

## ACKNOWLEDGMENT

The authors wish to thank S. Parthasarathy and A. E. Rosenberg for their original contributions to the fixed-phrase speaker verification system. Also, they would like to thank F. K. Soong and W. Chou for useful discussions.

## REFERENCES

- [1] Q. Li, B.-H. Juang, Q. Zhou, and C.-H. Lee, "Verbal information verification," in *Proc. Eurospeech*, Rhode, Greece, Sept. 22–25, 1997, pp. 839–842.
- [2] Q. Li and B.-H. Juang, "Speaker verification using verbal information verification for automatic enrollment," in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Processing*, Seattle, WA, May 1998.
- [3] Q. Li, S. Parthasarathy, and A. E. Rosenberg, "A fast algorithm for stochastic matching with application to robust speaker verification," in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Processing*, Munich, Germany, Apr. 1997, pp. 1543–1547.
- [4] M. G. Rahim, C.-H. Lee, and B.-H. Juang, "Robust utterance verification for connected digits recognition," in *Proc. IEEE Int. Conf. Acoust., Speech, Signal Processing*, Detroit, MI, May 1995, pp. 285–288.
- [5] M. G. Rahim, C.-H. Lee, B.-H. Juang, and W. Chou, "Discriminative utterance verification using minimum string verification error (MSVE) training," in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Processing*, Atlanta, GA, May 1996, pp. 3585–3588.
- [6] T. Kawahara, C.-H. Lee, and B.-H. Juang, "Combining key-phrase detection and subword-based verification for flexible speech understanding," in *Proc. Int. Conf. Acoustic, Speech, Signal Processing*, Munich, Germany, May 1997, pp. 1159–1162.
- [7] E. Lleida and R. C. Rose, "Efficient decoding and training procedures for utterance verification in continuous speech recognition," in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Processing*, Atlanta, GA, May 1996, pp. 507–510.
- [8] R. A. Sukkar, C.-H. Lee, "Vocabulary independent discriminative utterance verification for nonkeyword rejection in subword based speech recognition," *IEEE Trans. Speech Audio Processing*, vol. 4, pp. 420–429, Nov. 1996.
- [9] R. A. Sukkar, A. R. Setlur, M. G. Rahim, and C.-H. Lee, "Utterance verification of keyword string using word-based minimum verification error (WB-MVE) training," in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Processing*, Atlanta, GA, May 1996, pp. 518–521.
- [10] A. R. Setlur, R. A. Sukkar, and J. Jacob, "Correcting recognition errors via discriminative utterance verification," in *Proc. Int. Conf. Spoken Language Processing*, Philadelphia, PA, Oct. 1996, pp. 602–605.
- [11] A. E. Rosenberg and S. Parthasarathy, "Speaker background models for connected digit password speaker verification," in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Processing*, Atlanta, GA, May 1996, pp. 81–84.
- [12] S. Parthasarathy and A. E. Rosenberg, "General phrase speaker verification using sub-word background models and likelihood-ratio scoring," in *Proc. Int. Conf. Speech Language Processing '96*, Philadelphia, PA, Oct. 1996.
- [13] J. Neyman and E. S. Pearson, "On the use and interpretation of certain test criteria for purpose of statistical inference," *Biometrika*, pt. I, vol. 20A, pp. 175–240, 1928.
- [14] —, "On the problem of the most efficient tests of statistical hypotheses," *Phil. Trans. R. Soc. A*, vol. 231, pp. 289–337, 1933.
- [15] A. Wald, *Sequential Analysis*. London, U.K: Chapman & Hall, 1947.
- [16] T. W. Anderson, *An Introduction to Multivariate Statistical Analysis*, 2nd ed. New York: Wiley, 1984.
- [17] L. Rabiner and B.-H. Juang, *Fundamentals of Speech Recognition*. Englewood Cliffs, NJ: Prentice-Hall, 1993.
- [18] C.-H. Lee, B.-H. Juang, W. Chou, and J. J. Molina-Perez, "A study on task-independent subword selection and modeling for speech recognition," in *Proc. Int. Conf. Speech Language Processing*, Philadelphia, PA, Oct. 1996, pp. 1816–1819.

**Qi Li** (S'86–M'88) received the Ph.D. degree in electrical engineering from University of Rhode Island, Kingston.

From 1988 to 1994, he was with F.M. Engineering and Research, Norwood, MA, where he worked in research on patent recognition algorithms and in real-time systems. In 1991, he attended Harvard University to study statistical theory and methods. In 1995, he joined Bell Laboratories, Murray Hill, NJ, where is currently Member of Technical Staff in the Dialogue Systems Research Department.

His research interests include speaker and speech recognition, fast search algorithms, stochastic modeling, robust features, fast discriminative learning, and neural networks. He has published regularly and holds patents in his research areas.

Dr. Li has been active as a reviewer for several journals, including IEEE TRANSACTIONS ON SPEECH AND AUDIO PROCESSING, and as a Local Chair for the IEEE Workshop on Automatic Identification. He has received two awards and is listed in *Who's Who in America, Millennium Edition*.

**Biing-Hwang Juang** (S'79–M'80–SM'87–F'92) is Head of Acoustics & Speech Research Department, Bell Labs, Lucent Technologies, Murray Hill, NJ. He is engaged in a wide range of communication related research activities, from speech coding, speech recognition to multimedia communications. He has published extensively and holds a number of patents in the area of speech communication and communication services. He is co-author of the book *Fundamentals of Speech Recognition* (Englewood Cliffs, NJ: Prentice-Hall).

Dr. Juang received the 1993 Best Senior Paper Award, the 1994 Best Senior Paper Award, and the 1994 Best *Signal Processing Magazine* Paper Award, and was coauthor of a paper granted the 1994 Best Junior Paper Award, all from the IEEE Signal Processing Society. In 1997, he won the Bell Labs' President Award for leading the Bell Labs Automatic Speech Recognition (BLASR) team. He also received the 1998 Technical Achievement Award from the IEEE Signal Processing Society and was named the Society's 1999 Distinguished Lecturer. He was an Editor for the IEEE TRANSACTIONS ON ACOUSTICS, SPEECH, AND SIGNAL PROCESSING (1986–1988), the IEEE TRANSACTIONS ON NEURAL NETWORKS (1992–1993), and the *Journal of Speech Communication* (1992–1994). He has served on the Digital Signal Processing and the Speech Technical Committees as well as the Conference Board of the IEEE Signal Processing Society and was Chairman of the Technical Committee on Neural Networks for Signal Processing (1991–1993). He is currently Editor-in-Chief of the IEEE TRANSACTIONS ON SPEECH AND AUDIO PROCESSING and is a member of the editorial board of the PROCEEDINGS OF THE IEEE. He also serves on international advisory boards outside the United States.

**Qiru Zhou** (S'86–M'93) received the B.S. and M.S. degrees from Northern Jiao-Tong University, China, and Beijing University of Posts and Telecommunications, China, respectively, in electrical and computer engineering.

He joined Bell Labs, AT&T, in 1992. He is now Member of Technical Staff at Bell Labs, Lucent Technologies, Murray Hill, NJ, working in the Dialogue Systems Research Department. His research interests include speech and speaker recognition algorithms and software, multimodal dialogue systems, real-time distributed object-oriented architecture for multimedia applications, and internet multimedia communications. Since 1992, he has been involved in various projects in AT&T and Lucent to apply speech technologies into products. Recently, he has been a Technical Leader in Lucent speech software product development.