

Final Report for Period: 10/1997 - 09/2002**Submitted on:** 12/06/2002**Principal Investigator:** Zhou, G. Tong .**Award ID:** 9703312**Organization:** GA Tech Res Corp - GIT**Title:****CAREER:** A Research, Education, and Technology Transfer Proposal in Statistical Signal Processing with Emphasis on Nonlinear System Identification**Project Participants****Senior Personnel****Name:** Zhou, G. Tong**Worked for more than 160 Hours:** Yes**Contribution to Project:****Post-doc****Graduate Student****Name:** Kim, Yongsu**Worked for more than 160 Hours:** Yes**Contribution to Project:**

GRA, conducted research and wrote papers.

Name: Yang, Lei**Worked for more than 160 Hours:** Yes**Contribution to Project:**

GRA, performed research.

Name: Nagarajan, Krishnamurthy**Worked for more than 160 Hours:** Yes**Contribution to Project:**

GRA, conducted research and wrote papers.

Name: Redfern, Arthur**Worked for more than 160 Hours:** No**Contribution to Project:**

Completed a PhD dissertation on nonlinear communication channel equalization. Contributed to this project but was supported mainly by another fellowship.

Name: Craven, Stephen**Worked for more than 160 Hours:** No**Contribution to Project:**

Learned statistical signal processing theory, spectral regrowth in (nonlinear) power amplifiers and predistortion methods.

Name: Chen, Ning**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** Qian, Hua**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Undergraduate Student

Name: Lo, Hong-Jing

Worked for more than 160 Hours: Yes

Contribution to Project:

Part-time undergraduate assistant. Implemented Java applets. Co-authored an educational research paper.

Name: Rosen, Gail

Worked for more than 160 Hours: No

Contribution to Project:

Learned statistical signal processing theory, spectral regrowth in (nonlinear) power amplifiers and predistortion methods.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

University of California-San Diego

Prof. William Schafer in the Biology Department at UCSD collaborated with the PI. We visited each other's laboratories and co-authored three journal papers and one conference paper.

Chalmers University of Technology

During January - July 2001, the PI was Swedish Research Council for Engineering Sciences Guest Professor at the Chalmers University of Technology in Sweden. Collaborative research was initiated during that period and is on-going.

Other Collaborators or Contacts

Prof. Ronald Schafer at Georgia Tech.

Prof. Georgios B. Giannakis at the University of Minnesota.

Prof. Mats Viberg at the Chalmers University of Technology.

Prof. Tomas McKelvey at the Chalmers University of Technology.

Activities and Findings

Research and Education Activities:

1. Volterra nonlinear channel equalization (single or multiple user, time-invariant or time-varying)
2. Analysis of spectral regrowth of nonlinear power amplifiers
3. Predistortion linearization of power amplifiers for communications applications
4. Harmonic retrieval in the presence of nonstationary noise
5. Polynomial phase signal modeling of nonstationary processes
6. Network traffic analysis and resource allocation
7. Biological point process modeling
8. Communications channel estimation and equalization

Findings:

1. Developed methods to compensate for severely nonlinear systems.
2. Proposed a formula for predicting spectral regrowth of nonlinear power amplifiers, helpful for verifying transmission signal spectrum compliance.
3. Developed an algorithm to estimate the frequency of a harmonic embedded in nonstationary noise.
4. Developed an iterative procedure to estimate the parameters of

- a multi-component polynomial phase signal.
- 5. Constructed a fractional ARIMA model to account for long and short memories present in the variable bit rate (VBR) video streams.
- 6. Developed a new algorithm to efficiently allocate network resources (bandwidth and buffer size) to different type of sources.
- 7. Implemented an algorithm that tracks and subsequently equalizes time-selective fading channels.
- 8. Devised a point process model to interpret neuro-biological data.
- 9. Developed a 'hidden pilot' method for communications channel estimation.

These findings are reported in journal and conference papers (see the publications section).

Training and Development:

Students learned how to search the literature for relevant papers, devise new algorithms, write conference and journal papers, and give group and conference presentations. Four PhD students have graduated; one of them (Arthur Redfern) won a Georgia Tech research award.

Outreach Activities:

- 1. Developed a Java-based virtual laboratory on 'Random Signals'. These Java applets are included in the NEEDS (National Engineering Education Delivery System) and the World Lecture Hall databases. They are being translated into the Bahasa Malaysian language and used in a 'Cognitive Sciences and Human Development' research project at the Universiti Malaysia Sarawak, Kota Samarahan, Sarawak, Malaysia and the University of Otago, New Zealand.
- 2. Supervised research of female undergraduate students (Gail Rosen, Thao Tran).
- 3. Gave an eminent speaker seminar 'Applying Signal Processing Tools to the Study of Simple Animal Behavior' at the Department of Electrical Engineering, State University of New York at Buffalo, April 1999.

Journal Publications

L.E. Waggoner, G.T. Zhou, R.W. Schafer, and W.R. Schafer, "Control of alternative behavioral states by serotonin in *Caenorhabditis elegans*", *Neuron*, p. 203-214, vol. 21, (1998). Published

G.T. Zhou, W.R. Schafer, and R.W. Schafer, "A three-state biological point process model and its parameter estimation", *IEEE Trans. on Signal Processing*, p. 2698-2707, vol. 46, (1998). Published

A.J. Redfern and G.T. Zhou, "A root method for Volterra system equalization", *IEEE Signal Processing Letters*, p. 285-288, vol. 5, (1998). Published

M.Z. Ikram and G.T. Zhou, "Estimation of multicomponent polynomial phase signals of mixed orders", *Signal Processing*, p. 2293-2308, vol. 81, (2001). Published

A.J. Redfern and G.T. Zhou, "Blind zero forcing equalization of multichannel nonlinear CDMA systems", *IEEE Trans. on Signal Processing*, p. 2363-2371, vol. 49, (2001). Published

G.T. Zhou, "Analysis of spectral regrowth of weakly nonlinear power amplifiers", *IEEE Communications Letters*, p. 357-359, vol. 4, (2000). Published

A.J. Redfern and G.T. Zhou, "Multichannel and block based precoding methods for fixed point equalization of nonlinear communication channels", *Signal Processing*, p. 1041-1052, vol. 81, (2001). Published

F. Gini, G.B. Giannakis, M. Greco, and G.T. Zhou, "Time-averaged subspace methods for radar clutter texture retrieval", *IEEE Trans. on Signal Processing*, p. 1886-98, vol. 49, (2001). Published

G.T. Zhou and J.S. Kenney, "Predicting spectral regrowth of nonlinear power amplifiers", IEEE Trans. on Communications, p. 718-722, vol. 50, (2002). Published

G.T. Zhou, M. Viberg and T. McKelvey, "A first-order statistical method for channel estimation", IEEE Signal Processing Letters, p. , vol. , (2003). Accepted

L. Ding and G. T. Zhou, "Effects of Even-order Nonlinear Terms on Power Amplifier Modeling and Predistortion Linearization", IEEE Trans. on Vehicular Technology, p. , vol. , (). Submitted

Books or Other One-time Publications

G.B. Giannakis and G.T. Zhou, "Statistical Signal Processing: Higher-Order Tools", (1999). Book, Published
Editor(s): John Webster

Collection: Encyclopedia of Electrical and Electronics Engineering, John Wiley & Sons
Bibliography: vol. 20, pp. 492-509

G.T. Zhou and A. Vassiliou, "A hybrid second- and higher-order statistical method for blind deconvolution of seismic data", (1998). Conference Proceedings, Published
Collection: Proc. 4th IEEE International Conference on Signal Processing, Beijing, China
Bibliography: pp. 164-167

G.T. Zhou and Y. Kim, "Harmonic Retrieval in Nonstationary Noise", (1999). Conference Proceedings, Published
Collection: Proc. Intl. Conference on Acoustics, Speech, and Signal Processing, Phoenix, AZ

Bibliography: pp. 1585-1588

G.T. Zhou and H.J. Lo, "Developing Java-Based Virtual Laboratory Tools for an Undergraduate Random Signals and Noise Course", (1999). Conference Proceedings, Published
Collection: Proc. American Society for Engineering Education Annual Conference, Charlotte, NC
Bibliography: Session 3232, pp. 1-8.

K. Nagarajan and G.T. Zhou, "Modeling the Short and Long Memories of VBR Video Streams", (1999). Conference Proceedings, Published
Collection: Proc. Workshop on Heavy Tailed Distributions, Washington, DC
Bibliography: CDROM

A.J. Redfern and G.T. Zhou, "Blind equalization of CDMA systems with nonlinear channels", (1999). Conference Proceedings, Published
Collection: Proc. 33rd Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA
Bibliography: pp. 986-990

A.J. Redfern and G.T. Zhou, "Zero forcing equalization of multiuser time-varying nonlinear systems", (1999). Conference Proceedings, Published
Collection: Proc. 33rd Asilomar Conference on Signals, Systems, and Computers, Pacific Grove
Bibliography: pp. 529-533

G.T. Zhou, Y. Kim, and G.B. Giannakis, "Estimation and equalization of time-selective channels", (1999). Conference Proceedings, Published
Collection: Proc. 33rd Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA
Bibliography: pp. 248-251

K. Nagarajan and G.T. Zhou, "A new resource allocation scheme for Gaussian traffic sources", (2000). Conference Proceedings, Published
Collection: Proc. Intl. Conference on Acoustics, Speech, and Signal Processing, Istanbul, Turkey,
Bibliography: pp. 2609-2612

K. Nagarajan and G.T. Zhou, "A new resource allocation scheme for MPEG video sources", (2000). Conference Proceedings, Published
Collection: Proc. 34th Asilomar Conference on Signals, Systems, and Computers
Bibliography: pp. 842-846

R. Raich and G.T. Zhou, "Analyzing spectral regrowth of QPSK and OQPSK signals", (2001). Conference Proceedings, Published
Collection: Proc. Intl. Conference on Acoustics, Speech, and Signal Processing
Bibliography: pp. 2673-2676

W. Woo, L. Ding, G.T. Zhou, and J.S. Kenney, "An RF/DSP testbed for baseband pre-distortion of RF power amplifiers", (2001). Conference Proceedings, Published
Collection: Proc. 57th Automatic RF Techniques Group Conference
Bibliography: pp. 54-70

J.S. Kenney, W. Woo, L. Ding, R. Raich, and G.T. Zhou, "The impact of memory effects on predistortion linearization of RF power amplifiers", (2001). Conference Proceedings, Published
Collection: Proc. 8th Intl. Symposium on Microwave and Optical Technology
Bibliography: pp. 189-193

K. Nagarajan and G.T. Zhou, "Self-similar traffic sources: modeling and real-time resource allocation", (2001). Conference Proceedings, Published
Collection: Proc. 11th IEEE Statistical Signal Processing Workshop
Bibliography: pp. 74-77

G.T. Zhou, M. Viberg, and T. McKelvey, "Superimposed periodic pilots for blind channel estimation", (2001). Conference Proceedings, Published
Collection: " Proc. 35th Asilomar Conference on Signals, Systems, and Computers
Bibliography: pp. 653-657

L. Ding, R. Raich, and G.T. Zhou, "A Hammerstein predistortion linearization design based on the indirect learning architecture", (2002). Conference Proceedings, Published
Collection: Proc. Intl. Conference on Acoustics, Speech, and Signal Processing
Bibliography: vol. 3, pp. 2689-2692

Y.C. Park, W. Woo, R. Raich, J.S. Kenney, and G.T. Zhou, "Adaptive predistortion linearization of RF power amplifiers using lookup tables generated from subsampled data", (2002). Conference Proceedings, Published
Collection: Adaptive predistortion linearization of RF power amplifiers using lookup tables generated from subsampled data
Bibliography: pp. 233-236

N. Chen and G.T. Zhou, "A superimposed periodic pilot scheme for semi-blind channel estimation of OFDM systems", (2002). Conference Proceedings, Accepted
Collection: Proc. 10th IEEE DSP Workshop
Bibliography: to appear

H. Qian and G.T. Zhou, "A neural network predistorter for nonlinear power amplifiers with memory", (2002). Conference Proceedings, Accepted
Collection: Proc. 10th IEEE DSP Workshop
Bibliography: to appear

R. Raich and G.T. Zhou, "On the modeling of memory nonlinear effects of power amplifiers for communication applications", (2002). Conference Proceedings, Accepted
Editor(s): to appear
Collection: Proc. 10th IEEE DSP Workshop
Bibliography: to appear

L. Ding and G.T. Zhou, "Effects of even-order nonlinear terms on predistortion", (2002). Conference Proceedings, Accepted
Collection: Proc. 10th IEEE DSP Workshop
Bibliography: to appear

L. Ding, G.T. Zhou, D.R. Morgan, Z. Ma, J.S. Kenney, J. Kim, and C.R. Giardina, "Memory polynomial predistorter based on the indirect

learning architecture", (2002). Conference Proceedings, Accepted
 Collection: Memory polynomial predistorter based on the indirect learning architecture
 Bibliography: to appear

Web/Internet Site

URL(s):

<http://users.ece.gatech.edu/~gtz/java>

Description:

This site contains a Java-based "Random Signals and Noise" virtual laboratory, which implements the education component of the proposal.

Other Specific Products

Product Type: Teaching aids

Product Description:

Developed a course packet for a graduate level course 'Theory and Applications of Higher-Order and Cyclic Statistics in Signal Processing'. Taught the course both at Georgia Tech and at the Chalmers University of Technology, Sweden.

Sharing Information:

The course packet was made available by the Georgia Tech bookstore.

Contributions

Contributions within Discipline:

Currently, most statistical signal processing research is about linear, stationary, Gaussian processes, which is a simplification of real life data. We have investigated nonlinear, nonstationary, and/or non-Gaussian processes. This is a more challenging task but is closer to reality. Our work on adaptive predistortion of nonlinear power amplifiers has direct impact on increasing the efficiency of power amplifiers used in communications applications.

Contributions to Other Disciplines:

Some research projects are inter-disciplinary. For example, our work on biological point process modeling was the result of collaborative efforts with neuro-biologists. Our work on predistortion linearization of power amplifiers is based on collaboration with RF/microwave researchers. The Java applets on 'Random Signals' can be utilized by almost all science and engineering disciplines. They already are used in other countries (such as Malaysia).

Contributions to Human Resource Development:

PhDs graduated:

Arthur Redfern, PhD 1999. Current position: Member of the Technical Staff, Communications Systems Laboratory, Texas Instruments DSP R&D Center, Dallas, TX.

Yongsub Kim, PhD 2000. Current position: Director R&D, Danam USA, Inc. San Jose, CA.

Krishnamurthy Nagarajan, PhD 2000. Current position: Managing Director, CouthIT Pvt. Ltd., Vijayapuri, Secunderabad, India.

Muhammad Ikram, PhD 2001. Current position: Member of the Technical Staff, DSPS R&D Center, Texas Instruments, Dallas, TX.

Contributions to Resources for Research and Education:

Jointly with Prof. Schafer's lab at UCSD - Biology, we have developed an image processing and automatic tracking system that is capable of monitoring animal behavior under the microscope for long periods of time.

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Contributions: To Any Beyond Science and Engineering