on Robotics and Automation	2000-2003

Publications of John J. Leonard

Professor Leonard, together with his research group and collaborators, has published one book, 58 refereed journal articles and 133 refereed conference papers. Professor Leonard has mentored 11 M.Eng. students, 34 S.M students, 6 Engineer's degree students, 33 Ph.D. students, and 12 postdoctoral fellows, and he has served on 85 Ph.D. committees. He is a co-inventor for 12 patents. A list of his publications is provided below in chronological order:

- [1] C. Brown, H. Durrant-Whyte, J. Leonard, and B. Rao. Centralized and decentralized Kalman filter techniques for tracking, navigation, and control. In *DARPA Image Understanding Workshop*, pages 651–675, May 1989.
- [2] H. F. Durrant-Whyte and J. J. Leonard. Navigation by correlating geometric sensor data. In *Proc. IEEE Int. Workshop on Intelligent Robots and Systems*, 1989.
- [3] J. J. Leonard and H. F. Durrant-Whyte. Active sensor control for mobile robotics. In *IARP Int. Conf. on Multi-Sensor Fusion and Environment Modelling*, Toulouse, France, October 1989.
- [4] M. Brady, H. Durrant-Whyte, H. Hu, J. Leonard, P. Probert, and B. Rao. Sensor-based control of AGV's. In *IARP 1st Workshop on Domestic Robots and 2nd Workshop on Medical and Healthcare Robotics*, September 1989. Also published in *Int. Workshop on Sensorial Integration for Industrial Robots*, Zaragoza, Spain, November, 1989, and *IEE Computing and Control Journal*, March 1990.
- [5] J. J. Leonard, I. J. Cox, and H. F. Durrant-Whyte. Dynamic map building for an autonomous mobile robot. In *Proc. IEEE Int. Workshop on Intelligent Robots and Systems*, pages 89–96, 1990. Also published in *Autonomous Mobile Robots*, edited by S. Iyengar and A. Elfes, Los Alamitos, CA: IEEE Computer Society Press 1991.
- [6] J. J. Leonard and H. F. Durrant-Whyte. Application of multi-target tracking to sonar-based mobile robot navigation. In *29th IEEE Int. Conference on Decision and Control*, 1990.

- [7] J. J. Leonard. Sonar interpretation using regions of constant depth (rcds). In *IEE Colloquium on Robot Sensors*, pages 1/1–1/4. IET, 1991.
- [8] I. J. Cox and J. J. Leonard. Temporal integration of multiple sensor observations for dynamic world modeling: A multiple hypothesis approach. In *International Workshop on Information Processing for Autonomous Mobile Robots: Theory and Application*, Munich, Germany, 1991. Berlin: Springer-Verlag.
- [9] I. J. Cox and J. J. Leonard. Probabilistic data association for dynamic world modeling: A multiple hypothesis approach. In *International Conference on Advanced Robotics*, Pisa, Italy, 1991.
- [10] J. J. Leonard and H. Fl. Durrant-Whyte. Mobile robot localization by tracking geometric beacons. *IEEE Trans. Robotics and Automation*, 7(3):376–382, June 1991.
- [11] J. J. Leonard and H. F. Durrant-Whyte. Simultaneous map building and localization for an autonomous mobile robot. In *Proc. IEEE Int. Workshop on Intelligent Robots and Systems*, pages 1442–1447, Osaka, Japan, 1991.
- [12] J. J. Leonard and H. F. Durrant-Whyte. *Directed Sonar Sensing for Mobile Robot Navigation*. Boston: Kluwer Academic Publishers, 1992.
- [13] J. J. Leonard, I. J. Cox, and H. F. Durrant-Whyte. Dynamic map building for an autonomous mobile robot. *The International Journal of Robotics Research*, 11(4):286–298, August 1992.
- [14] C. Brown, H. Durrant-Whyte, J. Leonard, B. Rao, and B. Steer. Distributed data fusion using Kalman filtering: A robotics application. In M. A. Abidi and R. C. Gonzalez, editors, *Data Fusion in Robotics and Machine Intelligence*, pages 267–309. Academic Press, 1992.
- [15] H. F. Durrant-Whyte and J. J. Leonard. Modeling sonar sensors. In *The Robotics Review II*, pages 145–151. MIT Press, 1992.
- [16] J. J. Leonard and B. A. Moran. Sonar data fusion for 3-D scene reconstruction. In Paul S. Schenker, editor, *SPIE Sensor Fusion V*, pages 144–155, Boston, MA, November 1992.
- [17] J. J. Leonard and J. G. Bellingham. Directed sensing strategies for feature-relative navigation. In Paul S. Schenker, editor, *SPIE Sensor Fusion VI*, pages 120–129, Boston, MA, September 1993.
- [18] B. A. Moran, J. J. Leonard, and C. Chryssostomidis. Geometric shape from sonar ranging. In *Proc. Int. Symp. on Unmanned Untethered Submersible Technology*, pages 370–383, 1993.
- [19] S. T. Tuohy, N. M. Patrikalakis, J. J. Leonard, J. G. Bellingham, and C. Chryssostomidis. AUV navigation using geophysical maps with uncertainty. In *Proc. Int. Symp. on Unmanned Untethered Submersible Technology*, pages 265–276, 1993.
- [20] J. G. Bellingham, C. Chryssostomidis, M. Deffenbaugh, J. J. Leonard, and H. Schmidt. Arctic under-ice survey operations. In *Proc. Int. Symp. on Unmanned Untethered Submersible Technology*, pages 50–59, 1993.
- [21] I. Cox and J. Leonard. Modeling a dynamic environment using a Bayesian multiple hypothesis approach. *Artificial Intelligence*, pages 311–344, April 1994.

- [22] J. G. Bellingham and J. J. Leonard. Task configuration with layered control. In *Proceedings of the IARP 2nd Workshop on Mobile Robots for Subsea Environments*, pages 193–302, Monterey, CA, USA, May 1994.
- [23] J. Bellingham, C. Goudey, T. Consi, J. Bales, D. Atwood, J.J. Leonard, and C. Chryssostomidis. Odyssey II: A second generation survey AUV. In *IEEE Symposium on Autonomous Underwater Vehicle Technology*, Cambridge, MA, 1994.
- [24] I. J. Cox and J .J. Leonard. Unsupervised learning for mobile robot navigation using probabilistic data association. In *Proceedings of the workshop on Computational learning theory and natural learning systems (vol. 2): intersections between theory and experiment: intersections between theory and experiment*, pages 297–319. MIT Press, 1994.
- [25] J. G. Bellingham, J. J. Leonard, J. Vaganay, C. Goudey, D. Atwood, T. Consi, J. Bales, H. Schmidt, and C. Chryssostomidis. AUV operations in the arctic. In *Proceedings of the Sea Ice Mechanics and Arctic Modeling Workshop*, Anchorage, Alaska, USA, April 1995.
- [26] N. M. Patrikalakis, C. Chryssostomidis, S. T. Tuohy, J. G. Bellingham, J. J. Leonard, J. W. Bales, and J. W. Yoon. Virtual environments for ocean exploration and visualization. In *Workshop on Computer Graphics Technology in the Exploration of the Sea.*, Rostock, Germany, 1995.
- [27] J. J. Leonard, B. A. Moran, I. J. Cox, and M. L. Miller. Underwater sonar data fusion using an efficient multiple hypothesis algorithm. In *Proc. IEEE Int. Conf. Robotics and Automation*, pages 2995–3002, May 1995.
- [28] D. K. Atwood, J. J. Leonard, J. G. Bellingham, and B. A. Moran. An acoustic navigation system for multiple vehicles. In *Proc. Int. Symp. on Unmanned Untethered Submersible Technology*, pages 202–208, September 1995.
- [29] J. J. Leonard, S. T. Tuohy, J. G. Bellingham, B. A. Moran, J. H. Kim, H. Schmidt, N. M. Patrikalakis, and C. Chryssostomidis. Virtual environments for AUV development and ocean exploration. In *Proc. Int. Symp. on Unmanned Untethered Submersible Technology*, pages 436–443, September 1995.
- [30] A. B. Bennett, J. J. Leonard, and J. G. Bellingham. Bottom following for survey class autonomous underwater vehicles. In *Proc. Int. Symp. on Unmanned Untethered Submersible Technology*, pages 327–336, September 1995.
- [31] S. T. Tuohy, J. J. Leonard, J. G. Bellingham, N. M. Patrikalakis, and C. Chryssostomidis. Map based navigation for autonomous underwater vehicles. *International Journal of Offshore and Polar Engineering*, 6(1):9–18, March 1996.
- [32] J. Vaganay and V. Rigaud. Autonomous navigation: an example of localization algorithm switching based on navigation conditions. In *7th Int. Conf. on Advanced Robotics*, Sant Feliu de Guixols, Spain, September 1995.
- [33] J. Vaganay, J. G. Bellingham, and J. J. Leonard. Outlier rejection for autonomous acoustic navigation. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 2174–2181, April 1996.

- [34] J. H. Kim, B. A. Moran, J. J. Leonard, J. G. Bellingham, and S. T. Tuohy. Experiments in remote monitoring and control of autonomous underwater vehicles. In *IEEE Oceans*, pages 411–416, 1996.
- [35] A. A. Bennett and J. J. Leonard. Autonomous mapping with an AUV: an approach for ground truthing of remote sensing data. In *OCEANS'96. MTS/IEEE. 'Prospects for the 21st Century'. Conference Proceedings*, volume 3, pages 1099–1104. IEEE, 1996.
- [36] B. A. Moran, J. J. Leonard, and C. Chryssostomidis. Curved shape reconstruction using multiple hypothesis tracking. *IEEE J. of Oceanic Eng.*, 22(4):625–638, 1997.
- [37] C. M. Smith, J. J. Leonard, A. A. Bennett, and C. Shaw. Concurrent mapping and localization for autonomous underwater vehicles. In *Undersea Defence Technology*, pages 338–342, 1997.
- [38] J. J. Leonard and C. M. Smith. Sensor data fusion in marine robotics. In *Proceedings of the International Society of Offshore and Polar Engineering*, 1997.
- [39] C. M. Smith, J. J. Leonard, A. A. Bennett, and C. Shaw. Feature-based concurrent mapping and localization for auvs. In *OCEANS '97. MTS/IEEE Conference Proceedings*, volume 2, pages 896–901, October 1997.
- [40] C. M. Smith and J. J. Leonard. A multiple hypothesis approach to concurrent mapping and localization for autonomous underwater vehicles. In *International Conference on Field and Service Robotics*, Sydney, Australia, 1997.
- [41] J. Vaganay, J. G. Bellingham, and J. J. Leonard. Comparison of fix computation and filtering for autonomous acoustic navigation. *International Journal of Systems Science*, 29(10):1111–1122, October 1998.
- [42] H. J. S. Feder, C. M. Smith, and J. J. Leonard. Incorporating environmental measurements in navigation. In *IEEE AUV*, pages 117–124, Cambridge, MA, August 1998.
- [43] C. M. Smith, H. J. S. Feder, and J. J. Leonard. Making difficult decisions autonomously: The impact of integrated mapping and navigation. In *IEEE AUV*, pages 125–132, Cambridge, MA, August 1998.
- [44] H. J. S. Feder, J. J. Leonard, and C. M. Smith. Adaptive sensing for terrain aided navigation. In *IEEE Oceans*, Nice, France, September 1998.
- [45] H. J. S. Feder, J. J. Leonard, and C. M. Smith. Adaptive concurrent mapping and localization using sonar. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Victoria, B.C., Canada, October 1998.
- [46] C. M. Smith, H. J. S. Feder, and J. J. Leonard. Multiple target tracking with navigation uncertainty. In *IEEE Int. Conference on Decision and Control (CDC)*, pages 760–761, Tampa, FL, December 1998.
- [47] H. J. S. Feder, J. J. Leonard, and C. M. Smith. Adaptive mobile robot navigation and mapping. *The International Journal of Robotics Research*, 18(7):650–668, July 1999.
- [48] A. B. Bennett and J. J. Leonard. Feature-relative navigation of an autonomous underwater vehicle. In *Proc. Int. Symp. on Unmanned Untethered Submersible Technology*, August 1999.

- [49] J. J. Leonard, R. N. Carpenter, and H. J. S. Feder. Stochastic mapping using forward look sonar. In *International Conference on Field and Service Robotics*, pages 69–74, Pittsburgh, Pennsylvania, August 1999.
- [50] J. J. Leonard and H. J. S. Feder. A computationally efficient method for large-scale concurrent mapping and localization. In D Koditschek and J. Hollerbach, editors, *Robotics Research: The Ninth International Symposium*, pages 169–176, Snowbird, Utah, 2000. Springer Verlag.
- [51] J. J. Leonard and H. J. S. Feder. Experimental analysis of adaptive concurrent mapping and localization using sonar. In Peter Corke and James Trevelyan, editors, *Experimental Robotics VI*, volume 250 of *Lecture Notes in Control and Information Sciences*, pages 297–306. Springer-Verlag, 2000. ISBN: 1 85233 210 7.
- [52] A. Bennett and J. J. Leonard. A behavior-based approach to adaptive feature mapping with autonomous underwater vehicles. *IEEE J. of Oceanic Eng.*, 25(2):213–226, April 2000.
- [53] J. H. Lim and J. J. Leonard. Mobile robot relocation from echolocation constraints. *IEEE Trans. Pattern Analysis and Machine Intelligence*, 22(9):1035–1041, September 2000.
- [54] T. F. Fulton, C. J. Cassidy, R. G. Stokey, and J. J. Leonard. Navigation sensor data fusion for the AUV REMUS. In *Proceedings of the Symposium on Underwater Robotic Technology, World Automation Congress*, Hawaii, 2000.
- [55] J. J. Leonard. Cooperative mapping and navigation for multiple unmanned underwater vehicles. In *International Unmanned Undersea Vehicle Symposium, Naval Undersea Warfare Center*, Newport, RI, April 2000.
- [56] J. J. Leonard. Large-scale concurrent mapping and localization. In *Proceedings of SPIE*, volume 4196, page 370, 2000.
- [57] J. J. Leonard and R. Rikoski. Incorporation of delayed decision making into stochastic mapping. In D. Rus and S. Singh, editors, *Experimental Robotics VII*, Lecture Notes in Control and Information Sciences. Springer-Verlag, 2001.
- [58] J. J. Leonard, R. Carpenter, and H. J. S. Feder. Stochastic mapping using forward look sonar. *Robotica*, 19:467–480, 2001.
- [59] J. J. Leonard and H. J. S. Feder. Decoupled stochastic mapping. *IEEE J. of Oceanic Eng.*, 26(4):561–571, 2001.
- [60] J. J. Leonard, P. M. Newman, J. W. Fenwick, and R. J. Rikoski. Concurrent mapping and localization for multiple autonomous underwater vehicles. In *GOATS Workshop*, August 2001.
- [61] J.D. Tardós, J. Neira, P.M. Newman, and J.J. Leonard. Robust mapping and localization in indoor environments using sonar data. *Intl. J. of Robotics Research*, 21(4):311–330, April 2002.
- [62] John J. Leonard, Richard R. Rikoski, Paul M. Newman, and Michael Bosse. Mapping partially observable features from multiple uncertain vantage points. *Intl. J. of Robotics Research*, 7(3):943–975, October 2002.

- [63] R. Rikoski, J. Leonard, and P. Newman. Stochastic mapping frameworks. In *Proc. IEEE Int. Conf. Robotics and Automation*, pages 426–433, Washington, DC, May 2002.
- [64] J. Fenwick, P. Newman, and J. Leonard. Cooperative concurrent mapping and localization. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, volume 2, pages 1810–1817, 2002.
- [65] P. Newman, J. Leonard, J. Neira, and J. Tardós. Explore and return: Experimental validation of real time concurrent mapping and localization. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 1802–1809, Washington, DC, May 2002.
- [66] M. Bosse, R. Rikoski, J. Leonard, and S. Teller. Vanishing points and 3D lines from omnidirectional video. In *International Conference on Image Processing*, Rochester, NY, September 2002.
- [67] J. Leonard, P. Newman, R. Rikoski, J. Neira, and J. Tardós. Towards robust data association and feature modeling for concurrent mapping and localization. *Robotics Research*, pages 7–20, 2003.
- [68] M. Bosse, R. Rikoski, J. Leonard, and S. Teller. Vanishing points and three-dimensional lines from omni-directional video. *The Visual Computer*, 19(6):417–430, 2003.
- [69] P. Newman and J. Leonard. Pure range-only sub-sea SLAM. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, volume 2, pages 1921–1926, September 2003.
- [70] P. Newman, M. Bosse, and J. Leonard. Autonomous feature-based exploration. In *Proc. IEEE Int. Conf. Robotics and Automation*, volume 1, pages 1234–1240. IEEE, 2003.
- [71] M. Bosse, P. Newman, J. Leonard, and S. Teller. An atlas framework for scalable mapping. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 1899–1906, 2003.
- [72] R. Rikoski and J. Leonard. Sonar trajectory perception. In *Proc. IEEE Int. Conf. Robotics and Automation*, volume 1, pages 963–970, Taiwan, 2003. IEEE.
- [73] J. J. Leonard and P. M. Newman. Consistent, Convergent, and Constant-time SLAM. In *International Joint Conference on Artificial Intelligence*, volume 18, pages 1143–1150, 2003.
- [74] M. Bosse, P. Newman, J. Leonard, and S. Teller. Simultaneous localization and map building in large-scale cyclic environments using the Atlas framework. *Intl. J. of Robotics Research*, 23(12):1113–1139, December 2004.
- [75] E. Olson, J. J. Leonard, and S. Teller. Robust range-only beacon localization. In *AUV 2004*, June 2004.
- [76] J. Vaganay, J.J. Leonard, J.A. Curcio, and J.S. Willcox. Experimental validation of the moving long base line navigation concept. In *Autonomous Underwater Vehicles, 2004 IEEE/OES*, pages 59–65, June 2004.
- [77] M. Walter and J. Leonard. An experimental investigation of cooperative SLAM. In *Proceedings of the Fifth IFAC Symposium on Intelligent Autonomous Vehicles*, Lisbon, Portugal, July 2004.

- [78] D. Moore, J. Leonard, D. Rus, and S. Teller. Robust distributed network localization with noisy range measurements. In *Proceedings of the 2nd international conference on Embedded networked sensor systems*, pages 50–61. ACM, 2004.
- [79] P. M. Newman, J. J. Leonard, and R. J. Rikoski. Towards constant-time SLAM on an autonomous underwater vehicle using synthetic aperture sonar. *Robotics Research*, pages 409–420, 2005.
- [80] R. Eustice, H. Singh, and J. Leonard. Exactly sparse delayed state filters. In *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*, pages 2417–2424, Barcelona, Spain, 2005. IEEE.
- [81] R. Eustice, H. Singh, J. Leonard, M. Walter, and R. Ballard. Visually navigating the RMS Titanic with SLAM information filters. In *Robotics: Science and Systems (RSS)*, June 2005.
- [82] E. Olson, M. Walter, S. Teller, and J.J. Leonard. Single-cluster spectral graph partitioning for robotics applications. In *Proceedings of Robotics: Science and Systems*, Cambridge, USA, June 2005.
- [83] R. Eustice, M. Walter, and J. Leonard. Sparse extended information filters: Insights into sparsification. In *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*, pages 3281–3288. IEEE, 2005.
- [84] M. Walter, R. Eustice, and J. Leonard. A provably consistent method for imposing exact sparsity in feature-based SLAM information filters. In *Proceedings of the International Symposium of Robotics Research (ISRR)*, pages 214–234, San Francisco, CA, October 2005. Springer.
- [85] M. Dragone, R. O’Donoghue, J. J. Leonard, G. O’Hare, B. Duffy, A. Patrikalakis, and J. Leedekerken. Robot Soccer Anywhere: Achieving Persistent Autonomous Navigation, Mapping and Object Vision Tracking in Dynamic Environments. *Proceedings of SPIE Opto Ireland*, 2005.
- [86] J. Curcio, J. J. Leonard, J. Vaganay, A. Patrikalakis, A. Bahr, D. Battle, H. Schmidt, and M. Grund. Experiments in Moving Baseline Navigation using Autonomous Surface Craft. In *Proc. of the IEEE/MTS OCEANS Conf. and Exhibition*, volume 1, pages 730–735, September 2005.
- [87] J. Curcio, J. Leonard, and A. Patrikalakis. SCOUT – a low cost autonomous surface platform for research in cooperative autonomy. In *Proc. of the IEEE/MTS OCEANS Conf. and Exhibition*, Washington DC, September 2005.
- [88] R. Rikoski, J. Leonard, P. Newman, and H. Schmidt. Trajectory sonar perception in the ligurian sea. *Experimental Robotics IX*, pages 557–570, 2006.
- [89] M. Benjamin, J. Curcio, J. Leonard, and P. Newman. Protocol-based colregs collision avoidance navigation between unmanned marine surface craft. *J. of Field Robotics*, 23(5), May 2006.
- [90] E. Olson, J. Leonard, and S. Teller. Fast iterative alignment of pose graphs with poor initial estimates. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 2262–2269, May 2006.

- [91] M. Benjamin, J. Curcio, J. Leonard, and P. Newman. Navigation of unmanned marine vehicle in accordance with the rules of the road. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, Orlando, FL, May 2006.
- [92] D. P. Eickstedt, M. R. Benjamin, H. Schmidt, and J. J. Leonard. Adaptive control of heterogeneous marine sensor platforms in an autonomous sensor network. In *Intelligent Robots and Systems, 2006 IEEE/RSJ International Conference on*, pages 5514–5521. IEEE, 2006.
- [93] J. C. Leedekerken, J. J. Leonard, M. C. Bosse, and A. Balasuriya. Real-time obstacle avoidance and mapping for AUVs operating in complex environments. *Proceedings of the Seventh International Symposium on Technology and the Mine Problem: May 2-4, 2006, Naval Postgraduate School*, 1:35, 2006.
- [94] R.M. Eustice, H. Singh, J.J. Leonard, and M.R. Walter. Visually mapping the RMS Titanic: Conservative covariance estimates for SLAM information filters. *Intl. J. of Robotics Research*, 25(12):1223–1242, December 2006.
- [95] R.M. Eustice, H. Singh, and J.J. Leonard. Exactly sparse delayed-state filters for view-based SLAM. *IEEE Trans. Robotics*, 22(6):1100–1114, December 2006.
- [96] E. Olson, J.J. Leonard, and S. Teller. Robust range-only beacon localization. *IEEE Journal of Oceanic Engineering*, 31(4):949–958, October 2006.
- [97] D.P. Eickstedt, M.R. Benjamin, H. Schmidt, and J. Leonard. Adaptive tracking of underwater targets with autonomous sensor networks. *Journal of Underwater Acoustics (USN)*, 56:465–495, 2006.
- [98] M.R. Walter, R.M. Eustice, and J.J. Leonard. Exactly sparse extended information filters for feature-based SLAM. *Intl. J. of Robotics Research*, 26(4):335–359, 2007.
- [99] E. Olson, J. Leonard, and S. Teller. Spatially-adaptive learning rates for online incremental SLAM. In *Robotics: Science and Systems (RSS)*, June 2007.
- [100] A. Bahr and J. J. Leonard. Minimizing trilateration errors in the presence of noisy landmarks. In *European Conference on Mobile Robots*, 2007.
- [101] J. Folkesson, J. Leedekerken, R. Williams, and J. Leonard. Feature tracking for underwater navigation using sonar. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, San Diego, CA, October 2007.
- [102] A. Bahr and J. J. Leonard. Cooperative Localization for Autonomous Underwater Vehicles. In *Experimental Robotics*, pages 387–395, Rio de Janeiro, Brasil, 2008.
- [103] C. Detweiler, J. Leonard, D. Rus, and S. Teller. Passive mobile robot localization within a fixed beacon field. *Algorithmic Foundation of Robotics VII*, pages 425–440, 2008.
- [104] J.C. Leedekerken, R. Williams, and J.J. Leonard. Short-baseline acoustic tracking with autonomous surface vehicles. In *Proceedings of the 2008 IFAC Workshop Navigation, Guidance, and Control of Underwater Vehicles*, Limerick, Ireland, 2006.
- [105] J. Folkesson, J. Leedekerken, R. Williams, A. Patrikalakis, and J. Leonard. A feature based navigation system for an autonomous underwater robot. In *Field and Service Robotics*, volume 42, pages 105–114, 2008.

- [106] M. Walter, F. Hover, and J. Leonard. SLAM for ship hull inspection using exactly sparse extended information filters. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 1463–1470, May 2008.
- [107] S. Thrun and J. J. Leonard. Simultaneous localization and mapping. In B. Siciliano and O. Khatib, editors, *Springer Handbook of Robotics*. Springer, 2008.
- [108] A. J. Shafer, M. R. Benjamin, J. J. Leonard, and J. Curcio. Autonomous cooperation of heterogeneous platforms for sea-based search tasks. In *OCEANS 2008*, pages 1–10. IEEE, 2008.
- [109] J. Leonard, J. How, S. Teller, M. Berger, S. Campbell, G. Fiore, L. Fletcher, E. Frazzoli, A. Huang, S. Karaman, et al. A perception-driven autonomous urban vehicle. *J. of Field Robotics*, 25(10):727–774, 2008.
- [110] L. Fletcher, S. Teller, E. Olson, D. Moore, Y. Kuwata, J. How, J. Leonard, I. Miller, M. Campbell, D. Huttenlocher, et al. The MIT–Cornell collision and why it happened. *Journal of Field Robotics*, 25(10):775–807, 2008.
- [111] A. Bahr, J.J. Leonard, and M.F. Fallon. Cooperative localization for autonomous underwater vehicles. *Intl. J. of Robotics Research*, 28(6):714–728, 2009.
- [112] A. Bahr, M. Walter, and J.J. Leonard. Consistent cooperative localization. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 3415–3422, May 2009.
- [113] David C. Moore, Albert S. Huang, Matthew Walter, Edwin Olson, Luke Fletcher, John Leonard, and Seth Teller. Simultaneous local and global state estimation for robotic navigation. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, 2009.
- [114] M.F. Fallon, G. Papadopoulos, and J.J. Leonard. Cooperative AUV navigation using a single surface craft. In *Field and Service Robotics*, July 2009.
- [115] M. F. Fallon, G. Papadopoulos, J. J. Leonard, and N. M. Patrikalakis. Cooperative AUV navigation using a single maneuvering surface craft. *Intl. J. of Robotics Research*, 29(12):1461–1474, October 2010.
- [116] A. S. Huang, M. Antone, E. Olson, L. Fletcher, D. Moore, S. Teller, and J. Leonard. A high-rate, heterogeneous data set from the DARPA urban challenge. *Intl. J. of Robotics Research*, 29:1595–1601, November 2010.
- [117] M. Benjamin, H. Schmidt, P. Newman, and J.J. Leonard. Nested autonomy for unmanned marine vehicles with MOOS-IvP. *J. of Field Robotics*, 27:834–875, November 2010.
- [118] B. Kim, M. Kaess, L. Fletcher, J.J. Leonard, A. Bachrach, N. Roy, and S. Teller. Multiple relative pose graphs for robust cooperative mapping. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 3185–3192, Anchorage, Alaska, May 2010.
- [119] M. F. Fallon, G. Papadopoulos, and J. J. Leonard. A measurement distribution framework for cooperative navigation using multiple AUVs. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 4803–4808, May 2010.

- [120] H. Johannsson, M. Kaess, B. Englot, F. Hover, and J.J. Leonard. Imaging sonar-aided navigation for autonomous underwater harbor surveillance. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Taipei, Taiwan, October 2010.
- [121] G. Papadopoulos, M.F. Fallon, J.J. Leonard, and N. M. Patrikalakis. Cooperative localization of marine vehicles using nonlinear state estimation. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Taipei, Taiwan, October 2010.
- [122] J. C. Leedekerken, M. F. Fallon, and J. J. Leonard. Mapping complex marine environments with autonomous surface craft. In *Intl. Sym. on Experimental Robotics (ISER)*, Delhi, India, December 2010.
- [123] M. Kaess, H. Johannsson, B. Englot, F. Hover, and J.J. Leonard. Towards autonomous ship hull inspection using the Bluefin HAUV. In *Symposium on Technology and the Mine Problem*, Naval Postgraduate School, Monterey, CA, May 2010.
- [124] J. Folkesson and J. Leonard. Autonomy through SLAM for an underwater robot. *Robotics Research*, pages 55–70, 2011.
- [125] R. Truax, R. Platt, and J. Leonard. Identifying object pose and parameters from 3D laser point clouds. In *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, Shanghai, China, May 2011.
- [126] M.F. Fallon, M. Kaess, H. Johannsson, and J.J. Leonard. Efficient AUV navigation fusing acoustic ranging and side-scan sonar. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, Shanghai, China, May 2011.
- [127] M. Kaess, H. Johannsson, R. Roberts, V. Ila, J.J. Leonard, and F. Dellaert. iSAM2: Incremental smoothing and mapping with fluid relinearization and incremental variable reordering. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, Shanghai, China, May 2011.
- [128] C. Cadena, J. McDonald, J. Leonard, and J. Neira. Place recognition using near and far visual information. In *Proceedings of the 18th IFAC World Congress*, August 2011.
- [129] J. McDonald, M. Kaess, C. Cadena, J. Neira, and J.J. Leonard. 6-DOF multi-session visual SLAM using anchor nodes. In *European Conf. on Mobile Robotics (ECMR)*, Orbero, Sweden, September 2011.
- [130] M. Kaess, H. Johannsson, R. Roberts, V. Ila, J. J. Leonard, and F. Dellaert. iSAM2: Incremental smoothing and mapping using the Bayes tree. *The International Journal of Robotics Research*, 31:217–236, February 2012.
- [131] M.F. Fallon, H. Johannsson, and J.J. Leonard. Efficient scene simulation for robust Monte Carlo localization using an RGB-D camera. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 1663–1670, St. Paul, MN, May 2012.
- [132] D.M. Rosen, M. Kaess, and J.J. Leonard. An incremental trust-region method for robust online sparse least-squares estimation. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 1262–1269, St. Paul, MN, May 2012.

- [133] T. Whelan, M. Kaess, M.F. Fallon, H. Johannsson, J.J. Leonard, and J.B. McDonald. Kintinuous: Spatially extended KinectFusion. In *RSS Workshop on RGB-D: Advanced Reasoning with Depth Cameras*, Sydney, Australia, July 2012. Available as MIT CSAIL Technical Report MIT-CSAIL-TR-2012-020.
- [134] H. Johannsson, M. Kaess, M.F. Fallon, and J.J. Leonard. Temporally scalable visual SLAM using a reduced pose graph. In *RSS Workshop on Long-term Operation of Autonomous Robotic Systems in Changing Environments*, Sydney, Australia, July 2012. Available as MIT CSAIL Technical Report MIT-CSAIL-TR-2012-013.
- [135] M. Kaess, S. Williams, V. Indelman, R. Roberts, J.J. Leonard, and F. Dellaert. Concurrent filtering and smoothing. In *Intl. Conf. on Information Fusion (FUSION)*, pages 1300–1307, Singapore, July 2012.
- [136] M. F. Fallon, H. Johannsson, J. Brookshire, S. Teller, and J. J. Leonard. Sensor fusion for flexible human-portable building-scale mapping. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Algarve, Portugal, 2012.
- [137] A. Walcott-Bryant, M. Kaess, H. Johannsson, and J.J. Leonard. Dynamic pose graph SLAM: Long-term mapping in low dynamic environments. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Vilamoura, Portugal, October 2012.
- [138] A. Bahr, J.J. Leonard, and A. Martinoli. Dynamic positioning of beacon vehicles for cooperative underwater navigation. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Algarve, Portugal, 2012.
- [139] F.S. Hover, R.M. Eustice, A. Kim, B.J. Englot, H. Johannsson, M. Kaess, and J.J. Leonard. Advanced perception, navigation and planning for autonomous in-water ship hull inspection. *Intl. J. of Robotics Research*, 31(12):1445–1464, October 2012.
- [140] M. F. Fallon, J. Folkesson, H. McClelland, and J. J. Leonard. Relocating underwater features autonomously using sonar-based SLAM. *IEEE J. Ocean Engineering*, 38(3):500–513, 2013.
- [141] J. McDonald, M. Kaess, C. Cadena, J. Neira, and J.J. Leonard. Real-time 6-DOF multi-session visual SLAM over large scale environments. *J. of Robotics and Autonomous Systems*, 61(10):1144–1158, October 2013.
- [142] M. F. Fallon, H. Johannsson, M. Kaess, J. Folkesson, H. McClelland, B. J. Englot, F. S. Hover, and J. J. Leonard. Simultaneous localization and mapping in marine environments. In M. Seto, editor, *Marine Robot Autonomy*. Springer, 2013.
- [143] H. Johannsson, M. Kaess, M.F. Fallon, and J.J. Leonard. Temporally scalable visual SLAM using a reduced pose graph. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, Karlsruhe, Germany, May 2013.
- [144] D.M. Rosen, M. Kaess, and J.J. Leonard. Robust incremental online inference over sparse factor graphs: Beyond the Gaussian case. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, Karlsruhe, Germany, May 2013.
- [145] T. Whelan, H. Johannsson, M. Kaess, J.J. Leonard, and J.B. McDonald. Robust real-time visual odometry for dense RGB-D mapping. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, Karlsruhe, Germany, May 2013.

- [146] G Huang, M Kaess, J Leonard, and S Roumeliotis. Analytically-selected multi- hypothesis incremental MAP estimation. In *International Conference on Acoustics, Speech, and Signal Processing*, British Columbia, Canada, May 2013.
- [147] R. Finman, T. Whelan, M. Kaess, and J. Leonard. Toward lifelong object segmentation from change detection in dense RGB-D maps. In *European Conference on Mobile Robotics*, Barcelona, Spain, September 2013.
- [148] G. Huang, R. Truax, M. Kaess, and J.J. Leonard. Unscented iSAM: A consistent incremental solution to cooperative localization and target tracking. In *Proc. of European Conference on Mobile Robots (ECMR)*, pages 248–254, Barcelona, Spain, September 25–27, 2013.
- [149] G. Huang, M. Kaess, and J.J. Leonard. Consistent sparsification for graph optimization. In *Proc. of European Conference on Mobile Robots (ECMR)*, pages 150–157, Barcelona, Spain, September 25–27, 2013.
- [150] T. Whelan, M. Kaess, J.J. Leonard, and J.B. McDonald. Deformation-based loop closure for large scale dense RGB-D SLAM. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Tokyo, Japan, November 2013.
- [151] M. Fallon, H. Johannsson, M. Kaess, and J.J. Leonard. The MIT Stata Center dataset. *Intl. J. of Robotics Research*, 32(14):1695–1699, December 2013.
- [152] M. VanMiddlesworth, M. Kaess, F.S. Hover, and J.J. Leonard. Mapping 3D underwater environments with smoothed submaps. In *Field and Service Robotics*, Brisbane, Australia, December 2013.
- [153] D.M. Rosen, M. Kaess, and J.J. Leonard. RISE: An incremental trust-region method for robust online sparse least-squares estimation. *Robotics and Automation, IEEE Transactions on*, 30(5):1091–1108, October 2014.
- [154] B. Tweddle, A. Saenz-Otero, D. W. Miller, and J. Leonard. Factor graph modeling of rigid-body dynamics for localization, mapping and parameter estimation of a spinning object in space. *J. of Field Robotics*, 32(6):897–933, 2014.
- [155] Kaess G. Huang, M and J. J. Leonard. Towards consistent visual-inertial navigation. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, June 2014.
- [156] D. Rosen, G. Huang, and J. Leonard. Factor graphs with Gaussian process. In *Proc. of IEEE International Conference on Robotics and Automation (ICRA)*, Hong Kong, China, May 31 – June 5, 2014.
- [157] R. Finman, T. Whelan, M. Kaess, and J. J. Leonard. Efficient incremental map segmentation in dense RGB-D maps. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, June 2014.
- [158] R. Finman, T. Whelan, L. Paull, and J. J. Leonard. Physical words for place recognition in dense RGB-D maps. In *ICRA workshop on visual place recognition in changing environments*, June 2014.
- [159] J. Straub, G. Rosman, O. Freifed, J. J. Leonard, and J. W. Fisher. A mixture of manhattan frames: Beyond the manhattan world. In *Computer Vision and Pattern Recognition (CVPR), 2014 IEEE Conference on*, Portland, OR, June 2014.

- [160] Yasir Latif, Guaquan Huang, John Leonard, and Jose Neira. An online sparsity-cognizant loop-closure algorithm for visual navigation. In *Robotics: Science and Systems (RSS)*, Berkeley, CA, July 2014.
- [161] L. Paull, M. Seto, and J. J. Leonard. Decentralized cooperative trajectory estimation for autonomous underwater vehicles. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2014.
- [162] B. Tweddle, T. P. Setterfield, A. Saenz-Otero, D. W. Miller, and J. Leonard. Experimental evaluation of on-board, visual mapping of an object spinning in micro-gravity aboard the international space station. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2014.
- [163] H. Wei, W. Lu, P. Zhu, G. Huang, J. Leonard, and S. Ferrari. Optimized visibility motion planning for target tracking and localization. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2014.
- [164] S. Williams, V. Indelman, M. Kaess, J.J. Leonard R. Roberts, and F. Dellaert. Concurrent filtering and smoothing: A parallel architecture for real-time navigation and full smoothing. *The International Journal of Robotics Research*, 33(12):1544–1568, 2014.
- [165] Thomas Whelan, Michael Kaess, Ross Finman, Maurice Fallon, Hordur Johannsson, John J Leonard, and John McDonald. 3D mapping, localisation and object retrieval using low cost robotic platforms: A robotic search engine for the real-world. *RSS Workshop*, 2014.
- [166] G. Huang, M. Kaess, and J. J. Leonard. Consistent unscented incremental smoothing for multi-robot cooperative target tracking. *Robotics and Autonomous Systems*, 69:52–67, 2015.
- [167] T. Whelan, M. Kaess, H. Johannsson, M. Fallon, J. J. Leonard, and J. McDonald. Real-time large scale dense RGB-D SLAM with volumetric fusion. *Intl. J. of Robotics Research*, 34(4-5):598–626, 2015.
- [168] T. Steiner, G. Huang, and J. J. Leonard. Location utility-based map reduction. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, May 2015.
- [169] P. Corcoran, T.J. Steiner, M. Bertolotto, and J.J. Leonard. Appearance-based slam in a network space. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 5791–5798, 2015.
- [170] D. Rosen, C. DuHadway, and J. J. Leonard. A convex relaxation for approximate global optimization in simultaneous localization and mapping. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, May 2015.
- [171] L Paull, G Huang, M Seto, and J J Leonard. Communication-constrained multi-AUV cooperative SLAM. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, May 2015.
- [172] R. Finman, L. Paull, and J. J. Leonard. Toward object-based place recognition in dense rgb-d maps. In *ICRA workshop on visual place recognition in changing environments*, June 2015.
- [173] Beipeng Mu, Ali akbar Agha-mohammadi, Liam Paull, Matthew Graham, Jonathan How, and John Leonard. Two-stage focused inference for resource-constrained collision-free navigation. In *Proceedings of Robotics: Science and Systems*, Rome, Italy, July 2015.

- [174] Sudeep Pillai and John J. Leonard. Monocular SLAM supported object recognition. In *Robotics: Science and Systems (RSS)*, July 2015.
- [175] L. Carlone, D.M. Rosen, G.C. Calafiore, J.J. Leonard, and F. Dellaert. Lagrangian duality in 3D SLAM: Verification techniques and optimal solutions. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Hamburg, Germany, September 2015.
- [176] J. Straub, B. Nishchal, J. Leonard, and J. W. Fisher III. Real-time manhattan world rotation estimation in 3D. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Hamburg, Germany, September 2015.
- [177] H. Wang, C. Finn, L. Paull, M. Kaess, R. Rosenholtz, S. Teller, and J. Leonard. Bridging text spotting and SLAM with junction features. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, Hamburg, Germany, September 2015.
- [178] K.T. Yu, J. Leonard, and A. Rodriguez. Shape and pose recovery from planar pushing. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, pages 1208–1215, 2015.
- [179] Guoquan Huang, Kevin Eickenhoff, and John Leonard. Optimal-state-constraint ekf for visual-inertial navigation. In *Proceedings of the Second International Symposium of Robotics Research*, 2016.
- [180] D. Rosen, J. Mason, and J. J. Leonard. Towards lifelong feature-based mapping in semi-static environments. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, May 2016.
- [181] S. Pillai, S. Ramalingam, and J. J. Leonard. High-performance and tunable stereo reconstruction. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, 2016.
- [182] L. Paull and G. Huang J. J. Leonard. A unified resource-constrained framework for graph SLAM. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, May 2016.
- [183] C. Stachniss, J. J. Leonard, and S. Thrun. Simultaneous localization and mapping. In B. Siciliano and O. Khatib, editors, *Springer Handbook of Robotics, Second Edition*. Springer, 2016.
- [184] D. Fourie, J.J. Leonard, and M. Kaess. A nonparametric belief solution to the Bayes tree. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems, IROS*, Daejeon, Korea, Oct 2016.
- [185] B. Mu, S-Y. Liu, L. Paull, J. Leonard, and J. How. SLAM with objects using a nonparametric pose graph. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2016.
- [186] P. V. Teixeira, M. Kaess, F. S. Hover, and J. J. Leonard. Underwater inspection using sonar-based volumetric submaps. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2016.
- [187] Beipeng Mu, Matthew Giamou, Liam Paull, Ali akbar Agha-mohammadi, John J. Leonard, and Jonathan P. How. Information-based active SLAM via topological feature graphs. In *55th IEEE Int. Conference on Decision and Control*, 2016.
- [188] D. M. Rosen, L. Carlone, A. S. Bandeira, and J. J. Leonard. A certifiably correct algorithm for synchronization over the special euclidean group. In *Intl. Workshop on the Algorithmic Foundations of Robotics, WAFR*, 2016.

- [189] Kyle L. Woerner, Michael R. Benjamin, Michael Novitzky, and John J. Leonard. Collision avoidance road test for colregs-constrained autonomous vehicles. In *OCEANS 2016 MTS/IEEE Monterey*, pages 1–6. IEEE, 2016.
- [190] S Lowry, N Sunderhauf, P Newman, J. J. Leonard, D Cox, P Corke, and M. Milford. Visual place recognition: A survey. *IEEE Trans. Robotics*, 32(1):1–19, 2016.
- [191] C. D. Cadena Lerma, L. Carlone, H. Carrillo, Y. Latif, D. Scaramuzza, J. Neira, I. Reid, and J. Leonard. Past, present, and future of simultaneous localization and mapping: Towards the robust-perception age. *IEEE Trans. Robotics*, 2016.
- [192] Jacopo Tani, Liam Paull, Maria T Zuber, Daniela Rus, Jonathan How, John Leonard, and Andrea Censi. Duckietown: an innovative way to teach autonomy. In *International Conference EduRobotics 2016*, pages 104–121. Springer, 2016.
- [193] J. J. Leonard and A. Bahr. Autonomous underwater vehicle navigation. In M. R. Dhanak and N. I. Xiros, editors, *Springer Handbook of Ocean Engineering*. Springer, 2016.
- [194] B. Mu, L. Paull, A. Agha-mohammadi, J. Leonard, and J. How. Two-stage focused inference for resource-constrained minimal collision navigation. *IEEE Trans. Robotics*, 33(1):124–140, 2017.
- [195] T. P. Setterfield, D. Miller, A. Saenz-Otero, and J. J. Leonard. Smoothing-based estimation of an inspector satellite trajectory relative to a passive object. In *IEEE Aerospace*, pages 1–11, 2017.
- [196] Y. Latif, G. Huang, J. J. Leonard, and J. A. Neira. Sparse optimization for robust and efficient loop closing. *Robotics and Autonomous Systems*, 93:13–26, 2017.
- [197] Dehann Fourie, Samuel D. Claassens, Sudeep Pillai, Roxana Mata, and John J. Leonard. Centralized graph databases for mobile Robotics. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, Singapore, June 2017.
- [198] Liam Paull, Jacopo Tani, Heejin Ahn, Javier Alonso-Mora, Luca Carlone, Michal Cap, Yu Fan Chen, Changhyun Choi, Jeff Dusek, Yajun Fang, Daniel Hoehener, Shih-Yuan Liu, Michael Novitzky, Igor Franzoni Okuyama, Jason Pazis, Guy Rosman, Valerio Varricchio, Hsueh-Cheng Wang, Dmitry Yershov, Hang Zhao, Michael Benjamin, Christopher Carr, Maria Zuber, Sertac Karaman, Emilio Frazzoli, Domitilla Del Vecchio, Daniela Rus, Jonathan How, John Leonard, and Andrea Censi. Duckietown: an open, inexpensive and flexible platform for autonomy education and research. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, May 2017.
- [199] F. Naser, D. Dorhout, S. Proulx, S. Pendleton, H. Andersen, W. Schwarting, J. Alonso-Mora, L. Paull, S. Karaman, R. Tedrake, J. Leonard, and D. Rus. A parallel autonomy research platform, June 2017. In *IEEE Intelligent Vehicles Symposium*.
- [200] S. Pillai and J. Leonard. Towards visual ego-motion learning in robots. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2017.
- [201] S. Pillai and J. Leonard. Self-supervised place recognition in mobile robots. In *IROS 2017 Learning for Localization and Mapping Workshop*, 2017.

- [202] J. Straub, O. Freifeld, G. Rosman, J. J. Leonard, and J. W. Fisher III. The Manhattan frame model: Manhattan world inference in the space of surface normals. *IEEE Trans. Pattern Anal. Machine Intell.*, 40(1), January 2018.
- [203] L. Paull, M. Seto, J. J. Leonard, and H. Li. A probabilistic mobile robot area coverage framework and its application to cooperative autonomous seabed surveying. *Intl. J. of Robotics Research*, 37(1):21–45, 2018.
- [204] Timothy P. Setterfield, David W. Miller, John J. Leonard, and Alvar Saenz-Otero. Mapping and determining the center of mass of a rotating object using a moving observer. *The International Journal of Robotics Research*, 37(1):83–103, 2018.
- [205] Liam Paull, Mae Seto, Sajad Saeedi, and John J. Leonard. *Navigation for Underwater Vehicles*, pages 1–15. Springer Berlin Heidelberg, Berlin, Heidelberg, 2018.
- [206] P. V. Teixeira, M. Kaess, F. S. Hover, and J. J. Leonard. Multibeam data processing for underwater mapping. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2018.
- [207] 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. *The International Journal of Robotics Research*, 38(2-3):95–125, 2019.
- [208] Kyle Woerner, Michael R. Benjamin, Michael Novitzky, and John J. Leonard. Quantifying protocol evaluation for autonomous collision avoidance. *Autonomous Robots*, 43(4):967–991, 2019.
- [209] Stephen G. McGill, Guy Rosman, Teddy Ort, Alyssa Pierson, Igor Gilitschenski, Brandon Araki, Luke Fletcher, Sertac Karaman, Daniela Rus, and John J. Leonard. Probabilistic risk metrics for navigating occluded intersections. *IEEE Robotics and Automation Letters*, 4(4):4322–4329, 2019.
- [210] Mei Yi Cheung, Dehann Fourie, Nicholas Rahardiyana Rypkema, Pedro Vaz Teixeira, Henrik Schmidt, and John Leonard. Non-Gaussian SLAM utilizing synthetic aperture sonar. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*. IEEE, 2019.
- [211] K. Doherty, D. Fourie, and J. Leonard. Multimodal semantic SLAM with probabilistic data association. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, pages 2419–2425. IEEE, 2019.
- [212] P. V. Teixeira, D. Fourie, M. Kaess, and J. J. Leonard. Dense, sonar-based reconstruction of underwater scenes. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2019.
- [213] D. Fourie, P. Vaz. Teixeira, and J. J. Leonard. Non-parametric mixed-manifold products using multiscale kernel densities. In *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*. IEEE, 2019.
- [214] K. Doherty, D. Baxter, E. Schneeweiss, and J. Leonard. Probabilistic data association via mixture models for robust semantic SLAM. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*. IEEE, 2020.

- [215] D. Fourie, A. Teran Espinoza, M. Kaess, and J. Leonard. Characterizing marginalization and incremental operations on the Bayes tree. In *Intl. Workshop on the Algorithmic Foundations of Robotics, WAFR*. Springer, 2020.
- [216] Xin Huang, Stephen G McGill, Jonathan A DeCastro, Luke Fletcher, John J Leonard, Brian C Williams, and Guy Rosman. DiversityGAN: Diversity-aware vehicle motion prediction via latent semantic sampling. *IEEE Robotics and Automation Letters*, 5(4):5089–5096, 2020.
- [217] John D Martin, Kevin Doherty, Caralyn Cyr, Brendan Englot, and John Leonard. Variational filtering with copula models for SLAM. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 5066–5073. IEEE, 2020.
- [218] Dehann Fourie, Nicholas R Rypkema, Pedro Vaz Teixeira, Sam Claassens, Erin Fischell, and John Leonard. Towards real-time non-gaussian SLAM for underdetermined navigation. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 4438–4445. IEEE, 2020.
- [219] Timothy P. Osedach, Kurran Singh, Pedro Vaz Texeira, Jean-Baptiste Arber, Alexandre Levesque, Clement Chahbazian, Darshan Jain, Brendan Englot, John J. Leonard, Stephane Vannuffelen, and Sepand Ossia. Proxy platform for underwater inspection, maintenance, and repair. In *Global Oceans 2020: Singapore – U.S. Gulf Coast*, pages 1–5, 2020.
- [220] David M Rosen, Kevin J Doherty, Antonio Terán Espinoza, and John J Leonard. Advances in inference and representation for simultaneous localization and mapping. *Annual Review of Control, Robotics, and Autonomous Systems*, 4:215–242, 2021.
- [221] Y. Zhang and J. J. Leonard. A front-end for dense monocular SLAM using a learned outlier mask prior. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*. IEEE, 2021.
- [222] Q. Huang, C. Pu, D. Fourie, K. Khosoussi, J. P. How, and J. J. Leonard. NF-iSAM: Incremental smoothing and mapping via normalizing flows. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*. IEEE, 2021.
- [223] Victor Amblard, Timothy P. Osedach, Arnaud Croux, Andrew Speck, and John J. Leonard. Lidar-monocular surface reconstruction using line segments. In *2021 IEEE International Conference on Robotics and Automation (ICRA)*, pages 5631–5637, 2021.
- [224] Xin Huang, Stephen G. McGill, Jonathan A. DeCastro, Luke Fletcher, John J. Leonard, Brian C. Williams, and Guy Rosman. Carpal: Confidence-aware intent recognition for parallel autonomy. *IEEE Robotics and Automation Letters*, 6(3):4433–4440, 2021.
- [225] Y. Zhang and J. J. Leonard. Bootstrapped self-supervised training with monocular video for semantic segmentation and depth estimation. In *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2021.
- [226] Z. Lu, Q. Huang, K. Doherty, and J. J. Leonard. Consensus-informed optimization over mixtures for ambiguity-aware object SLAM. In *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2021.
- [227] J. Fu, Q. Huang, K. Doherty, Y. Wang, and J. J. Leonard. A multi-hypothesis approach to pose ambiguity in object-based SLAM. In *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2021.

- [228] Qiangqiang Huang, Alan Papalia, and John J. Leonard. Nested sampling for non-Gaussian inference in SLAM factor graphs. *IEEE Robotics and Automation Letters*, 7(4):9232–9239, 2022.
- [229] Jesse R. Pelletier, Brendan W. O’Neill, John J. Leonard, Lee Freitag, and Eric Gallimore. AUV-assisted diver navigation. *IEEE Robotics and Automation Letters*, 7(4):10208–10215, 2022.
- [230] Jiahui Fu, Chengyuan Lin, Yuichi Taguchi, Andrea Cohen, Yifu Zhang, Stephen Mylabathula, and John J. Leonard. Planesdf-based change detection for long-term dense mapping. *IEEE Robotics and Automation Letters*, 7(4):9667–9674, 2022.
- [231] Qiangqiang Huang, Can Pu, Kasra Khosoussi, David Rosen, Dehann Fourie, Jonathan How, and John J. Leonard. Incremental non-Gaussian inference for SLAM using normalizing flows. *IEEE Transactions on Robotics*, 2022.
- [232] Kevin J. Doherty, Ziqi Lu, Kurran Singh, and John J. Leonard. Discrete-continuous smoothing and mapping. *IEEE Robotics and Automation Letters*, 7(4):1–8, 2022.
- [233] Avinash Balachandran, Tiffany Chen, Jonathan Goh, Stephen McGill, Guy Rosman, Simon Stent, and John Leonard. Human-centric intelligent driving: Collaborating with the driver to improve safety. *Lecture Notes in Mobility*, 9, 2022.
- [234] Kevin J. Doherty, David M. Rosen, and John J. Leonard. Performance guarantees for spectral initialization in rotation averaging and pose-graph SLAM. In *2022 International Conference on Robotics and Automation (ICRA)*, pages 5608–5614, 2022.
- [235] Alan Papalia, Nicole Thumma, and John Leonard. Prioritized planning for cooperative range-only localization in multi-robot networks. In *2022 International Conference on Robotics and Automation (ICRA)*, pages 10753–10759, Philadelphia, PA, 2022.
- [236] Xin Huang, Guy Rosman, Igor Gilitschenski, Ashkan Jasour, Stephen G. McGill, John J. Leonard, and Brian C. Williams. HYPER: Learned hybrid trajectory prediction via factored inference and adaptive sampling. In *2022 International Conference on Robotics and Automation (ICRA)*, pages 2906–2912, 2022.
- [237] Yen-Ling Kuo, Xin Huang, Andrei Barbu, Stephen G. McGill, Boris Katz, John J. Leonard, and Guy Rosman. Trajectory prediction with linguistic representations. In *2022 International Conference on Robotics and Automation (ICRA)*, pages 2868–2875, 2022.
- [238] Ziqi Lu, Yihao Zhang, Kevin Doherty, Odin Aleksander Severinsen, Ethan Yang, and John Leonard. SLAM-supported self-training for 6D object pose estimation. In *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022.
- [239] Jiahui Fu, Yilun Du, Kurran Singh, Joshua Tenenbaum, and John Leonard. Robust change detection based on neural descriptor fields. In *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022.
- [240] Kevin J. Doherty, David M. Rosen, and John J. Leonard. Spectral measurement sparsification for pose-graph SLAM. In *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022.

- [241] Xin Huang, Guy Rosman, Ashkan M. Jasour, Stephen McGill, John Leonard, and Brian Williams. TIP: Task-informed motion prediction for intelligent systems. In *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2022.
- [242] Brendan W. O’Neill, Jesse R. Pelletier, S. Calvert, Alan Papalia, John J. Leonard, Lee Freitag, and Eric Gallimore. Loosely-coupled human-robot teams for enhanced undersea operations. In *Proc. of the IEEE/MTS OCEANS Conf. and Exhibition*, Hampton Roads, VA, October 2022.
- [243] Antoni Rosinol and John J. Leonard and Luca Carlone. Probabilistic volumetric fusion for dense monocular SLAM. In *Proceedings of IEEE/CVF Winter Applications of Computer Vision*, Hawaii, January 2023.
- [244] Qiangqiang Huang, Joseph DeGol, Victor Fragoso, Sudipta N. Sinha, and John J. Leonard. Optimizing fiducial marker placement for improved visual localization. *IEEE Robotics and Automation Letters*, 8(5):2756–2763, 2023.
- [245] 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 Intl. Conf. on Robotics and Automation (ICRA)*, London, UK, 2023. To Appear.
- [246] Yihao Zhang, Odin A. Severinsen, John J. Leonard, Luca Carlone, and Kasra Khosoussi. Data-association-free landmark-based SLAM. In *IEEE Intl. Conf. on Robotics and Automation (ICRA)*, London, UK, 2023. To Appear.
- [247] Megan Flynn, Brendan W. O’Neill, Douglas P. Hart, and John J. Leonard. Maneuvering strategies for improved cooperative range-based localization. In *Proc. of the IEEE/MTS OCEANS Conf. and Exhibition*, Limerick, Ireland, June 2023. To Appear.
- [248] Kurran Singh, Nick Rypkema, and John J. Leonard. Attention-based unsupervised hierarchical semantic segmentation for underwater imagery. In *Proc. of the IEEE/MTS OCEANS Conf. and Exhibition*, Limerick, Ireland, June 2023. To Appear.

Patents of John J. Leonard

- [1] Ingemar Cox, John J. Leonard, and Hugh Durrant-Whyte, Navigation System for a Mobile Robot, U.S. Patent No. 5,363,305, 1994.
- [2] J. J Leonard, M. Kaess, J. McDonald, T. J. Whelan, Method for Mapping an Environment, US Patent No. 9,412,173, August 9, 2016.
- [3] John William Fisher, Oren Freifeld, John J Leonard, Guy Rosman, Julian Straub, System and method for extracting dominant orientations from a scene, U.S. Patent No. 9,665,791, May 30, 2017.
- [4] Dehann Fourie and John Leonard, Inertial Odometry With Retroactive Sensor Calibration, U.S. Patent No. 10,317,214, June 11, 2019.

- [5] High-speed and tunable scene reconstruction systems and methods using stereo imagery J. J. Leonard and S. Pillai, U.S. Patent No. 10,477,178, November 12, 2019.
- [6] Systems and Methods For Switching Between A Driver Mode and an Autonomous Driving Mode For A Vehicle, Stephen McGill, Luke Fletcher, Kazunori Nimura, John Leonard, and Gill Pratt, U.S. Patent No. 10,633,025, April 28, 2020.
- [7] John J. Leonard, Stephen G. McGill, Luke S. Fletcher. Vehicle systems and methods for providing turn assistance at an intersection. US Patent No. 10,752,249, August 25, 2020.
- [8] Guy Rosman, Jonathan DeCastro, Nikos Arechiga Gonzalez, John Joseph Leonard, Luke S. Fletcher, and Daniel Stonier. Systems and Methods for Agent Tracking. U.S. Patent No. 10,882,522, January 5th, 2021.
- [9] Leonard, John J., Simon I. Stent, Luke S. Fletcher, and Stephen G. McGill. Systems and methods for incentivizing user-aided improvement of autonomous vehicle control systems and methods of operating a vehicle using the same. U.S. Patent No. 11,079,758, August 3rd, 2021.
- [10] Stephen G. McGill, Guy Rosman, John Joseph Leonard, Luke S. Fletcher, Yusuke Sawamura, and Xin Huang. Systems and methods for predicting the trajectory of a road agent external to a vehicle. U.S. Patent No. 11,126,186, September 21, 2021.
- [11] Stephen G. McGill, Guy Rosman, Luke S. Fletcher, John J. Leonard, Simon Stent. Methods and systems for collecting sensor data according to a data collection configuration based on an estimated information gain. U.S. Patent No. 11,475,720. October 18, 2022.