

VIJAYAKUMAR BHAGAVATULA
(B.V.K. Vijaya Kumar)

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Electrical and Computer Engineering
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EDUCATION

- Ph.D. (Electrical Engineering) from Carnegie Mellon University, February 1980.
- M.Tech. (Electrical Engineering) from Indian Institute of Technology, Kanpur, India, June 1977.
- B.Tech. (Electrical Engineering) from Indian Institute of Technology, Kanpur, India, May 1975.

EMPLOYMENT

- Acting Head of the Department, Electrical and Computer Engineering (ECE) Department, CMU, July 2004-February 2005.
- Professor of ECE, CMU since September 1991.
- Associate Department Head of ECE, CMU from July 1994 to June 1996.
- Associate Professor of ECE, CMU from September 1987 to August 1991.
- Assistant Professor of ECE, CMU from September 1982 to August 1987.
- Research Associate in ECE, CMU from March 1980 to August 1982.

TECHNICAL CONSULTING

- Lockheed Missiles and Space Company, Palo Alto, CA.
- General Dynamics, Pomona, CA.
- Unicorn Systems Inc., Pittsburgh, PA.
- Westinghouse Electric Corp., Pittsburgh, PA.
- Two-Six Inc., Saxonburg, PA.
- Carnegie Mellon Research Institute, Pittsburgh, PA.
- Teledyne Brown Engineering, Huntsville, AL.
- Dynetics Inc., Huntsville, AL.
- US Army Missile Command Laboratories, Huntsville, AL.
- Rosemount Analytical, Inc., Pittsburgh, PA.
- Martin Marietta Company, Orlando, FL.
- Hughes Missile Systems Company, Tucson AZ.
- Southwest Intelligent Systems Inc., Tucson, AZ.
- Hughes Research Laboratories, Malibu, CA.
- Mytec Technologies Inc., Toronto, Canada
- Raytheon Systems Company, Tucson, AZ.
- ADC Communications, Pittsburgh, PA.
- Litton TASC Institute, VA.
- Maxoptix Corp., Fremont, CA
- Northrop Grumman, Pittsburgh, PA.
- Lockheed Martin, Orlando, FL.
- Lucent Technologies, NJ.
- Mine Safety Appliances, Pittsburgh, PA.
- Media Balance, East Lansing, Michigan.

- Pukoa Scientific, Hawaii.
- Utopia Compression, CA.

LEGAL CONSULTING

- Morgan, Lewis and Bockius, Washington, DC.
- Baker and McKenzie, San Francisco, CA.
- Finnegan, Henderson, Farabow, Garrett and Dunner, Washington, DC.
- McAndrews, Held & Malloy, Chicago, Illinois.
- Weil, Gotshal & Manges, Redwood Shores, CA.

TEACHING

Carnegie Mellon Courses

- Mathematical Foundations of Electrical Engineering
- Signals and Systems
- Digital Communications
- Applied Stochastic Processes
- Digital Signal Processing
- Advanced Digital Signal Processing
- Pattern Recognition Theory
- Error Control Coding
- Detection and Estimation Theory
- Linear IC Applications
- Special Topics in Signal processing: Biometrics

Short Courses

- Algorithms for Biometric Recognition (Intl. Conf. on Image Processing, Singapore; SPIE Defense & Security Symposium)
- Statistical Pattern Recognition (SPIE Aerosense Symposium)
- Advanced Correlation Filters (SPIE Aerosense Symposium)
- Partial response Maximum Likelihood (PRML) methods for Optical Data Storage (Optical Data Storage conference)
- MATLAB for Signal Processing (TASC Institute)
- Coding for Data Storage (StorageTek Inc.)
- Low Density Parity Check (LDPC) Codes (Data Storage Institute, Singapore)
- Correlation Filters for Biometric Recognition (Indian National Academy of Engineer's Workshop on Image and Speech processing, IIT/Madras, Chennai, India)
- Frequency-domain methods for biometric recognition (ICASSP 2007)

INVITED TALKS

1. "Performance of synthetic discriminant functions for distortion-invariant pattern recognition," **Jet Propulsion Laboratories**, Pasadena, California, March 1987.
2. "Optimal detection of digital information on particulate magnetic recording media," **Hewlett-Packard Laboratories**, Palo Alto, California, March 1987.
3. "Detection of digital signals on particulate media in non-stationary noise," **Control Data**, Minneapolis, Minnesota, May 1987.
4. "Optical correlators for pattern recognition," **IEEE ASSP Society and IEEE Controls Society Chapter meeting**, Pittsburgh, Pennsylvania, October 1987.
5. "Associative Memory from Neural Networks," Joint Seminar, **Department of Electrical Engineering and Division of Imaging Science**, Yale University, New Haven, Connecticut, November 1987.

6. "Input-output characterization of laterally inhibited networks," **Electrical and Computer Engineering**, University of Missouri, Columbia, Missouri, February 1988.
7. "Optical Pattern Recognition," **Defense Research and Development Laboratories**, Hyderabad, India, June 1988.
8. "Image Reconstruction from Partial Fourier Information," **Center for Fluorescence Research**, Carnegie Mellon University, Pittsburgh, Pennsylvania, October 1988.
9. "Noise Modeling in Magnetic Recording," **Magnetics Technology Center**, Carnegie Mellon University, Pittsburgh, Pennsylvania, November 1988.
10. "Input-Output characteristics of a class of Laterally Inhibited Neural Networks," **Jet Propulsion Laboratories**, Pasadena, California, January 1989.
11. "Input-output characterization of a class of laterally inhibited neural networks," **US West Advanced Technologies**, Englewood, Colorado, February 1989.
12. "Phase-only and binary phase-only filters for optical pattern recognition," **NSF Center for Opto-Electric Computing Systems**, University of Colorado, Boulder, Colorado, February 1989.
13. "Optical Data Processing Research at CMU," **ECE Graduate Seminar**, Carnegie Mellon University, Pittsburgh, Pennsylvania, September 1989.
14. "Partial-Information Correlator Systems," **Litton Data Systems**, Van Nuys, California, January 1990.
15. "Design of phase-only and binary phase-only correlation filters," **Rockwell International Sciences Center**, Los Angeles, California, July 1990.
16. "Binary phase-only filter design," **Litton Data Systems**, Van Nuys, California, July 1990.
17. "Partial-information correlation filter design," **Sandia National Laboratories**, Albuquerque, New Mexico, July 1990.
18. "Three-level composite filters for optical pattern recognition," **Litton Data Systems**, Van Nuys, California, March 1991.
19. "Advances in correlation filter design," **U.S. Army Night Vision Laboratories**, April 1991.
20. "Trade-off in the design of correlation filters," **SPIE Critical Reviews**, San Jose, California, November 1991.
21. "Filter design for optical correlators," **Martin-Marietta Company**, Orlando, Florida, April 1992.
22. "Design of Filters for Optical Correlators," **Sandia National Laboratories**, Albuquerque, New Mexico, January 1993.
23. "Application of Differential Learning to Pattern Recognition," **Indian Institute of Technology**, Madras, India, June 1993.
24. "Efficient statistical pattern recognition through differential learning," **Indian Statistical Institute**, Calcutta, India, July 1993.
25. "Applications of Signal Processing in Data Storage Systems," **KODAK**, Rochester, New York, September 1993.

26. "Differential learning approaches," **Hughes Missile Systems Company**, Canoga Park, California, March 1994.
27. "Neural networks for Pattern Recognition," **NASA Johnson Space Center**, Houston, Texas, May 1994.
28. "Correlation filters for Automatic Target Recognition," **Westinghouse Science & Technology Center**, Pittsburgh, PA, September 1994.
29. "Correlation Filters for Pattern Recognition," **Hughes Research Labs**, Malibu, California, October 1994.
30. "Equalization for Holographic Data Storage," **University of Arizona**, Tucson, AZ, January 1996.
31. "Correlation Filters for Automatic Target Recognition," **Northrop Grumman Norden Systems**, Norwalk, CT, July 1996.
32. "Coding for Data Storage," **Storage Technologies Inc.**, Boulder, CO, December 1996.
33. "Coding for High-density Data Storage," Computational Sciences Center, **University of Kentucky**, Lexington, KY, March 1997.
34. "Advanced correlation filters for pattern recognition," **Indian Statistical Institute**, New Delhi, India, May 1997.
35. "Run-length limited Codes for high-density data storage," **Hughes Missile Systems Company**, Tucson, AZ, October 1997.
36. "Partial response methods for high density data storage," **Raytheon Missile Systems Company**, Tucson, AZ, March 1998.
37. "Equalization methods for optical data storage," **Calimetrics Inc.**, Oakland, CA, June 1998.
38. "Equalization methods for optical data storage," **Quantum Electronics**, Shrewesbury, MA, July 24, 1998.
39. "Advanced optical correlation methods," **Raytheon Missile Systems Company**, Tucson, AZ, August 1998.
40. "Coding and Signal processing for high-density data storage systems," **Indiana University of Pennsylvania**, Indiana, PA, September 1998.
41. "Equalization for holographic data storage," **International Workshop for Holographic Data Storage**, Nice, France, March 1999.
42. "Clutter rejection methods for automatic target recognition," **Northrop Grumman Science and Technology Center**, Pittsburgh, PA, October 1999.
43. "Optical data storage research at DSSC," **Optical Data Storage Center, University of Arizona**, Tucson, AZ, October 1999.
44. "Signal Processing for Optical Data Storage," **NSIC Optical Data Storage Road Map Workshop**, Los Gatos, CA, November 1999.
45. "Timing recovery for data storage," **Seagate**, Minneapolis, MN, December 14, 1999.

46. "Turbo codes for data storage," **IEEE Magnetics Society Seminar**, Minneapolis, MN, December 14, 1999.
47. "Characterization and equalization of tape dropouts," **Imation**, Minneapolis, MN, December 15, 1999.
48. "Turbo coding for optical data storage," **Infineon Technologies**, Santa Cruz, CA, May 5, 2000.
49. "Turbo codes for data storage," **Quantum Inc.**, Milpitas, CA, May 5, 2000.
50. "Eigen and non-linear for improved clutter rejection in correlation-based automatic target recognition," **Northrop Grumman Science and Technology Center**, Pittsburgh, PA, September 29, 2000.
51. "Coding and Signal Processing for Data Storage," **Lucent Technologies**, Allentown, PA October 13, 2000.
52. "Correlation Filters: State of the Art," **Raytheon Systems Company**, Tucson, AZ, March 2001.
53. "Low Density Parity Check (LDPC) Codes for Data Storage," **Samsung Information Systems of America**, San Jose, CA, March 2001.
54. "Advanced correlation filters for Automatic Target Recognition," **Lockheed Martin**, Orlando, FL, April 2001.
55. "Coding and Signal Processing for Optical Data Storage," **Philips Laboratories**, Eindhoven, Netherlands, June 2001.
56. "Role of Coding and Signal Processing for Digital Data Preservation," **NIST**, Gaithersburg, MD, August 2001.
57. "Biometric verification algorithms," **Lockheed Martin**, Orlando, Florida, March 2002.
58. "Coding and Signal Processing Research at Data Storage Systems Center," **Data Storage Institute**, Singapore, December 2002.
59. "Advanced timing recovery methods for low-SNR data storage channels," Coding and Signal Processing Group, **Data Storage Institute**, Singapore, December 2002.
60. "Correlation filter methods for face verification," ECE Dept., **Natl. Univ. of Singapore**, Singapore, December 2002.
61. "Biometric verification using correlation filters," Computer Science Department, **IIT/Madras**, Madras, India, December 2002.
62. "Biometric recognition using correlation filters," Cal-IT2 seminar, **University of California at San Diego**, CA, October 2003.
63. "Biometrics for Security," **IEEE Erie Section New Members Dinner Meeting**, Erie, PA, November 2003.
64. "Correlation Pattern Recognition," Dowd Fellowship Seminar, **Carnegie Institute of Technology**, CMU, Pittsburgh, PA, December 2003.
65. "Biometrics for Human Identification," **Indian National Academy of Sciences (INSA) Chennai Chapter**, Chennai, India, January 9, 2004.

66. "Correlation filters for biometric authentication," **Siemens Corporate Research Center**, Princeton, NJ, March 19, 2004.
67. "Biometrics research at Carnegie Mellon's CyLab," **West Virginia University**, Morgantown, WV, September 29, 2004.
68. "Biometrics Research at Carnegie Mellon's Cylab," **IEEE Communications Society Queensland Chapter**, Brisbane, Australia, December 7, 2004.
69. "Biometric Authentication using Correlation Filters," **Michigan State University**, February 8, 2005.
70. "DSSC Coding and Signal Processing Research," **Broadcom**, Longmont, Colorado, July 28, 2005.
71. "Frequency-domain Biometric Authentication," **North Carolina State University**, Raleigh, NC, August 30, 2005.
72. "Correlation Filters for Face Recognition," **Face Recognition Advanced Study Workshop**, Morgantown, WV, November 2005.
73. "DSSC Channels research," **LSI Logic**, Fort Collins, CO, December 2005.
74. "Frequency-domain approach to Image Biometric Authentication," Invited talk, **IAPR International Conference on Biometrics (ICB)**, Hong Kong, January 5, 2006.
75. "Introduction to Correlation Filters for Biometric Recognition," **IIT**, Hyderabad, January 12, 2006.
76. "Iris verification," **IIT/Madras**, Chennai, India, February 27, 2006.
77. "Spatial-frequency domain methods for face recognition and iris recognition," **Booz Allen Hamilton**, McLean, VA, May 2, 2006.
78. "Spatial-frequency domain techniques for face recognition grand challenge (FRGC)," **CyLab**, Carnegie Mellon university, Pittsburgh, June 5, 2006.
79. "FPGA-based evaluation of LDPC codes," **Sabanci University**, Istanbul, Turkey, September 14, 2006.
80. "Correlation filters for ATR & Biometrics," **General Dynamics Robotic Systems**, Pittsburgh, September 25, 2006.
81. "Image biometric verification in spatial frequency domain," **Royal Melbourne Institute of Technology (RMIT) University**, Melbourne, Australia, October 6, 2006.
82. "Coding and signal processing for holographic data storage," **Data Storage Institute (DSI)**, Singapore, June 20, 2007.
83. "Biometric recognition in spatial frequency domain," **University of Gottingen**, Germany, September 8, 2007.
84. "Spatial frequency domain biometric recognition," **Air Force Institute of Technology**, Dayton, Ohio, November 9, 2007.
85. "Image biometric recognition via spatial frequency domain," Keynote speech, **3rd Indian International Conference on Artificial Intelligence**, Pune, India, December 17, 2007.
86. "Iris verification," Invited talk, **Workshop on Image and Signal Processing**, Guwahati, India, December 28, 2007.

87. "Face recognition," Invited talk, **Workshop on Image and Signal Processing**, Guwahati, India, December 29, 2007.
88. "Signal processing approaches for face and iris recognition," **Syracuse University**, Syracuse, NY, February 13, 2008.
89. "Coding and signal processing for bit-patterned media," **LSI**, Milpitas, CA, December 12, 2008.
90. "Super-resolution for face recognition, **CyLab**, Carnegie Mellon University, February 16, 2009.
91. "Error control coding for data storage," **Jet Propulsion Labs**, Pasadena, CA, May 4, 2009.

STUDENT/Post-Doc SUPERVISION

Visiting Faculty

- Prof. Fei Su, Beijing Univ. of Posts & Telecommunications, China (Feb. 2008-Jan. 2009)

Post-Docs

- Dr. Hyungshin Kim, Ph.D. from KAIST, Korea (May 2003-Feb. 2004)
- Dr. Zongwang Li (January 2004-October 2005)

Industry Visitors

- Toshihiro Horigome, Sony, Japan (July 2002-February 2004)

Ph.D. Students

1. Christopher Carroll, "Application of Optical Signal Processing to Adaptive Phased Array Radar," May 1987.
2. Bruce Montgomery, "On decoding algorithms for linear binary block codes," July 1987.
3. Zouhir Bahri, "Phase-only and binary phase-only filters in optical correlators," September 1989.
4. Michael Lemmon, "Parameter Estimation using competitively inhibited neural networks," April 1990.
5. Laurence Hassebrook, "Linear phase filters and filter banks for distortion-invariant optical pattern recognition," July 1990.
6. James Connelly, "Two-dimensional correlation using one-dimensional acousto-optic devices," October 1990.
7. Ashraf Ali Kassim, "A neural network architecture for generating potential fields," March 1993.
8. Charles Hendrix, "Two-level and three-level filter design for distortion-invariant pattern recognition," August 1993.
9. John Hampshire, "A differential theory of learning for efficient statistical pattern recognition," September 1993.
10. Inci Ozgunes, "Modeling Magneto-Optic Read Channels," December 1995.
11. Khaled Al-Ghoneim, "Learning ranks for pattern recognition," April 1996.
12. Srinivasan Gopalswamy, "Multi-channel signal processing for high track density optical recording systems," May 1996.

13. Daniel Carlson, "Optimal tradeoff composite filters," August 1996.
14. Greg Silvas, "Detection of ultra-high-density magnetic tape signals in the presence of nonlinearities," September 1996.
15. Usha Pillai, "Readback signal simulation and development of data detection techniques for a scanner-based multi-channel optical tape system," January 1999.
16. Venkatesh Vadde, "2-Dimensional equalization, detection and coding for volume holographic data storage," August 1999.
17. Mohamed Alkanhal, "Eigen and nonlinear correlation filters for automatic target recognition," September 2000.
18. Yifei Yuan, "Timing recovery for data storage," December 2000.
19. Mehmet Keskinöz, "Two-dimensional equalization and detection for quadratic storage channels," July 2001.
20. Fatih Sarigoz, "Characterization and mitigation of dropouts in magnetic tape recording: A read channel perspective," September 2001. (co-advisor: Dr. James Bain)
21. Hongwei Song, "Iterative soft detection/decoding for data storage channels," December 2002.
22. Jingfeng Liu, "Timing recovery for low-SNR data storage channels," April 2003.
23. Marios Savvides, "Reduced-Complexity Face Recognition using Advanced Correlation Filters and Fourier subspace Methods for Biometric Applications," April 2004 (co-advisor: Prof. Pradeep Khosla).
24. Xiaoming Liu, "Pose-robust video-based face recognition," October 2004 (co-advisor: Prof. Tsuhan Chen).
25. Lingyan Sun, "Implementation and evaluation of iterative soft detection/decoding using field programmable gate array," August 2005 (Recipient of the Milnes Award for the best Ph.D. thesis in ECE Department, CMU, 2005-2006).
26. Jin Xie, "Timing recovery for data storage using Kalman filters," July 2006.
27. Chunyan Xie, "Class-dependence feature analysis for large population face recognition," August 2006.
28. Krithika Venkataramani, "Optimal classifier ensembles for improved biometric verification," January 2007.
29. Jason Thornton, "Iris pattern matching: a probabilistic model based on discriminative cues," April 2007, Recipient of the Milnes Award for the best Ph.D. thesis in ECE Department, CMU, 2006-2007 (co-advisor: Dr. Marios Savvides).
30. Ryan Kerekes, "Combining correlation outputs for enhanced distortion-tolerant target recognition," May 2007.
31. Lakshmi Ramamoorthy, "Advanced coding and signal processing for holographic data storage," February 2008.
32. Xinde Hu, "Low density parity check (LDPC) codes for magnetic recording systems," March 2008.
33. Pablo Hennings, "Simultaneous Super-resolution and recognition," October 2008.

34. Sheida Nabavi, "Signal processing for bit-patterned media channels with inter-track interference," December 2008.
35. Soowoong Lee, "Soft-Decision decoding of Reed-Solomon codes using pattern information over partial response channels," September 2009.
36. Seungjune Jeon
37. Euseok Hwang (co-advisor: Prof. Rohit Negi, ECE, CMU)
38. Vishnu Naresh Boddeti
39. Kathy Brigham
40. Yibin Ng (co-advisor: Dr. Cai Kui, DSI, Singapore)
41. Andres Rodriguez
42. Qi Wu (co-advisor: Prof. Tsuhan Chen, ECE, Cornell)
43. Can Ye (co-advisor: Prof. Miguel Coimbra, Univ. of Porto, Portugal)

Master's Students

1. Christopher Carroll, October 1983.
2. Craig Rahenkamp, July 1985.
3. Keith DeVos, October 1985.
4. Zouhir Bahri, October 1986.
5. Venugopal Veeravalli, October 1986.
6. Michael Lemmon, December 1987.
7. James Connelly, February 1988.
8. Dean Hering, December 1989 (joint advisor: Prof. P. Khosla)
9. Phillip Wong, May 1990.
10. Wei Shi, August 1990.
11. Charles Hendrix, December 1990.
12. Greg Silvus, November 1991.
13. Daniel Carlson, May 1992.
14. Chu-Lung Chen, August 1993.
15. Hooman Yaghoobi, May 1994.
16. Aida Ibrahim, September 1995.
17. Fatih Sarigoz, May 1996.
18. Magdalena Wong, August 1996.
19. Glen Clark, May 1997.
20. Mehmet Keskinöz, December 1997.

21. Reese Bovard, December 1999.
22. Siriluck Tipmongkonsilp, May 2000.
23. Rajan Singh, May 2002.
24. Krithika Venkataramani, December 2002.
25. Shilpi Sahu, December 2002.
26. Jason Thornton, December 2003.
27. Mike Beattie, December 2004.
28. Sheida Nabavi, May 2005.
29. Ryan Kerekes, May 2005.
30. Euseok Hwang, May 2008.
31. Naresh Boddeti, May 2009.
32. Se-Hwan Jung, May 2009.

MAJOR RESEARCH CONTRIBUTIONS

Correlation Filters

- Developed the concept of **composite correlation filters**, designed to handle the lack of tolerance of matched filters to common image distortions such as rotations and scale changes.
- Introduced the use of constrained optimization methods in the design of **minimum variance synthetic discriminant function (MVSDF) filters** that have maximum tolerance to input noise
- With Abhijit Mahalanobis and Dave Casasent, developed the **minimum average correlation energy (MACE) filters** designed to produce sharp correlation peaks and achieve very good discrimination; this ground-breaking work was the first to approach correlation filter design in the spatial frequency domain, leading to a computationally-friendly, closed form filter solution.
- With graduate students and colleagues, introduced several other advanced composite correlation filter designs including **unconstrained filters** (to improve their generalization capability), **distance classifier correlation filters** (to make use of the entire correlation output rather than just the peak value), **polynomial correlation filters** (to increase the versatility of correlation filters by allowing point nonlinearities of input images), **optimal trade-off circular harmonic function filters** (to achieve desired filter response to in-plane rotations) and **Mellin radial harmonic (MRH) filters** (to achieve desired filter response to in-plane scale changes).
- Developed algorithms to design optimal correlation filters that can be implemented on optical processors that use **limited-modulation devices** in the filter plane; this work resulted in several advances to **phase-only, binary phase-only, complex ternary and cross-coupled correlation filters**.
- With colleagues from industry and government labs, demonstrated the application of correlation filters for several **automatic target recognition** tasks based on images collected using optical, synthetic aperture radar, infrared and LADAR sensors.
- Developed the **statistical modeling** to quantify the relationships between the number of training images used and the resulting performance from correlation filters.
- Developed **correlation filter performance metrics** such as signal-to-noise ratio (SNR), peak-to-correlation energy (PCE) and light throughput efficiency.
- Extended the correlation filters to **multi-frame, multi-view and multi-filter processing**. This offers us the ability to extract maximum detection information in situations involving video sequences, multiple cameras and multiple correlation filters.

Biometrics (much of this, jointly with Marios Savvides)

- Developed and demonstrated **correlation filters for biometric recognition**; introduced the face recognition research community to the advantages of using frequency domain methods; developed a **correlation-filter based face verification demo** to illustrate the approach.
- Developed **reduced-complexity correlation filters**, suitable for implementation on limited-capability platforms.
- Developed **Eigenphase** method, an improvement over the Eigenface method introduced for face recognition; Eigenphases is built on the understanding that phase is more important than the magnitude in the Fourier transform of face images.
- Combined the best features of the correlation filters and Eigenfaces methods to introduce a new shift-invariant approach called **CoreFaces** for face recognition.
- With colleagues from Mytec (now BioScript), developed a method for **encryption using biometric signatures** such as fingerprint.
- Demonstrated the use of correlation filters for other biometric modalities such as **palmprint** recognition.
- Developed **cancelable biometrics**, which allow us to reuse the same biometric signature (e.g., same face image) even when the smart card with the template is lost or stolen.
- Developed **face authentication from cell phone camera images** containing illumination and pose variations.
- Developed a new approach called **class-dependence feature analysis (CFA)** that extends the correlation filter approach to take advantage of the availability of generic training sets; using CFA, **achieved excellent performance in the face recognition grand challenge (FRGC)**.
- Developed a new **probabilistic framework for correlation filters** to take into account spatially-varying deformations in iris imagery; using this new approach, achieved **outstanding verification results in the iris challenge evaluation (ICE)**.

Low-Density Parity Check (LDPC) Codes

- Developed **structured LDPC codes** of potential use in magnetic recording systems; structured LDPC codes have parity check matrices with nonzero elements in well-defined locations, making their implementation easier than LDPC codes with random parity check matrices.
- Showed that use of LDPC codes can lead to **increased storage density** (for a given target bit error rate) using real signals from magnetic tape recording test stand.
- Developed a **field programmable gate array (FPGA) platform** for the evaluation of channels employing generalized structured LDPC codes; using this platform, demonstrated bit error rates down to 10^{-12} .
- Developed methods to **combine the run-length constraints with LDPC codes**; run-length constraints are needed in magnetic and optical data storage systems to reduce inter-symbol interference and improve timing recovery.
- **Extended the FPGA LDPC code evaluation platform to longitudinal and perpendicular magnetic recording channels with realistic impairments** such as transition noise, nonlinear transition shift, partial erasure and transition percolation.

Timing Recovery for Data Storage

- Introduced a new timing recovery method (called the **Dual-segmented Kalman Filter-based Timing Recovery or DSKSTR**), that reduces the loss of lock (also called cycle slip, leading to mis-indexing of detected bits which lead to the entire sectors failing) rate at low signal-to-noise ratios by almost three orders of magnitude in magnetic recording simulations.
- Introduced new acquisition (i.e., the early stage of timing recovery, based on a known preamble pattern) methods, called extended digital zero-phase start (**EDZPS**) and digital zero frequency/phase start (**DZF/PS**) to cope with low SNRs and higher timing disturbances in future high-density magnetic recording systems.
- Developed **Kalman filter-based timing recovery methods to deal with low SNR**; showed that these approaches can handle large frequency offset in zero-phase start, provide optimal loop gains as a function of loop delay and improved loss of lock rates in the presence of dropouts.

Equalization/Detection for Data storage

- Developed **channel models** and analyzed equalization/detection methods for magneto-optic recording systems exhibiting **transition noise**.
- Developed **nonlinear channel identification** methods for magnetic tape recording systems exhibiting nonlinear effects such as nonlinear transition shift, partial erasure, etc.
- Developed and analyzed **multi-track equalization/detection** methods for data storage systems reading multiple adjacent tracks in parallel.
- Developed **channel models for page-oriented holographic data storage** systems exhibiting complicated noise sources (electronic noise as well as complex light field noise) as well as nonlinearity induced by intensity detection by the output camera.
- Developed novel **2-D equalization and detection** methods suitable for page-oriented holographic data storage.
- Developed a **model for dropouts** in magnetic tape recording systems and proposed a **dropout-compensation** method.
- Developing **coding and signal processing methods for bit-patterned media**.

Artificial Neural Networks

- Developed the mathematical models for **competitively inhibited neural networks**.
- Developed a planar neural network architecture called **wave expansion neural network**, useful for problems involving shortest path selection.
- Showed that the conventional artificial neural network training methods based on minimum squared error are suboptimal for pattern recognition applications and proposed a new metric called the **Classification Figure of Merit (CFM)**, better suited for pattern recognition.
- Extended the CFM metric to **ranking figure of merit**, to accommodate the case where individual classifiers provide relative rankings of the input pattern into multiple classes.

Others

- Developed and evaluated **optical processing architectures to generate ambiguity functions of sonar signals**
- Developed and analyzed methods to **process signals using their Wigner distributions**; Wigner distribution is one example of a joint time-frequency representation of signals
- Investigated methods to implement **adaptive radar array computations using optical processors**.
- Developed improved methods for **minimum distance decoding** of error correcting codes.
- Developed an **acousto-optic correlator** for achieving 2-D correlations using 1-D processors.
- Developed channel models and equalization/detection methods for an **optical tape recording system employing a sinusoidal scanner**, where the relationship between space on the tape and time in the readback is sinusoidal and hence nonlinear.
- Developed **image processing and pattern recognition methods for disk forensics**.
- Showed that composite correlation filters can be used to achieve **rotation-tolerant watermark detection**.

BOOKS

1. B.V.K. Vijaya Kumar, A. Mahalanobis and Richard Juday, **Correlation Pattern Recognition**, Cambridge University Press, United Kingdom, November 2005.
2. B.V.K. Vijaya Kumar and H. Kobori, editors, **Proc. of Optical Data Storage 2004**, SPIE, October 2004.
3. V. Bhagavatula, V. Govindaraju, editors, **Proc. of the Fourth IEEE Workshop on Automatic Identification Advanced Technologies**, Buffalo, NY, October 17-18, 2005.
4. B.V.K. Vijaya Kumar, S. Prabhakar and A. Ross, editors, **Proc. of Biometric Technology for Human Identification V**, vol. 6944, SPIE, March 2008.

BOOK CHAPTERS

1. D. Casasent and B.V.K. Vijaya Kumar, "Optical linear algebra processors," Chapter 6.1, *Optical Signal Processing* (edited by J.L. Horner), Academic Press, 389-407, 1987.
2. M. Lemmon and B.V.K. Vijaya Kumar, "Competitively Inhibited Neural Networks: Analysis and Applications," Chapter 3 in *Neural Networks: Concepts, Applications and Implementations, Vol. III*, 48-83, Prentice-Hall, 1991.
3. B.V.K. Vijaya Kumar and P. Wong, "Optical Associative Memories," Chapter in *Artificial Neural Networks and Statistical Pattern Recognition: Old and New Connections*, 219-241, North-Holland, 1991.
4. B.V.K. Vijaya Kumar, "Optical Pattern Recognition," Chapter in *Optical Signal Processing*, 39-88, Academic Press, 1994.
5. A. Kassim and B.V.K. Vijaya Kumar, "Artificial potential fields and neural networks," Chapter in *The Handbook of Brain Theory and Neural Networks*, edited by Michael Arbib, 749-753, Bradford Books, 1995.
6. C. Soutar, D. Roberge, A. Stoianov, R. Gilroy and B.V.K. Vijaya Kumar, "Biometric EncryptionTM," Chapter 22 in *ICSA Guide to Cryptography*, edited by Randall K. Nicholls, 649-675, 1999.
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OTHER PUBLICATIONS

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2. B.V.K. Vijaya Kumar, Foreword to the book, *Competitively Inhibited Neural Networks for Adaptive Parameter Estimation* by M. Lemmon, Kluwer Academic Publishers, 1991.
3. B.V.K. Vijaya Kumar, *Electrical and Computer Engineering at Carnegie Mellon - a New Curriculum*, contributor, Dept. of ECE, Carnegie Mellon University, 1995.
4. D. Casasent, B.V.K. Vijaya Kumar, J. Moura and R. Stern, "Signal Processing," part of the book *Our Vision: Frontiers in Electrical and Computer Engineering*, edited by Robert M. White, Dept. of Electrical and Computer Engineering, Carnegie Mellon university, Pittsburgh, 1997.
5. B.V.K. Vijaya Kumar, "Channels and ECC", Section 7 of the Executive Report of the *NSIC International Workshop on Holographic Data Storage*, Nice, France, March 8-11, 1999.
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8. B.V.K. Vijaya Kumar, "Coding and signal processing for optical storage," section in *INSIC Optical Storage Road Map*, February 2003 (member of the team).
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PATENTS

- C. Soutar, D. Roberge, A. Stoianov, R. Gilroy and B.V.K. Vijaya Kumar, "Method for secure key management using a biometric," US patent # 6219794.
- A. Mahalanobis and B.V.K. Vijaya Kumar, "Polynomial filters for higher order correlation and multi-input information fusion," US patent # 6295373.
- H. Song, J. Liu and B.V.K. Vijaya Kumar, "Encoding method using a low density parity check code with a column weight of two," US patent # 7058873.
- J. Liu, H. Song and B.V.K. Vijaya Kumar, "Timing recovery system and method," US patent # 7239682.
- V. Bhagavatula and M. Savvides, "Reduced complexity correlation filters," US patent # 7483569.

MEDIA COVERAGE

- "Riconoscere un naso da pochi pixel un software ricrea i volti nascosti," *La Repubblica*, September 19, 2008 (http://www.repubblica.it/2008/09/sezioni/scienza_e_tecnologia/software-volti-nascosti/software-volti-nascosti/software-volti-nascosti.html)
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- "Private eyes are watching you," *ABCNews.com* article, May 19, 2008 (<http://abcnews.go.com/Technology/GadgetGuide/Story?id=4872498&page=1>)
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- "Tech lets you pay with your finger," *Discovery channel news article*, August 16, 2007 (http://dsc.discovery.com/news/2007/08/16/fingerpay_tec.html?category=technology&guid=20070816101500)
- "Dotting the eyes on terror," *RMIT Openline*, the online magazine of RMIT University, Melbourne, Australia, October 02, 2006 (<http://www.rmit.edu.au/browse;ID=t5rql1xgdeby>)
- "Correlation pattern recognition for biometrics," *SPIE Newsroom* article, June 2006 (<http://newsroom.spie.org/x3165.xml?highlight=x535>)
- "Airport security becomes high-tech," *Beaver County Times* (PA), February 21, 2006 (<http://www.tmcnet.com/usubmit/2006/02/21/1390479.htm>)
- Our biometrics research was featured in *Currents*, ECE Department's news magazine.
- Our face verification demo was one of the demonstration items at the OSA Annual meeting (in Tucson) and was featured on local TV in Tucson, Arizona (October 2003).
- January 2004 newsletter of the International Association of Pattern Recognition (IAPR) devoted two pages (including the cover page) to discuss our correlation filters research.
- Our face recognition demo was featured on local TV in Pittsburgh (October 2002) during the C3S (predecessor to CyLab) inauguration events.
- Our biometrics work was featured in the May 2003 *Pittsburgher* monthly magazine.

HONORS AND AWARDS

- Recipient, Government of India Merit Scholarship (1970-75).
- Fellow, Optical Society of America (1993).
- Fellow, SPIE, the International Society of Optical Engineering (1991).

- Fellow, IAPR, the International Association of Pattern Recognition (2006)
- Listed in *Who's Who Among Asian Americans*.
- Listed in Marquis *Who's Who in Optical Sciences and Engineering*.
- Listed in *American Men and Women of Science*.
- Listed in Marquis *Who's Who in Sciences and Engineering*.
- Listed in Marquis *Who's Who in Education*.
- Listed in Marquis *Who's Who in Finance and Business*
- Listed in Marquis *Who's Who in America*
- Listed in Marquis *Who's Who in the World*.
- Recipient of Carnegie Institute of Technology's Philip Dowd Fellowship (2003)
- Recipient of Eta Kappa Nu award for Outstanding Faculty in the Electrical and Computer Engineering (ECE) Department at CMU, May 2003.
- Co-author of the 2008 Best Student paper in Data Storage area, Data Storage Technical Committee of IEEE Communications Society.
- Co-recipient of 2008 Carnegie Institute of Technology (Engineering College at CMU) Outstanding Faculty Research Award.

PROFESSIONAL SOCIETY ACTIVITIES

- Member, Sigma Xi
- Senior Member, IEEE
- Fellow, Optical Society of America (OSA)
- Fellow, Society of Photo-optical Instrumentation Engineers (SPIE)
- Fellow, Intl. Assoc. of Pattern Recognition (IAPR)
- President, Pittsburgh section of OSA (1982)
- Chairman, 1988 Max Born award committee for OSA
- Vice President, Pittsburgh Chapter of Sigma Xi (1992-93)
- Vice Chair, IEEE Signal Processing for Storage Technical Committee, IEEE Communications Society (1998-2000)
- Chair, IEEE Signal Processing for Storage Technical Committee, IEEE Communications Society (2000-2002)
- Member, IEEE Biometrics Council (2008-)
- Member, IEEE Technical Committee on Information Forensics and Security (IFS) (2008-)

PROFESSIONAL CONFERENCE ACTIVITIES

- Program Committee for the SPIE Conference on Optical Information Processing, San Diego (1990 - 1994).
- Program Committee for the 1990 IEEE International Conference on Systems Engineering, Pittsburgh.
- Program Committee for the 1991 SPIE Conference on Emerging Optoelectronic Technologies in Bangalore, India.
- Poster Chairman, The Magnetic Recording Conference (TMRC), Hidden Valley, Pennsylvania, June 1991.
- Program Committees of the SPIE Conference on Optical Pattern Recognition in Orlando, Florida (1992-).
- Program Committee, Florida Artificial Intelligence Research Symposium (FLAIRS), Orlando, (1997-2000).
- International Program Committee, IASTED International Conference on Neural Networks (NN'2000), Pittsburgh, PA, May 2000.
- Co-organizer (with Dr. Mike Melas of IBM Almaden Research Center), Workshop on Data Storage in the Third Millennium, International Communications Conference, New Orleans, LA, June 2000.
- Program Committee, Optical Data Storage conference (2001-)
- Member, Technical Program Committee, International Symposium on Optical memories (ISOM) (2001-2005).

- Co-chair, Technical Program Committee, Optical Data Storage (ODS) conference, Vancouver, BC, Canada, May 2003.
- Program Committee, Globecom (2004-2007).
- General co-chair, Optical Data Storage (ODS) Conference, Monterey, CA, April 2004.
- Program Committee, Biometric Authentication Workshop, Prague, May 2004.
- Program Committee, International Communications Conference (ICC), (2005, 2006).
- Co-General chair, Advisory Committee, Optical Data Storage (ODS) conference, Hawaii, July 2005.
- Program Committee, Audio, Video-based Person Authentication (AVBPA) conference, New York, July 2005.
- Program Committee, SPIE Conference on Biometric Technology for Human Identification (2005-)
- Co-General chair, 4th IEEE workshop on Automatic Identification Advanced Technologies, Buffalo, October 2005.
- Program Committee, International Association of Pattern Recognition International Conference on Biometrics (IAPR ICB), Hong Kong, January 2006.
- Program committee, International Conference on Pattern Recognition (ICPR), Hong Kong, August 2006.
- Program Committee, CVPR Biometrics Workshop, New York City, June 2006.
- Chair, *Biometrics* special session, Intl. Workshop on Multimedia Content Representation, Classification and Security (MRCS 2006), Istanbul, Turkey, September 2006.
- Program Committee, 5th IEEE workshop on Automatic Identification Advanced Technologies, Italy, June 2007.
- Program Committee, Intl. Conf. on Image Analysis and Recognition (ICIAR) (2005-2007)
- Program Committee, Biometrics Consortium Conference (2006-08)
- Program Committee, Intl. Conf. on Computer Vision (ICCV), 2007.
- Co-chair, SPIE Conference on Biometric Technology for Human Identification (2008, 2009, 2010)
- Program Committee, Face & Gesture conference, 2008.
- Reviewer, CVPR (2008, 2009, 2010).
- Advisory Committee, Intl. Conference on Biometrics, Italy (2009)
- Program Committee, First IEEE Workshop on Information Forensics and Security, London, December 2009
- Co-chair, Biometrics track, International Conference on Pattern Recognition (ICPR), Istanbul, 2010.

PROFESSIONAL JOURNAL ACTIVITIES

- Reviewer for many journals (including *Applied Optics*, *Optics Letters*, *Optical Engineering*, *Optics Communications*, *JOSA-A*, *IEEE Trans. on Magnetics*, *IEEE Trans. on Signal Processing*, *IEEE Trans. on Vehicular Technology*, *IEEE Trans. on Sys. Man and Cybernetics*, *IEEE Trans. on Image Processing* and *IEEE Trans. on Pattern Analysis, Machine Intelligence*)
- Topical Editor for Pattern Recognition, *Applied Optics* (1990-1996)
- Member, Editorial panel of *Asia-Pacific Engineering Journal* (1991-93)
- Guest Editor, September 1990 Special Issue of *Optical Engineering* on Optical Pattern Recognition
- Co-Guest Editor, April 2001 special issue of the *IEEE Journal of Special Areas of Communications (JSAC)* on *Signal Processing for High-Density Storage Channels*.
- Editorial Board member, *IEEE Surveys and Tutorials in communications* (2001-2007)
- Co-Guest Editor, *IEEE Signal Processing Magazine* special issue on soft algorithms for communications, January 2004.
- Associate Editor, *IEEE Transactions on Information Forensics and Security* (2005-)
- Co-Guest Editor, special issue of *IEEE Trans. Information Forensics and Security* devoted to *Human Detection and Recognition* (September 2007)

OTHER COMMITTEE ACTIVITIES

- Member, Wipe the Slate Clean Committee, ECE Department, CMU: This committee developed the current ECE undergraduate curriculum at CMU.
- Chairman, ECE Head Search Committee (1992)

- Member, ECE Head Search Committee (1998)
- Member, Tri-Service Automatic Target Recognition Technology Assessment Plan (ATRTP) for Conventional Weapon Committee (1995)
- Member, Enrollment Process Reengineering Committee, CMU (1995)
- Member, Continuing Education Committee, Carnegie Institute of Technology, CMU (1994-95)
- Member, CIT Faculty Awards Committee: this committee developed the current CIT Faculty Awards process.
- Faculty Senate, Carnegie Mellon University (2000-2002)
- Chairman, Graduate Studies Committee, ECE Dept., CMU (2003-2004)
- Member, Undergraduate Studies Committee, ECE Dept., CMU (2005-2006)
- Member, Undergraduate Advising Committee (2008-2009)
- Member, NSF Electrical Engineering Panel for Graduate Research Fellowship Program (2008, 2009)
- Panel member, Jack Kent Cooke Foundation Fellowship Program (2008)

VOLUNTEER ACTIVITIES

- Member of the Executive Committee, S.V. Temple, Pittsburgh, PA (1990-92)
- President, Executive Committee, S.V. Temple, Pittsburgh, PA (1991-92)
- Member of the Board of Directors, S.V. Temple, Pittsburgh, PA (1992-94)
- Secretary, Board of Directors, S.V. Temple, Pittsburgh, PA (1993-94).
- Executive Committee, Pittsburgh Area Telugu Association (1999-2002).