

BHASKAR D. RAO

Address

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Education

- Ph.D** Electrical Engineering, University of Southern California, Los Angeles (August 1983)
- M.S** Computer Engineering, University of Southern California, Los Angeles, (1981)
- B.Tech** Electronics and Electrical Communication Engineering, I.I.T. Kharagpur, India (1979)

Professional Experience

- Distinguished Professor, Department of Electrical and Computer Engineering, University of California, San Diego. (2016-present)
- Professor, Department of Electrical and Computer Engineering, University of California, San Diego. (1995-2016)
- Consultant, Qualcomm Inc., Fall 2011
- Visiting Researcher, Speech technology department, Microsoft Research, (Winter 2012)
- Consultant Intel, Santa Clara (Spring 2012)
- Consultant, Speech Research Department, AT&T Bell Laboratories, Murray Hill, New Jersey, (Jan.-June, 1995).
- Associate Professor, Department of Electrical and Computer Engineering, University of California, San Diego. (1989-1995)
- Visiting Associate Professor, Department of Electrical Engineering, Stanford University. (1989-1990)
- Assistant Professor, Department of Electrical and Computer Engineering, University of California, San Diego. (1989-1995)

Awards and Honors

1. 2020-21 ECE Best Graduate Teacher Award
2. 2016 Signal Processing Society Technical Achievement Award for fundamental contributions to array processing and sparsity-based signal processing.
3. Fulbright-Nokia Distinguished Chair in Information and Communications Technologies, 2015-2016
4. Director, Center for Wireless Communications, 2008-2011
5. Ericsson endowed chair in wireless access networks since May 2008.
6. IEEE Signal Processing Society Distinguished Lecturer for the term 1 January 2014 through 31 December 2015.
7. IEEE Fellow, 2000, for the statistical analysis of subspace algorithms for harmonic retrieval.
8. 2012 Signal Processing Society (SPS) Best Paper Award for the paper An Empirical Bayesian Strategy for Solving the Simultaneous Sparse Approximation Problem, by David P. Wipf and Bhaskar D. Rao published in IEEE Transaction on Signal Processing, Volume: 55, No. 7, July 2007
9. 2008 Stephen O. Rice Prize Paper Award in the Field of Communication Systems for the paper Network Duality for Multiuser MIMO Beamforming Networks and Applications, by B. Song, R. L. Cruz and B. D. Rao that appeared in the IEEE Transactions on Communications, Vol. 55, No. 3, March 2007, pp. 618-630.
(<http://www.comsoc.org/awards/rice.html>)
10. Best paper award at the Fall 2013, IEEE Vehicular Technology Conference for the paper Multicell Random Beamforming with CDF-based Scheduling: Exact Rate and Scaling Laws, by Yichao Huang and Bhaskar D Rao.
11. Best paper Award (one of two papers chosen) at the Speech Coding Workshop, 2000, for the paper A. D. Subramaniam and B. D. Rao, "PDF Optimized Parametric Vector Quantization of Speech Line Spectral Frequencies."
12. Best student paper award at NIPS 2006 for D. Wipf for the paper "Analysis of Empirical Bayesian Methods for Neuroelectromagnetic Source Localization," by D.P.Wipf, R.R. Ramirez, J.A. Palmer, S. Makeig, and B.D. Rao in Advances in Neural Information Processing Systems, Dec. 2006 (<http://nips.cc/ConferenceInformation/PaperAwards>)
13. Student paper award for Jun Zheng at ICASSP 2006 for the paper "Capacity analysis of multiple antenna systems with mismatched channel quantization schemes," by J. Zheng and B. D. Rao, ICASSP, Toulouse, France, May 2006.
14. Best Student Paper Award for J. McCall and D, Wipf at the IEEE International Workshop on Machine Vision for Intelligent Vehicles (MVIV'05) held In conjunction with IEEE International Conference on Computer Vision and Pattern Recognition

(CVPR'05) at San Diego, CA, June 21, 2005 for the paper "Lane change intent analysis using robust operators and sparse Bayesian learning" by J. McCall, D. Wipf, M. Trivedi and B. D. Rao

15. Student paper award for Haichang Sui for the paper "RAKE Finger Placement for CDMA Downlink Equalization," by H. Sui, E. Masry and B. D. Rao at the 2005 IEEE International Conference on Acoustics, Speech, and Signal Processing, Philadelphia, PA, Mar. 19-23, 2005.
16. IBM Faculty Award, 2002
17. Member of the EURASIP Signal Processing editorial board
18. Member of the Machine Learning for Signal Processing Technical Committee (TC) of the IEEE Signal Processing Society (2012-present). Vice-Chair of TC during 2017-2018, Chair of TC during 2019-2020.
19. Member of the Signal Processing for Communications Technical committee of the IEEE Signal Processing Society (2005-2008).
20. Member of the Signal Processing Theory and Methods Technical committee of the IEEE Signal Processing Society (for six years).

Research Interests

- Areas of Interest
 - Signal Processing
 - Estimation Theory and Time Series Analysis
 - Optimization Theory
 - Machine Learning
- Application Areas
 - Wireless Communications
 - Speech Processing
 - Medical Imaging
 - Biomedical Signal Processing
- Current Research Topics
 - Sparse Signal Recovery and Compressed Sensing
 - Massive MIMO Wireless Communications
 - Hearing Aids
 - Microphone Arrays
 - Medical and Brain Imaging, e.g. SPECT, EEG, fMRI

Graduate Students

Prof. Rao has graduated 39 Ph.D students over his career to date and is currently supervising 7 Ph.D students. The current students in the group are engaged in the following research areas:

1. David Ho, Massive MIMO and low complexity architectures
2. Govind Gopal, Distributed Massive MIMO and Access Point Placement
3. Louis Pisha, (Joint with Prof. Shahrokh Yadegari) Speech Enhancement and Hearing Aids
4. Rohan Pote, MM-Wave Communications and Machine Learning
5. Aditya Sant, MM-Wave Communications and Machine Learning
6. Kuan-Lin Chen, Deep Learning: Theory and Architectures
7. Hitesh Khunti, Medical Imaging (SPECT) and Machine Learning

Active Research Grants

1. "Nested Hybrid Arrays And Bayesian Inference For Robust Communications," 2018-2021, \$950K, Co-PI with Prof. Pal
2. "Low Complexity Massive MIMO Systems: Synergistic use of Array Geometry, Modeling and Learning," NSF, 2021-2024, \$500K, PI with Co-PI Prof. Pal
3. "6G Wireless Communications via Enhanced Channel Modeling and Estimation, Channel Morphing and Machine Learning for mmWave Bands," NSF-Academy of Finland Grant, 2022-2025, \$600k, PI.
4. "Connected and Autonomous Vehicles," Center for Wireless Communications Project
5. Fellow-Mentor-Advisor program grant from Qualcomm, Machine Learning and Wireless Communications, \$75K

Research Record

Prof. Bhaskar D. Rao has a publication record of approximately 160 refereed journal publications, 4 book chapters and 320 refereed conference publications. Ten recent publications and some selected publications are listed below. The complete list of publications can be found at my google scholar profile <https://scholar.google.com/citations?user=dJRKST0AAAAJ&hl=en>

Ten Recent Publications

1. Kuan-Lin Chen, Harinath. Garudadri, and Bhaskar D. Rao, "ResNEsts and DenseNEsts: Block-based DNN Models with Improved Representation Guarantees," NeurIPS 2021
2. K. Pratik, B. D. Rao and M. Welling, "RE-MIMO: Recurrent and Permutation Equivariant Neural MIMO Detection," in IEEE Transactions on Signal Processing, vol. 69, pp. 459-473, 2021.
3. C. H. Lee, B. D. Rao and H. Garudadri, "Proportionate Adaptive Filtering Algorithms Derived Using an Iterative Reweighting Framework," in IEEE/ACM Transactions on Audio, Speech, and Language Processing, vol. 29, pp. 171-186, 2021.
4. C. H. Lee, I. Fedorov, B. D. Rao and H. Garudadri, "SSGD: Sparsity-Promoting Stochastic Gradient Descent Algorithm for Unbiased Dnn Pruning," ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 2020, pp. 5410-5414.
5. L. Pisha et al., "A Wearable, Extensible, Open-Source Platform for Hearing Healthcare Research," in IEEE Access, vol. 7, pp. 162083-162101, 2019.
6. Y. Han, B. D. Rao and J. Lee, "Massive Uncoordinated Access With Massive MIMO: A Dictionary Learning Approach," in IEEE Transactions on Wireless Communications, vol. 19, no. 2, pp. 1320-1332, Feb. 2020.
7. J. Liu and B. D. Rao, "Sparse Bayesian Learning for Robust PCA: Algorithms and Analyses," in IEEE Transactions on Signal Processing, vol. 67, no. 22, pp. 5837-5849, 15 Nov.15, 2019.
8. D. K. W. Ho and B. D. Rao, "Antithetic Dithered 1-Bit Massive MIMO Architecture: Efficient Channel Estimation via Parameter Expansion and PML," in IEEE Transactions on Signal Processing, vol. 67, no. 9, pp. 2291-2303, 1 May1, 2019.
9. Y. Ding and B. D. Rao, "Dictionary Learning-Based Sparse Channel Representation and Estimation for FDD Massive MIMO Systems," in IEEE Transactions on Wireless Communications, vol. 17, no. 8, pp. 5437-5451, Aug. 2018.
10. A. Nalci, I. Fedorov, M. Al-Shoukairi, T. T. Liu and B. D. Rao, "Rectified Gaussian Scale Mixtures and the Sparse Non-Negative Least Squares Problem," in IEEE Transactions on Signal Processing, vol. 66, no. 12, pp. 3124-3139, 15 June15, 2018.

Selected Publications

Compressed Sensing/Sparse Signal Recovery

1. R. Giri and B. D. Rao. "Type I and Type II Bayesian Methods for Sparse Signal Recovery Using Scale Mixtures." *IEEE Trans. Signal Processing* 64.13 (2016): 3418-3428.
2. Y. Jin and B. D. Rao, "Support Recovery of Sparse Signals in the Presence of Multiple Measurement Vectors" *IEEE Transactions on Information Theory*, Volume: 59 , Issue: 5, Page(s): 3139 - 3157, May 2013
3. Z. Zhang and B. D. Rao, "Sparse Signal Recovery with Temporally Correlated Source Vectors Using Sparse Bayesian Learning," *IEEE Journal of Selected Topics in Signal Processing*, Special Issue on Adaptive Sparse Representation of Data and Applications in Signal and Image Processing, vol.5, no. 5, pp. 912-926, Sept. 2011
4. D. P. Wipf, B. D. Rao and S. Nagarajan, "Latent Variable Bayesian Models for Promoting Sparsity," *IEEE Transactions on Information Theory*, pages, 6236-6255, Sept. 2011
5. S. F. Cotter, B. D. Rao, K. Engan, and K. Kreutz-Delgado, "Sparse Solutions to Linear Inverse Problems with Multiple Measurement Vectors," *IEEE Trans. on Signal Processing*, July 2005.
6. I. F. Gorodnitsky and B. D. Rao, Sparse Signal Reconstruction from Limited Data Using FOCUSS: A Re-Weighted Norm Minimization Algorithm, *IEEE Trans. On Signal Processing*, Mar-1997,

Wireless Communications

1. E. Nayebi, A. Ashikhmin, T. L. Marzetta, H. Yang and B. D. Rao, "Precoding and Power Optimization in Cell-Free Massive MIMO Systems," in *IEEE Transactions on Wireless Communications*, vol. 16, no. 7, pp. 4445-4459, July 2017, doi: 10.1109/TWC.2017.2698449
2. P. C. Nguyen, A. H. Nguyen, and B. D. Rao. "Delay Control for Temporally Fair Scheduling Policies via Opportunistic Mixing." *IEEE Transactions on Signal Processing* 64.19 (2016): 5011-5024.
3. Y. Huang and B. D. Rao, "Random Beamforming with Heterogeneous Users and Selective Feedback: Individual Sum Rate and Individual Scaling Laws ", *IEEE Transactions on Wireless Communications*, Volume 12, Issue 5, Pages 2080-2090, May 2013.
4. M. Pugh and B. D. Rao, "Reduced Feedback Schemes using Random Beamforming in MIMO Broadcast Channels," *IEEE Transactions on Signal Processing*, March 2010.
5. B. Song, R. L. Cruz and B. D. Rao, "Network Duality for Multiuser MIMO Beamforming Networks and Applications," in *IEEE Transactions on Communications*, vol. 55, no. 3, pp. 618-630, March 2007, doi: 10.1109/TCOMM.2006.888889.

6. J. C. Roh and B. D. Rao, "Transmit Beamforming in Multiple-Antenna Systems with Finite Rate Feedback: A VQ-Based Approach," *IEEE Trans. Information Theory*. vol. 52, no. 3, pp. 1101-1112, Mar. 2006.

Machine Learning

1. K-L Chen, C-H Lee, H. Garudadri, and B. D Rao, "ResNEsts and DenseNEsts: Block-based DNN Models with Improved Representation Guarantees," *Advances in neural information processing systems*, 12/6/2021, Vol 34, pages 3413-3424
2. K. Pratik, B. D. Rao and M. Welling, "RE-MIMO: Recurrent and Permutation Equivariant Neural MIMO Detection," in *IEEE Transactions on Signal Processing*, vol. 69, pp. 459-473, 2021, doi: 10.1109/TSP.2020.3045199.
3. C. -H. Lee, I. Fedorov, B. D. Rao and H. Garudadri, "SSGD: Sparsity-Promoting Stochastic Gradient Descent Algorithm for Unbiased Dnn Pruning," *ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2020, pp. 5410-5414, doi: 10.1109/ICASSP40776.2020.9054436.
4. Y. Han, B. D. Rao and J. Lee, "Massive Uncoordinated Access With Massive MIMO: A Dictionary Learning Approach," in *IEEE Transactions on Wireless Communications*, vol. 19, no. 2, pp. 1320-1332, Feb. 2020, doi: 10.1109/TWC.2019.2952843.
5. Y. Ding and B. D. Rao, "Dictionary Learning-Based Sparse Channel Representation and Estimation for FDD Massive MIMO Systems," in *IEEE Transactions on Wireless Communications*, vol. 17, no. 8, pp. 5437-5451, Aug. 2018, doi: 10.1109/TWC.2018.2843786.
6. R. Parisi, E. D. Di Claudio, G. Orlandi and B. D. Rao, "A generalized learning paradigm exploiting the structure of feedforward neural networks," in *IEEE Transactions on Neural Networks*, vol. 7, no. 6, pp. 1450-1460, Nov. 1996, doi: 10.1109/72.548172.

Speech and Audio-Visual Processing

1. N. Radmanesh, I. S. Burnett, and B. D. Rao. "A Lasso-LS optimization with a frequency variable dictionary in a multizone sound system." *IEEE/ACM Transactions on Audio, Speech and Language Processing (TASLP)* 24.3 (2016): 583-593.
2. A. Masnadi-Shirazi and Bhaskar D. Rao, "An ICA-SCT-PHD Filter Approach for Tracking and Separation of Unknown Time-Varying Number of Sources," *IEEE Transactions on Audio, Speech and Language Processing*, Volume: 21, Issue: 4, Page(s): 828 - 841, April 2013
3. W. Zhang and B.D. Rao, "A Two Microphone-Based Approach for Source Localization of Multiple Speech Sources," *IEEE Transactions on Audio, Speech and Language Processing*, Vol. 18, No. 8 (November 2010), pp. 1913-1928.
4. S. Shivappa, M. M. Trivedi, and B. D. Rao, "Audio-visual Information Fusion In Human Computer Interfaces and Intelligent Environments: A Survey," *Proceedings of the IEEE*, October 2010.

5. S. Dharanipragada, U. H. Yapanel, and B. D. Rao, "Robust Feature Extraction for Continuous Speech Recognition using the MVDR Spectrum Estimation Method", *IEEE Trans. on Speech, Audio and Language Processing*, pages 224-234, Jan. 2007.
6. A. D. Subramaniam, B. D. Rao, and W. R. Gardner, "Low-Complexity Source Coding using Gaussian Mixture Models, Lattice Vector Quantization and Recursive Coding with Application to Speech Spectrum Quantization," *IEEE Trans. on Speech and Audio Proc.*, 2006.

Statistical Signal Processing

1. B.D. Rao and K.V.S. Hari, "Weighted subspace methods and spatial smoothing: analysis and comparison," *IEEE Transactions on Signal Processing*, Vol. 41, No. 2 (February 1993), pp. 788-803.
2. B.D. Rao and K.S. Arun, "Model based processing of signals: a state space approach," *Proceedings of the IEEE*, Vol. 80, No. 2 (February 1992), pp. 283-309.
3. B.D. Rao and K.V.S. Hari, "Performance analysis of root-music," *IEEE Transactions on Acoustics, Speech, and Signal Processing (ASSP)*, Vol. 37, No. 12 (December 1989), pp. 1939-1949.
4. B.D. Rao and R. Peng, "Tracking characteristics of the constrained IIR adaptive notch filter," *IEEE Transactions on Acoustics, Speech, and Signal Processing (ASSP)*, Vol. 36, No. 9 (September 1988), pp. 1466-1479.
5. B. D. Rao, "Perturbation analysis of an SVD-based linear prediction method for estimating the frequencies of multiple sinusoids," in *IEEE Transactions on Acoustics, Speech, and Signal Processing*, vol. 36, no. 7, pp. 1026-1035, July 1988, doi: 10.1109/29.1626.
6. S.Y. Kung, K.S. Arun, R.J. Gal-Ezer, and B.D. Rao, "Wavefront array processor: language, architecture and applications," *IEEE Transactions on Computers*, Vol. 31, No. 11 (November 1982), pp. 1054-1066.

Teaching

Prof. Rao has been teaching graduate and undergraduate courses for the past 30 years. He has consistently received high student evaluations and is the recipient of the graduate teaching award in 1998 and 2021. A sampling of courses he has taught in recent years are as follows:

1. Digital Signal processing (ECE 161A)
2. Wavelets and Filter Banks (ECE 251C)
3. Statistical Signal Processing (ECE 251A)
4. Adaptive Signal processing (ECE 251B)
5. Array Signal processing (ECE 251D)
6. Estimation Theory (ECE 275A)
7. Sparse Signal Recovery and Compressed Sensing (ECE 285, Special topics)
8. Digital Communications (ECE 258A)
9. MIMO Wireless communications (ECE 285, special topics)

Prof. Rao in the past also taught courses in speech coding and recognition, probability theory and random processes, Kalman Filtering, and optimization theory.