

- Tourlakis, G. J. [2003]. *Lectures in Logic and Set Theory*, Cambridge University Press, Cambridge, UK.
- Toussaint, G. T. [1982]. "Computational Geometric Problems in Pattern Recognition," In *Pattern Recognition Theory and Applications*, Kittler, J., Fu, K. S., and Pau, L. F. (eds.), Reidel, New York, pp. 73–91.
- Tsai, J.-C., Hsieh, C.-H., and Hsu, T.-C. [2000]. "A New Dynamic Finite-State Vector Quantization Algorithm for Image Compression," *IEEE Trans. Image Processing*, vol. 9, no. 11, pp. 1825–1836.
- Tsujii, O., Freedman, M. T., and Mun, K. S. [1998]. "Anatomic Region-Based Dynamic Range Compression for Chest Radiographs Using Warping Transformation of Correlated Distribution," *IEEE Trans. Medical Imaging*, vol. 17, no. 3, pp. 407–418.
- Udpikar, V. R. and Raina, J. P. [1987]. "BTC Image Coding Using Vector Quantization," *IEEE Trans. Comm.*, vol. COM-35, no. 3, pp. 352–356.
- Ueda, N. [2000]. "Optimal Linear Combination of Neural Networks for Improving Classification Performance," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 22, no. 2, pp. 207–215.
- Ullman, S. [1981]. "Analysis of Visual Motion by Biological and Computer Systems," *IEEE Computer*, vol. 14, no. 8, pp. 57–69.
- Umbaugh, S. E. [2005]. *Computer Imaging: Digital Image Analysis and Processing*, CRC Press, Boca Raton, FL.
- Umeyama, S. [1988]. "An Eigendecomposition Approach to Weighted Graph Matching Problems," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 10, no. 5, pp. 695–703.
- Unser, M. [1995]. "Texture Classification and Segmentation Using Wavelet Frames," *IEEE Trans. on Image Processing*, vol. 4, no. 11, pp. 1549–1560.
- Unser, M., Aldroubi, A., and Eden, M. [1993]. "A Family of Polynomial Spline Wavelet Transforms," *Signal Proc.*, vol. 30, no. 2, pp. 141–162.
- Unser, M., Aldroubi, A., and Eden, M. [1993]. "B-Spline Signal Processing, Parts I and II," *IEEE Trans. Signal Proc.*, vol. 41, no. 2, pp. 821–848.
- Unser, M., Aldroubi, A., and Eden, M. [1995]. "Enlargement or Reduction of Digital Images with Minimum Loss of Information," *IEEE Trans. Image Processing*, vol. 4, no. 5, pp. 247–257.
- Vaidyanathan, P. P. and Hoang, P.-Q. [1988]. "Lattice Structures for Optimal Design and Robust Implementaion of Two-Channel Perfect Reconstruction Filter Banks," *IEEE Trans. Acoust., Speech, and Signal Proc.*, vol. 36, no. 1, pp. 81–94.
- Vailaya, A., Jain, A. and Zhang, H. J. [1998]. "On Image Classification: City Images vs. Landscapes," *Pattern Recog.*, vol. 31, no. 12, pp. 1921–1935.
- Vetterli, M. [1986]. "Filter Banks Allowing Perfect Reconstruction," *Signal Proc.*, vol. 10, no. 3, pp. 219–244.
- Vetterli, M. and Kovacevic, J. [1995]. *Wavelets and Subband Coding*, Prentice Hall, Englewood Cliffs, N.J.
- Vincent, L. [1993]. "Morphological Grayscale Reconstruction in Image Analysis: Applications and Efficient Algorithms," *IEEE Trans. Image Proc.*, vol. 2, no. 2, pp. 176–201.
- Voss, K. and Suesse, H. [1997]. "Invariant Fitting of Planar Objects by Primitives," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 19, no. 1, pp. 80–84.
- Vuylsteke, P. and Kittler, J. [1990]. "Edge-Labeling Using Dictionary-Based Relaxation," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 12, no. 2, pp. 165–181.
- Walsh, J. W. T. [1958]. *Photometry*, Dover, New York.
- Wang, D., Zhang, L., Vincent, A., and Speranza, F. [2006]. "Curved Wavelet Transform for Image Coding," *IEEE Trans. Image Proc.*, vol. 15, no. 8, pp. 2413–2421.
- Wang, G., Zhang, J., and Pan, G.-W. [1995]. "Solution of Inverse Problems in Image Processing by Wavelet Expansion," *IEEE Trans. Image Processing*, vol. 4, no. 5, pp. 579–593.

- Wang, Y.-P., Lee, S. L., and Toraichi, K. [1999]. "Multiscale Curvature-Based Shape Representation Using  $\beta$ -Spline Wavelets," *IEEE Trans. Image Processing*, vol. 8, no. 11, pp. 1586–1592.
- Wang, Z., Rao, K. R., and Ben-Arie, J. [1996]. "Optimal Ramp Edge Detection Using Expansion Matching," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 18, no. 11, pp. 1092–1097.
- Watt, A. [1993]. *3D Computer Graphics*, 2nd ed., Addison-Wesley, Reading, Mass.
- Wechsler [1980]. "Texture Analysis—A Survey," *Signal Proc.*, vol. 2, pp. 271–280.
- Wei, D., Tian, J., Wells, R. O., Jr., and Burrus, C. S. [1998]. "A New Class of Biorthogonal Wavelet Systems for Image Transform Coding," *IEEE Trans. Image Processing*, vol. 7, no. 7, pp. 1000–1013.
- Weinberger, M. J., Seroussi, G., and Sapiro, G. [2000]. "The LOCO-I Lossless Image Compression Algorithm: Principles and Standardization into JPEG-LS," *IEEE Trans. Image Processing*, vol. 9, no. 8, pp. 1309–1324.
- Westenberg, M. A. and Roerdink, J. B. T. M. [2000]. "Frequency Domain Volume Rendering by the Wavelet X-Ray Transform," *IEEE Trans. Image Processing*, vol. 9, no. 7, pp. 1249–1261.
- Weszka, J. S. [1978]. "A Survey of Threshold Selection Techniques," *Comput. Graphics Image Proc.*, vol. 7, pp. 259–265.
- White, J. M. and Rohrer, G. D. [1983]. "Image Thresholding for Optical Character Recognition and Other Applications Requiring Character Image Extraction," *IBM J. Res. Devel.*, vol. 27, no. 4, pp. 400–411.
- Widrow, B. [1962]. "Generalization and Information Storage in Networks of 'Adaline' Neurons," In *Self-Organizing Systems 1962*, Yovitz, M. C., et al. (eds.), Spartan, Washington, D. C., pp. 435–461.
- Widrow, B. and Hoff, M. E. [1960]. "Adaptive Switching Circuits," *1960 IRE WESCON Convention Record, Part 4*, pp. 96–104.
- Widrow, B. and Stearns, S. D. [1985]. *Adaptive Signal Processing*, Prentice Hall, Englewood Cliffs, N.J.
- Wiener, N. [1942]. *Extrapolation, Interpolation, and Smoothing of Stationary Time Series*, the MIT Press, Cambridge, Mass.
- Wilburn, J. B. [1998]. "Developments in Generalized Ranked-Order Filters," *J. Opt. Soc. Amer.-A. Optics, Image Science, and Vision*, vol. 15, no. 5, pp. 1084–1099.
- Windyga, P. S. [2001]. "Fast Impulsive Noise Removal," *IEEE Trans. Image Processing*, vol. 10, no. 1, pp. 173–179.
- Wintz, P. A. [1972]. "Transform Picture Coding," *Proc. IEEE*, vol. 60, no. 7, pp. 809–820.
- Witten, I. H., Neal, R. M., and Cleary, J. G. [1987]. "Arithmetic Coding for Data Compression," *Comm. ACM*, vol. 30, no. 6, pp. 520–540.
- Wolberg, G. [1990]. *Digital Image Warping*, IEEE Computer Society Press, Los Alamitos, CA.
- Wolff, R. S. and Yaeger, L. [1993]. *Visualization of Natural Phenomena*, Springer-Verlag, New York.
- Won, C. S. and Gray, R. M. [2004]. *Stochastic Image Processing*, Kluwer Academic/Plenum Publishers, New York.
- Woods, J. W. and O'Neil, S. D. [1986]. "Subband Coding of Images," *IEEE Trans. Acous. Speech Signal Proc.*, vol. ASSP-35, no. 5, pp. 1278–1288.
- Woods, R. E. and Gonzalez, R. C. [1981]. "Real-Time Digital Image Enhancement," *Proc. IEEE*, vol. 69, no. 5, pp. 643–654.
- Xu, Y., Weaver, J. B., Healy, D. M., Jr., and Lu, J. [1994]. "Wavelet Transform Domain Filters: A Spatially Selective Noise Filtration Technique," *IEEE Trans. Image Processing*, vol. 3, no. 6, pp. 747–758.

- Xu, R., Pattanaik, S., and Hughes, C. [2005]. "High-Dynamic-Range Still-Image Encoding in JPEG 2000," *IEEE Computer Graphics and Applications*, vol. 25, no. 6, pp. 57–64.
- Yachida, M. [1983]. "Determining Velocity Maps by Spatio-Temporal Neighborhoods from Image Sequences," *Comput. Vis. Graph. Image Proc.*, vol. 21, no. 2, pp. 262–279.
- Yamazaki, Y., Wakahara, Y., and Teramura, H. [1976]. "Digital Facsimile Equipment 'Quick-FAX' Using a New Redundancy Reduction Technique," *NTC '76*, pp. 6.2-1–6.2-5.
- Yan, Y. and Cosman, P. [2003]. "Fast and Memory Efficient Text Image Compression with JBIG2," *IEER Trans. Image Proc.*, vol. 12, no. 8, pp. 944–956.
- Yang, X. and Ramchandran, K. [2000]. "Scalable Wavelet Video Coding Using Aliasing-Reduced Hierarchical Motion Compensation," *IEEE Trans. Image Processing*, vol. 9, no. 5, pp. 778–791.
- Yates, F. [1937]. "The Design and Analysis of Factorial Experiments," Commonwealth Agricultural Bureaux, Farnham Royal, Burks, England.
- Yin, P. Y., Yin, L. H., and Chen, L. H. [1997]. "A Fast Iterative Scheme for Multilevel Thresholding Methods," *Signal Processing*, vol. 60, pp. 305–313.
- Yitzhaky, Y., Lantzman, A., and Kopeika, N. S. [1998]. "Direct Method for Restoration of Motion Blurred Images," *J. Opt. Soc. Amer.-A. Optics, Image Science, and Vision*, vol. 15, no. 6, pp. 1512–1519.
- You, J. and Bhattacharya, P. [2000]. "A Wavelet-Based Coarse-to-Fine Image Matching Scheme in a Parallel Virtual Machine Environment," *IEEE Trans. Image Processing*, vol. 9, no. 9, pp. 1547–1559.
- Yu, D. and Yan, H. [2001]. "Reconstruction of Broken Handwritten Digits Based on Structural Morphology," *Pattern Recog.*, vol. 34, no. 2, pp. 235–254.
- Yu, S. S. and Tsai, W. H. [1990]. "A New Thinning Algorithm for Gray-Scale Images," *Pattern Recog.*, vol. 23, no. 10, pp. 1067–1076.
- Yuan, M. and Li, J. [1987]. "A Production System for LSI Chip Anatomizing," *Pattern Recog. Letters*, vol. 5, no. 3, pp. 227–232.
- Zadeh, L. A. [1965]. "Fuzzy Sets," *Inform. and Control*, vol. 8, pp. 338–353.
- Zadeh, L. A. [1973]. "Outline of New Approach to the Analysis of Complex Systems and Decision Processes," *IEEE Trans. Systems, Man, Cyb.*, vol. SMC-3, no. 1, pp. 28–44.
- Zadeh, L. A. [1976]. "A Fuzzy-Algorithmic Approach to the Definition of Complex or Imprecise Concepts," *Int. J. Man-Machine Studies*, vol. 8, pp. 249–291.
- Zahara, E., Shu-Kai, S., and Du-Ming, T. [2005]. "Optimal Multi-Thresholding Using a Hybrid Optimization Approach," *Pattern Recognition Letters*, vol. 26, no. 8, pp. 1082–1095.
- Zahn, C. T. and Roskies, R. Z. [1972]. "Fourier Descriptors for Plane Closed Curves," *IEEE Trans. Comput.*, vol. C-21, no. 3, pp. 269–281.
- Zhang, T. Y. and Suen, C. Y. [1984]. "A Fast Parallel Algorithm for Thinning Digital Patterns," *Comm. ACM*, vol. 27, no. 3, pp. 236–239.
- Zhang, Y. and Rockett, P. I. [2006]. "The Bayesian Operating Point of the Canny Edge Detector," *IEEE Trans. Image Proc.*, vol. 15, no. 11, pp. 3409–3416.
- Zhu, H., Chan F. H. Y., and Lam, F. K. [1999]. "Image Contrast Enhancement by Constrained Local Histogram Equalization," *Computer Vision and Image Understanding*, vol. 73, no. 2, pp. 281–290.
- Zhu, P. and Chirlian, P. M. [1995]. "On Critical Point Detection of Digital Shapes," *IEEE Trans. Pattern Anal. Machine Intell.*, vol. 17, no. 8, pp. 737–748.
- Zimmer, Y., Tepper, R., and Akselrod, S. [1997]. "An Improved Method to Compute the Convex Hull of a Shape in a Binary Image," *Pattern Recog.*, vol. 30, no. 3, pp. 397–402.
- Ziou, D. [2001]. "The Influence of Edge Direction on the Estimation of Edge Contrast and Orientation," *Pattern Recog.*, vol. 34, no. 4, pp. 855–863.

- Ziv, J. and Lempel, A. [1977]. "A Universal Algorithm for Sequential Data Compression," *IEEE Trans. Info. Theory*, vol. IT-23, no. 3, pp. 337–343.
- Ziv, J. and Lempel, A. [1978]. "Compression of Individual Sequences Via Variable-Rate Coding," *IEEE Trans. Info. Theory*, vol. IT-24, no. 5, pp. 530–536.
- Zucker, S. W. [1976]. "Region Growing: Childhood and Adolescence," *Comput. Graphics Image Proc.*, vol. 5, pp. 382–399.
- Zugaj, D. and Lattuati, V. [1998]. "A New Approach of Color Images Segmentation Based on Fusing Region and Edge Segmentation Outputs," *Pattern Recog.*, vol. 31, no. 2, pp. 105–113.

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