References

[1] M. R. Bai, J. G. Ih, and J. Benesty, *Acoustic Array Systems:Theory, Implementation, and Application.* Wiley-IEEE Press, 2013.

[2] J. Capon, "High-resolution frequency-wavenumber spectrum analysis," *Proceedings of the IEEE*, vol. 57, no. 8, pp. 1408 – 1418, aug. 1969.

[3] R. O. Schmidt, "Multiple emitter location and signal parameter estimation," in *Proceedings of RADC Spectrum Estimation Workshop, Griffiss AFB, NY*, 1979, pp. 243–258.

[4] B. Yegnanarayana and Hema A. Murthy, "Significance of group delay functions in spectrum estimation," *IEEE Trans. on Signal Processing*, vol. 40, pp. 2281–2289, Sep. 1992.

[5] B. Yegnanarayana, "Formant extraction from linear-prediction phase spectra," *The Journal of the Acoustical Society of America*, vol. 63, no. 5, pp. 1638–1640, 1978.

[6] R. DuHamel, "Pattern synthesis for antenna arrays on circular, elliptical and spherical surfaces," *Radio Direction Finding Section Elect. Eng. Res. Lab. Rep., Univ. of Illinois, Urbana*, 1952.

[7] M. Hoffman, "Conventions for the analysis of spherical arrays," *Antennas and Propagation, IEEE Transactions on*, vol. 11, no. 4, pp. 390–393, 1963.

[8] A. K. Chan, A. Ishimaru *et al.*, "Equally spaced spherical array." DTIC Document, Tech. Rep., 1966.

[9] B. Preetham Kumar and G. R. Branner, "The far-field of a spherical array of point dipoles," *IEEE transactions on antennas and propagation*, vol. 42, no. 4, pp. 473–477, 1994.

[10] J. Meyer and G. Elko, "A highly scalable spherical microphone array based on an orthonormal decomposition of the soundfield," in *Acoustics, Speech, and Signal Processing (ICASSP), 2002 IEEE International Conference on*, vol. 2. IEEE, 2002, pp. II–1781.

[11] T. D. Abhayapala and D. B. Ward, "Theory and design of high order sound field microphones using spherical microphone array," in *Acoustics, Speech, and Signal Processing (ICASSP), 2002 IEEE International Conference on*, vol. 2. IEEE, 2002, pp. II–1949.

[12] Q. Huang and T. Wang, "Acoustic source localization in mixed field using spherical microphone arrays," *EURASIP Journal on Advances in Signal Processing*, vol. 2014, no. 1, pp. 1–16, June 2014.

[13] L. Kumar, K. Singhal, and R. M. Hegde, "Near-field source localization using spherical microphone array," in *Hands-free Speech Communication and Microphone Arrays (HSCMA), 2014 4th Joint Workshop on*, May 2014, pp. 82–86.

[14] ——, "Robust source localization and tracking using MUSIC-Group delay spectrum over spherical arrays," in *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2013 IEEE 5th International Workshop on, St. Martin, France*. IEEE, 2013, pp. 304–307.

[15] X. Li, S. Yan, X. Ma, and C. Hou, "Spherical harmonics MUSIC versus conventional MUSIC," *Applied Acoustics*, vol. 72, no. 9, pp. 646–652, 2011.

[16] D. Khaykin and B. Rafaely, "Acoustic analysis by spherical microphone array processing of room impulse responses," *The Journal of the Acoustical Society of America*, vol. 132, p. 261, 2012.

[17] H. Sun, H. Teutsch, E. Mabande, and W. Kellermann, "Robust localization of multiple sources in reverberant environments using EB-ESPRIT with spherical microphone ar-

rays," in *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on.* IEEE, 2011, pp. 117–120.

[18] K. Ichige, K. Saito, and H. Arai, "High resolution doa estimation using unwrapped phase information of music-based noise subspace," *IEICE Trans. Fundam. Electron. Commun. Comput. Sci.*, vol. E91-A, pp. 1990–1999, August 2008.

[19] M. Shukla and R. M. Hegde, "Significance of the music-group delay spectrum in speech acquisition from distant microphones," in *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on.* IEEE, 2010, pp. 2738–2741.

[20] A. Barabell, "Improving the resolution performance of eigenstructure-based direction-finding algorithms," in *Acoustics, Speech, and Signal Processing, IEEE International Conference on ICASSP'83.*, vol. 8. IEEE, 1983, pp. 336–339.

[21] R. Roy and T. Kailath, "ESPRIT-estimation of signal parameters via rotational invariance techniques," *Acoustics, Speech and Signal Processing, IEEE Transactions on*, vol. 37, no. 7, pp. 984–995, 1989.

[22] C. P. Mathews and M. D. Zoltowski, "Eigenstructure techniques for 2-d angle estimation with uniform circular arrays," *Signal Processing, IEEE Transactions on*, vol. 42, no. 9, pp. 2395–2407, 1994.

[23] R. A. Kennedy, T. D. Abhayapala, and D. B. Ward, "Broadband nearfield beamforming using a radial beampattern transformation," *Signal Processing, IEEE Transactions on*, vol. 46, no. 8, pp. 2147–2156, 1998.

[24] E. Fisher and B. Rafaely, "Near-field spherical microphone array processing with radial filtering," *Audio, Speech, and Language Processing, IEEE Transactions on*, vol. 19, no. 2, pp. 256–265, 2011.

[25] L. Kumar, A. Tripathy, and R. Hegde, "Robust multi-source localization over planar arrays using music-group delay spectrum," *Signal Processing, IEEE Transactions on*, vol. 62, no. 17, pp. 4627–4636, Sept 2014.

[26] L. Kumar and R. Hegde, "Stochastic cramér-rao bound analysis for doa estimation in spherical harmonics domain," *Signal Processing Letters, IEEE*, vol. 22, no. 8, pp. 1030–1034, Aug 2015.

[27] E. G. Williams, *Fourier acoustics: sound radiation and nearfield acoustical holography*. academic press, 1999.

[28] C. Coskun, "Robust adaptive beamforming," Ph.D. dissertation, Technical University of Denmark, DTU, DK-2800 Kgs. Lyngby, Denmark, 2008.

[29] L. E. Kinsler, A. R. Frey, A. B. Coppens, and J. V. Sanders, *Fundamentals of acoustics*. John Wiley & Sons, Inc., 1999.

[30] J. Nahas, "Simulation of array-based sound field synthesis methods," *Audio Communication Group,TU Berlin, Diploma thesis*, 2011. [Online]. Available: http://www2.ak.tu-berlin.de/~akgroup/ak_pub/abschlussarbeiten/2011/NahasJohnny_DiplA.pdf

[31] R. P. Feynman, R. B. Leighton, and M. Sands, *The Feynman Lectures on Physics, Desktop Edition Volume I*. Basic Books, 2013, vol. 1.

[32] P. T. D. Abhayapala, "Modal analysis and synthesis of broadband nearfield beamforming arrays," Ph.D. dissertation, The Australian National University, Telecommunications Engineering Group, http://hdl.handle.net/1885/46049, 2000.

[33] J. McDonough, K. Kumatani, T. Arakawa, K. Yamamoto, and B. Raj, "Speaker tracking with spherical microphone arrays," in *Acoustics, Speech and Signal Processing (ICASSP), 2013 IEEE International Conference on*. IEEE, 2013, pp. 3981–3985.

[34] D. Colton and R. Kress, *Inverse acoustic and electromagnetic scattering theory*. Springer Science & Business Media, 2012, vol. 93.

[35] B. Rafaely, "Plane wave decomposition of the sound field on a sphereby spherical convolution," Institute of Sound and Vibration Research, University of Southampton, Tech. Rep., May 2003. [Online]. Available: http://eprints.soton.ac.uk/46555/1/Pub9273.pdf?origin=publication_detail

[36] M. C. Chan, "Theory and design of higher order sound field recording," *Department of Engineering, FEIT, ANU, Honours Thesis*, 2003. [Online]. Available: http://users.cecs.anu.edu.au/~thush/ugstudents/MCTChanThesis.pdf

[37] C. A. Balanis, *Antenna theory: analysis and design.* John Wiley & Sons, 2012.

[38] E. Fisher and B. Rafaely, "The nearfield spherical microphone array," in *Acoustics, Speech and Signal Processing, 2008. ICASSP 2008. IEEE International Conference on*, 2008, pp. 5272–5275.

[39] *The Eigenmike Microphone Array*, http://www.mhacoustics.com/.

[40] J. H. Reed, *Software radio: a modern approach to radio engineering.* Prentice Hall Professional, 2002.

[41] E. F. Deprettere, *SVD and signal processing: algorithms, applications and architectures.* North-Holland Publishing Co., 1989.

[42] A. A. Gareta, "A multi-microphone approach to speech processing in a smart-room environment," Ph.D. dissertation, Universitat Politecnica de Catalunya, 2007.

[43] A. Manikas, *Differential geometry in array processing.* World Scientific, 2004, vol. 57.

[44] J. Benesty, J. Chen, and Y. Huang, *Microphone array signal processing.* Springer Science & Business Media, 2008, vol. 1.

[45] E. C. Ifeachor and B. W. Jervis, *Digital signal processing: a practical approach.* Pearson Education, 2002.

[46] I. McCowan, "Microphone arrays: A tutorial," *Queensland University, Australia*, pp. 1–38, 2001.

[47] C. P. Mathews and M. D. Zoltowski, "Signal subspace techniques for source localization with circular sensor arrays," [Technical Reports], 1994, http://docs.lib.purdue.edu/ecetr/.

[48] H. L. Van Trees, *Optimum Array Processing.* Wiley-Interscience, 2002.

[49] B. Rafaely, B. Weiss, and E. Bachmat, "Spatial aliasing in spherical microphone arrays," *Signal Processing, IEEE Transactions on*, vol. 55, no. 3, pp. 1003–1010, 2007.

[50] I. Cohen and J. Benesty, *Speech processing in modern communication: challenges and perspectives.* Springer, 2010, vol. 3.

[51] P. A. Naylor and N. D. Gaubitch, *Speech dereverberation.* Springer Science & Business Media, 2010.

[52] P. Zahorik, in *Direct-to-reverberant energy ratio sensitivity*, vol. 112. Acoustical Society Of America, November, 2002, pp. 2110–2117.

[53] C. Knapp and G. Carter, "The generalized correlation method for estimation of time delay," *Acoustics, Speech and Signal Processing, IEEE Transactions on*, vol. 24, no. 4, pp. 320–327, 1976.

[54] P. R. Roth, "Effective measurements using digital signal analysis," *Spectrum, IEEE*, vol. 8, no. 4, pp. 62–70, 1971.

[55] P. Stoica and R. L. Moses, *Spectral analysis of signals.* Pearson/Prentice Hall Upper Saddle River, NJ, 2005.

[56] W. Herbordt and W. Kellermann, "Adaptive beamforming for audio signal acquisition," in *Adaptive Signal Processing.* Springer, 2003, pp. 155–194.

[57] R. Kumaresan and D. W. Tufts, "Estimating the angles of arrival of multiple plane waves," *Aerospace and Electronic Systems, IEEE Transactions on*, no. 1, pp. 134–139, 1983.

[58] J. Chen, K. Yao, and R. Hudson, "Source localization and beamforming," *Signal Processing Magazine, IEEE*, vol. 19, no. 2, pp. 30–39, 2002.

[59] L. Kumar, R. Mandala, and R. M. Hegde, "Music-group delay based methods for robust doa estimation using shrinkage estimators," in *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th.* IEEE, 2012, pp. 281–284.

[60] M. J. Daniels and R. E. Kass, "Shrinkage estimators for covariance matrices,," *Biometrics*, vol. 57, no. 4, pp. 1173–1184, 2001.

[61] J. P. Hoffbeck and D. A. Landgrebe, "Covariance matrix estimation and classification with limited training data,," *IEEE Transactions on Pattern Analysis and Machine Intelligence,,* vol. E91–A, no. 8, 2008.

[62] R. Mandala, M. Shukla, and R. Hegde, "Group delay based methods for recognition of distant talking speech," in *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, Nov 2010, pp. 1702–1706.

[63] M. Zatman, "How narrow is narrowband?" *IEE Proceedings-Radar, Sonar and Navigation*, vol. 145, no. 2, pp. 85–91, 1998.

[64] S. Chandran, *Advances in Direction-of-arrival Estimation.* Artech House, 2005.

[65] D. Ying and Y. Yan, "Robust and fast localization of single speech source using a planar array," *Signal Processing Letters, IEEE*, vol. 20, no. 9, pp. 909–912, 2013.

[66] F. Wang, X. Cui, M. Lu, and Z. Feng, "Decoupled 2D direction-of-arrival estimation based on sparse signal reconstruction," *EURASIP Journal on Advances in Signal Processing*, vol. 2015, no. 1, pp. 1–16, 2015.

[67] A. Griffin, D. Pavlidi, M. Puigt, and A. Mouchtaris, "Real-time multiple speaker doa estimation in a circular microphone array based on matching pursuit," in *Signal Processing Conference (EUSIPCO), 2012 Proceedings of the 20th European.* IEEE, 2012, pp. 2303–2307.

[68] T. Filik and T. E. Tuncer, "Design and evaluation of V-shaped arrays for 2-D DOA estimation," in *Acoustics, Speech and Signal Processing, 2008. ICASSP 2008. IEEE International Conference on.* IEEE, 2008, pp. 2477–2480.

[69] R. Mandala, M. Shukla, and R. Hegde, "Group delay based methods for recognition of distant talking speech," in *Signals, Systems and Computers (ASILOMAR), 2010*

Conference Record of the Forty Fourth Asilomar Conference on, Nov 2010, pp. 1702–1706.

[70] J.B. Allen and A. Berkley, "Image method for efficiently simulating small-room acoustics," *Journal of the Acoustical Society of America*, vol. 65, pp. 943–950, 1979.

[71] E. A. Habets, "Room impulse response generator," [Online], 2003-2010, http://home.tiscali.nl/ehabets/rir_generator.html.

[72] K. Wong and M. Zoltowski, "Root-music-based azimuth-elevation angle-of-arrival estimation with uniformly spaced but arbitrarily oriented velocity hydrophones," *Signal Processing, IEEE Transactions on*, vol. 47, no. 12, pp. 3250 –3260, Dec. 1999.

[73] H. Y., "Techniques of eigenvalues estimation and association," *Digital Signal Processing*, vol. 7, pp. 253–259(7), October 1997.

[74] V. Cevher and J. H. McClellan, "2-d sensor perturbation analysis: equivalence to awgn on array outputs," in *SAM 2002*, Washington, DC, 4–6 August 2002.

[75] P. Stoica and N. Arye, "MUSIC, maximum likelihood, and Cramer-Rao bound," *Acoustics, Speech and Signal Processing, IEEE Transactions on*, vol. 37, no. 5, pp. 720–741, 1989.

[76] P. Stoica and A. Nehorai, "Comparative performance study of element-space and beam-space music estimators," *Circuits, Systems and Signal Processing*, vol. 10, no. 3, pp. 285–292, 1991.

[77] S. Markovich, S. Gannot, and I. Cohen, "Multichannel eigenspace beamforming in a reverberant noisy environment with multiple interfering speech signals," *Audio, Speech, and Language Processing, IEEE Transactions on*, vol. 17, no. 6, pp. 1071–1086, 2009.

[78] A. Varga and H. J. Steeneken, "Assessment for automatic speech recognition: Ii. noisex-92: A database and an experiment to study the effect of additive noise on speech recognition systems," *Speech Communication*, vol. 12, no. 3, pp. 247 – 251, 1993.

[79] John S. Garofolo, *TIMIT Acoustic-Phonetic Continuous Speech Corpus.* Philadelphia: Linguistic Data Consortium, 1993.

[80] J. Hansen and B. Pellom, "An effective quality evaluation protocol for speech enhancement algorithms," in *Proc. ICSLP*, vol. 7, 1998, pp. 2819–2822.

[81] D. Klatt, "Prediction of perceived phonetic distance from critical-band spectra: A first step," in *Acoustics, Speech, and Signal Processing, IEEE International Conference on ICASSP'82.*, vol. 7. IEEE, 1982, pp. 1278–1281.

[82] *"Perceptual evaluation of speech quality (PESQ): An objective method for end-to-end speech quality assessment of narrow-band telephone networks and speech codecs,"* ITU-T Draft Recommendation P.862, 2001.

[83] M. Seltzer, "Bridging the gap: Towards a unified framework for hands-free speech recognition using microphone arrays," in *Hands-Free Speech Communication and Microphone Arrays, 2008. HSCMA 2008*, May 2008, pp. 104 –107.

[84] W. Zhang and B. Rao, "Robust broadband beamformer with diagonally loaded constraint matrix and its application to speech recognition," in *Proc. IEEE Int. Conf. Acoust., Speech, Signal Processing.* , 2006, pp. 785–788.

[85] CSLU, "Multi channel overlapping numbers corpus distribution," Linguistic Data Consortium, http://www.cslu.ogi.edu/corpora/corpCurrent.html.

[86] R. Goossens and H. Rogier, "Closed-form 2D angle estimation with a spherical array via spherical phase mode excitation and ESPRIT," in *Acoustics, Speech and Signal Processing, 2008. ICASSP 2008. IEEE International Conference on.* IEEE, 2008, pp. 2321–2324.

[87] D. N. Zotkin, R. Duraiswami, and N. A. Gumerov, "Sound field decomposition using spherical microphone arrays," in *Acoustics, Speech and Signal Processing, 2008. ICASSP 2008. IEEE International Conference on.* IEEE, 2008, pp. 277–280.

[88] B. Rafaely, "Analysis and design of spherical microphone arrays," *Speech and Audio Processing, IEEE Transactions on*, vol. 13, no. 1, pp. 135–143, 2005.

[89] J. R. Driscoll and D. M. Healy, "Computing Fourier transforms and convolutions on the 2-sphere," *Advances in applied mathematics*, vol. 15, no. 2, pp. 202–250, 1994.

[90] B. Rafaely, "Phase-mode versus delay-and-sum spherical microphone array processing," *Signal Processing Letters, IEEE*, vol. 12, no. 10, pp. 713–716, 2005.

[91] G. Arfken and H. J. Weber, *Mathematical Methods For Physicists.* 5th ed. San Diego : Academic press, 2001.

[92] Z. Li and R. Duraiswami, "Flexible and optimal design of spherical microphone arrays for beamforming," *Audio, Speech, and Language Processing, IEEE Transactions on*, vol. 15, no. 2, pp. 702–714, 2007.

[93] B. Rafaely, Y. Peled, M. Agmon, D. Khaykin, and E. Fisher, "Spherical microphone array beamforming," in *Speech Processing in Modern Communication.* Springer, 2010, pp. 281–305.

[94] P. Stoica, E. G. Larsson, and A. B. Gershman, "The stochastic CRB for array processing: a textbook derivation," *Signal Processing Letters, IEEE*, vol. 8, no. 5, pp. 148–150, 2001.

[95] H. Gazzah and S. Marcos, "Cramer-Rao bounds for antenna array design," *Signal Processing, IEEE Transactions on*, vol. 54, no. 1, pp. 336–345, 2006.

[96] A. Weiss and B. Friedlander, "Range and bearing estimation using polynomial rooting," *Oceanic Engineering, IEEE Journal of*, vol. 18, no. 2, pp. 130–137, 1993.

[97] J.-P. Delmas and H. Gazzah, "CRB analysis of near-field source localization using uniform circular arrays," in *Acoustics, Speech and Signal Processing (ICASSP), 2013 IEEE International Conference on.* IEEE, 2013, pp. 3996–4000.

[98] D. T. Vu, A. Renaux, R. Boyer, and S. Marcos, "A Cramér Rao bounds based analysis of 3D antenna array geometries made from ULA branches," *Multidimensional Systems and Signal Processing*, vol. 24, no. 1, pp. 121–155, 2013.

[99] D. Tse and P. Viswanath, *Fundamentals of wireless communication.* Cambridge university press, 2005.

[100] S. M. Kay, "Fundamentals of statistical signal processing, volume i: Estimation theory (v. 1)," 1993.

[101] H.-C. Song and B.-w. Yoon, "Direction finding of wideband sources in sparse arrays," in *Sensor Array and Multichannel Signal Processing Workshop Proceedings, 2002.* IEEE, 2002, pp. 518–522.

[102] D. P. Jarrett, E. A. Habets, M. R. Thomas, and P. A. Naylor, "Simulating room impulse responses for spherical microphone arrays," in *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on.* IEEE, 2011, pp. 129–132.

[103] R. Goossens, H. Rogier, and S. Werbrouck, "Uca root-music with sparse uniform circular arrays," *Signal Processing, IEEE Transactions on*, vol. 56, no. 8, pp. 4095–4099, 2008.

[104] F. Belloni, A. Richter, and V. Koivunen, "Extension of root-music to non-ula array configurations," in *Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proceedings. 2006 IEEE International Conference on*, vol. 4. IEEE, 2006, pp. IV–IV.

[105] M. Costa, A. Richter, and V. Koivunen, "Unified array manifold decomposition based on spherical harmonics and 2-d fourier basis," *Signal Processing, IEEE Transactions on*, vol. 58, no. 9, pp. 4634–4645, 2010.

[106] E. Gonen and J. M. Mendel, "Subspace-based direction finding methods," *Madisetti, VK and Williams DB, editor, The Digital Signal Processing Handbook, chapter*, vol. 62, 1999.

[107] J. Meyer and G. W. Elko, "Position independent close-talking microphone," *Signal processing*, vol. 86, no. 6, pp. 1254–1259, 2006.

[108] M. Abramowitz and I. A. Stegun, *Handbook of mathematical functions: with formulas, graphs, and mathematical tables.* Courier Dover Publications, 2012.