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DISSENY D'UN PROTOCOL NUMÈRIC PER A LA
CLASSIFICACIÓ INVARIANT D'IMATGES APLICANT
TÈCNIQUES MULTIVARIANTS

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Bibliografia

- [Abu84] Y.S. Abu Mostafa, D. Psaltis. "Recognition Aspect of Moment Invariants", IEEE Trans. on PAMI., vol. 6, 698-706, 1984.
- [Amm90] Maan Ammar, Yuuji Yoshida, Teruo Fukumura, "Structural Description and Classification of Signature Images", Pattern Recognition, vol. 23(7), 697-710, 1990.
- [Baj97] Reena Bajaj, Santanu Chaudhury, "Signature Verification Using Multiple Neural Classifiers", Pattern Recognition, vol. 30(1), 1-7, 1997.
- [Bah93] P. Bhandare, Y. Mendelson, R. A. Peura, G. Janatsch, J. D. Kruse-Jarres, R. Marbach, H. M. Heise, "Multivariate Determination of Glucose in Whole Blood Using Partial Least-Squares and Neural Networks Based on MID-Infrared Spectroscopy", Applied Spectroscopy, vol. 47(8), 1214-1222, 1993.
- [Bas94] Alexander Basilevsky, *Statistical Factor Analysis and Related Methods. Theory and Applications*, Wiley Series in Probability and Mathematical Statistics, John Wiley & Sons Inc., 1994.
- [Bee87] Kenneth R. Beebe, Bruce R. Kowalski, "An Introduction to Multivariate Calibration and Analysis", Analytical Chemistry, vol. 59(17), 1007a-1017a, 1987.

- [Bel91] S.O. Belkasim, M. Shridhar, M. Ahmadi, "Pattern Recognition With Moment Invariants: A Comparative Study and New Results", *Pattern Recognition*, vol. 24(12), 1117-1138, 1991.
- [Bun93] Horst Bunke, "Structural and Syntactic Pattern Recognition", *Handbook of Pattern Recognition and Computer Vision*, 163-209, 1993. C.H. Chen, L. F Pau and P. S. P. Wang eds., World Scientific Publishing Company.
- [Cas87] David Casasent, Lee Cheatham i Donald Fetterly, "Optical System to Compute Intensity Moments: Design", *Applied Optics*, vol. 21(18), 1987.
- [Che84] R. Chellappa, R. Bagdazian, "Fourier Coding of Image Boundaries", *IEEE Trans. on PAMI.*, vol. 6(1), 102-105, 1984.
- [Che91] S. Chen, C.F.N. Cowan, P.M. Grant, "Orthogonal Least Squares Learning Algorithm for Radial Basis Function Networks", *IEEE Tans. on Neural Networks*, vol. 2(2), 302-309, 1991.
- [Che92] Yong-Qing Cheng, Yong-Ming Zhuang, Jing-Yu Yang, "Optimal Fisher Discriminant Analysis Using the Rank Decomposition", *Pattern Recognition*, vol. 25(1), 101-111, 1992.
- [Cov67] T. M. Cover, P. E. Hart, "Nearest Neighbor Pattern Classification", *IEEE Trans. Inf. Theory*, vol. IT-13, 21-27, 1967.
- [Cri82] Thomas C. Crimmins, "A Complete Set of Fourier Descriptors for Two-Dimensional Shapes", *IEEE Trans. on Systems, Man, and Cybernetics.*, vol. 12(6), 848-855, 1982.
- [Cua81] Carlos M^a Cuadras, *Métodos de Análisis Multivariante*, Eunibar, 1981.
- [Cyb89] G. Cybenko, "Approximations by superposition of a sigmoidal function", *Math. Contr., Signals Syst.*, vol. 2(4), 303-314, 1989.
- [Dev82] L. Devroye, T. J. Wagner, "Nearest Neighbor Methods in Discrimination", *Handbook of Statistics*, vol. 2, 193-197, P. R. Krisnaiah, L. N. Kanal eds. 1982.
- [Dom93] A. Domingo, *Tratamiento digital de imágenes*, Anaya Multimedia, 1993.
- [Dra81] N. R. Draper, H. Smith, *Applied Regression Analysis*, 2nd. ed., John Wiley & Sons Inc., New York, 1981.
- [Drö87] J. B. M. Dröge, W. J. Rinsma, H. A. Van't Klooster, A. C. Tas, J. Van Der Greef "An Evaluation of SIMCA. Part 2 - Classification of Pyrolysis Mass Spectra of Pseudomonas and Serratia Bacteria by Pattern Recognition Using the SIMCA Classifier", *Journal of Chemometrics*, vol. 1, 231-241, 1987.
- [Dro96] J-P. Drouhard, R. Sabourin, M. Godbout, "A Neural Network Approach to Off-Line Signature Verification Using Directional PDF", *Pattern Recognition*, vol. 29(3), 415-424, 1996.

- [Dud73] Richard O. Duda, Peter E. Hart, *Pattern Recognition and Scene Analysis*, John Wiley & Sons Inc., 1973.
- [Dud87] S.A. Dudani, K.J. Breedig, R.B. Mc Ghee, "Aircraft Identification by Moments Invariants", *IEEE Trans. Comput.* C-26, 39-45, 1987.
- [Dun89] George H. Dunteman, *Principal Component Analysis*, Series on Quantitative Applications in the Social Sciences, Sage Publications Inc., 1989.
- [Duv87] Jacques Duveroy i Yun-Long Sheng, "Effective Optical Processor for Computing Image Moments at TV Rate: Use in Handwriting Recognition", *Applied Optics*, vol. 26, No. 12; June 1987.
- [Eas82] H.T. Eastment, W.J. Krzanowski, "Cross-Validatory Choice of the Number of Components From a Principal Component Analysis", *Technometrics*, vol. 24(1), 73-76, 1982.
- [Esb94] Kim Esbensen, Suzanne Schönkopf, Tonje Midtgaard, *Multivariate Analysis in Practice*, Camo AS, 1994.
- [Fis36] R. A. Fisher, "The Use of Multiple Measurements in Taxonomic Problems", *Annals of Eugenies*, vol. 7, 179-188, 1936.
- [Fis38] R. A. Fisher, "The Statistical Utilization of Multiple Measurements", *Annals of Eugenies*, vol. 8, 376-386, 1938.
- [Flu93] Jan Flusser, Tomas Suk, "Pattern Recognition by Affine Moment Invariants", *Pattern Recognition*, vol.26(1), 167-174, 1993.
- [Fol72] Donald H. Foley, "Considerations on Sample and Feature Size", *IEEE Trans. Inform. Theory*, vol. IT-18, 618-626, 1972.
- [Fol75] Donald H. Foley, John W. Sammon, JR, "An Optimal Set of Discriminant Vectors", *Journal of Chemometrics*, vol. C-24(3), 281-289, 1975.
- [Fra89a] I. E. Frank, J. H. Friedman, "Classification: Oldtimers and Newcomers", *Chemometrics and Intelligent Laboratory Systems*, vol. 3, 463-475, 1989.
- [Fra89b] I. E. Frank, S. Lanteri, "Classification Models: Discriminant Analysis, SIMCA, CART", *Chemometrics and Intelligent Laboratory Systems*, vol. 5, 247-256, 1989.
- [Fuk71] Keinosuke Fukunaga, David L. Kessell, "Estimation of Classification Error", *IEEE Trans. Comput.*, vol. C-20, 1521-1527, 1971.
- [Fuk72] Keinosuke Fukunaga, *Introduction to Statistical Pattern Recognition*, Academic Press Inc., New York, 1972.
- [Fuk89] Keinosuke Fukunaga, "Effects of Sample Size in Classifier Design", *IEEE Trans. on PAMI*, vol. 11(8), 873-885, 1989.

- [Fuk90] Keinosuke Fukunaga, *Introduction to Statistical Pattern Recognition*, Academic Press Inc., New York, 1990.
- [Fun89] K. Funahashi, "On the Approximate Realization of Continuous Mappings by Neural Networks", *Neural Networks*, vol. 2, 183-192, 1989.
- [Gas93] J. Gasteiger, J. Zupan, "Neural Networks in Chemistry", *Angew. Chem. Ind.*, vol. 32, 503-523, 1993.
- [Gel86] Paul Geladi, Bruce R. Kowalski, "Partial Least Squares Regression: A Tutorial", *Analytica Chimica Acta*, vol. 185, 1-17, 1986.
- [Gon93] Rafael.C. González i Richard.C. Woods, *Digital Image Processing*. Addison-Wesley, 1993.
- [Gra72] G. H. Granlund, "Fourier Preprocessing for Hand Print Character Recognition", *IEEE Trans. on Comput.*, vol. 21, 195-201, 1972.
- [Gup87] L. Gupta, M. D. Srinath, "Contour Sequence Moments for the Classification of Closed Planar Shapes", *Pattern Recognition*, vol. 20(3), 267-272, 1987.
- [Haa88] David M. Haaland, Edward V. Thomas, "Partial Least-Squares Methods for Spectral Analysis. 1. Relation to Other Quantitative Calibration Methods and the Extraction of Qualitative Information", *Analytical Chemistry*, vol. 60(11), 1193-1202, 1988.
- [Hu61] M.K. Hu, "Pattern Recognition by Moment Invariants", *Proc. IRE*, vol. 49, 1428, 1961.
- [Hu62] M.K. Hu, "Visual Pattern Recognition by Moment Invariants", *IEEE Trans. Inf. Theory*, IT-8, 179-187, 1962.
- [Hua97] Kai Huang, Hong Yan, "Off-Line Signature Verification Based on Geometric Feature Extraction and A Neural Network Classification", *Pattern Recognition*, vol. 30(1), 9-17, 1997.
- [Hub94] Carl J. Huberty, *Applied Discriminant Analysis*, John Wiley & Sons Inc., 1994.
- [Jai78] A. K. Jain, W. G. Waller, "On the Optimal Number of Features in the Classification of Multivariate Gaussian Data", *Pattern Recognition*, vol. 10, 365-374, 1978.
- [Jai82] A.k. Jain, B. Chandrasekaran, "Dimensionality and Sample Size Considerations in Pattern Recognition Practice", in *Handbook of Statistics*, vol. 2, P. R. Krishnaiah and L. N. Kanal, Eds. Amsterdam, The Netherlands: North Holland, 835-855, 1982.
- [Jai89] A.H. Jain, *Fundamentals of Digital Image Processing*, Englewood Cliffs, NJ Prentice-Hall cop., 1989.
- [Jai97] Anil Jain, Douglas Zongker, "Feature Selection: Evaluation, Application, and Small Sample Performance", *IEEE Trans. on PAMI*, vol. 19(2), 153-158, 1997.

- [Jan95] Jyh-Shing Roger Jang, Chuen-Tsai Sun, "Neuro-Fuzzy Modelling and Control", Proceedings of the IEEE, vol. 83(3), 378-405, 1995.
- [Joh92] R. A. Johnson, D. W. Wichern, *Applied Multivariate Statistical Analysis*, 3rd. Ed. Prentice Hall, Englewood Cliffs, New Jersey, 1992.
- [Jun98] L. Junco Navascués, L. Sánchez, "Localization and Fuzzy Classification of Manufacturing Defects in Sheets of Glass", *Mathware & Soft Computing*, vol. 5, 213-221, 1998.
- [Kan71] L. Kanal, B. Chandrasekaran, "On Dimensionality and Sample Size in Statistical Pattern Recognition", *Pattern Recognition*, vol. 3, 225-234, 1971.
- [Kii92] H. T. Kiiveri, "Canonical Variate Analysis of High-Dimensional Spectral Data", *Technometrics*, vol. 34(3), 321-331, 1992.
- [Kle80] William R. Klecka, *Discriminant Analysis*. SAGE Publications Inc. Newbury Park, California, 1980.
- [Kos92] B. Kosko, *Neural Networks and Fuzzy Systems*, International Editions, Prentice-Hall Inc., 1992.
- [Kow91] B.R. Kowalski, M.B. Seasholtz, "Recent Developments in Multivariate Calibration", *Journal of Chemometrics*, vol. 5, 129-145, 1991.
- [Koz91] Gy Kozmann, R. L. Lux, M. Scott, "Sample Size and Dimensionality in Multivariate Classification: Implications for Body Surface Potential Mapping", *Computers and Biomedical Research*, vol. 24, 170-182, 1991.
- [Krz79] W.J. Krzanowski, "Between-Groups Comparison of Principal Components". *Journal of the American Statistical Association*, vol. 74, 703-707, 1979.
- [Krz93] W.J. Krzanowski, *Principles of Multivariate Analysis. A User's Perspective*, Oxford University Press, New York, 1993.
- [Krz94] W.J. Krzanowski, F.C. Marriott, *Multivariate Analysis. Part I*, Ed. Edward Arnold, 1994.
- [Krz95] W.J. Krzanowski, "Orthogonal Canonical Variates for Discrimination and Classification", *Journal of Chemometrics*, vol. 9(6), 509-520, 1995.
- [Kud00] Minechi Kudo, Jack Sklansky, "Comparison of Algorithms that select Features for Pattern Classifiers". *Pattern Recognition*, vol. 33(1), 25-41, 2000.
- [Lac67] Peter A. Lachenbruch, "An Almost Unbiased Method of Obtaining Confidence Intervals for the Probability of Misclassification in Discriminant Analysis", *Biometrics*, vol. 23, 639-645, 1967.
- [Lac75] Peter A. Lachenbruch, *Discriminant Analysis*, Hafner Press, a Division of Macmillan Publishing Co. Inc., 1975.

- [Lan94] X. Lana, G. Fernández Mills, "Minimum Sample Size for Synoptic Weather Type Classification. Application to Winter Period Data Recorded on the Catalan Coast (North-East Spain)", *International Journal of Climatology*, vol. 14, 1051-1060, 1994.
- [Lee90] C.C. Lee, "Fuzzy Logic in Control Systems: Fuzzy Logic Controller", *IEEE Trans. on Systems, Man and Cybernetics*, vol. 20, 404-435, 1990.
- [Lee96] Luan L. Lee, Toby Berger, Erez Aviczer, "Reliable On-Line Human Signature Verification Systems", *IEEE Trans. on PAMI.*, vol. 18(6), 643-647, 1996.
- [Leg82] J.R. Leger, S.H. Lee, "Image Classification by an Optical Implementation of the Fukunaga-Koontz Transform", *J. Opt. Soc. Am.*, vol. 72, 556-564, 1982.
- [Li92] Y. Li, "Reforming the Theory of Invariant Moments for Pattern Recognition", *Pattern Recognition*, vol. 25, 723-730, 1992.
- [Lie94] M.A.Lieberman, R.B. Patil, "Clustering and Neural Networks to Categorize Cotton Trash", *Opt. Eng.*, vol. 33, 1642-1653, 1994.
- [Lie97] Lieberman, R.B. Patil, "Evaluation of Learning Vector Quantization to Classify Cotton Trash", *Opt. Eng.*, vol. 36, 914-921, 1997.
- [Lin87] C. C. Lin, R. Chellappa, "Classification of Partial 2-D Shapes Using Fourier Descriptors", *IEEE Trans. on PAMI*, vol. 9(5), 686-690, 1987.
- [Lin93] Frederik Lindgren, Paul Geladi, Svante Wold, "The Kernel Algorithm for PLS", *Journal of Chemometrics*, vol. 7, 4-22, 1993.
- [Lip87] R.P. Lippmann, "An Introduction to Computing with Neural Nets", *IEEE ASSp Magazine*, April 4-22, 1987.
- [Lor87] Avraham Lorber, Lawrence E. Wangen, Bruce R. Kowalski, "A Theoretical Foundation for the PLS Algorithm", *Journal of Chemometrics*, vol. 1, 19-31, 1987.
- [Mah94] Sabri A. Mahmoud, "Arabic Character Recognition Using Fourier Descriptors and Character Contour Encoding", *Pattern Recognition*, vol. 27(6), 815-824, 1994.
- [Mal77] E. R. Malinowski, "Determination of The Number of Factors and The Experimental Error in a Data Matrix", *Analytical Chemistry*, vol. 49, 612-617, 1977.
- [Man87] Rolf Manne, "Analysis of Two Partial Least-Squares Algorithms for Multivariate Calibration", *Chemometrics and Intelligent Laboratory Systems*, vol. 2, 187-197, 1987.
- [Mar93] D. Maravall, *Reconocimiento de formas y visión artificial*. Ra-ma, 1993.

- [Mar89] H. Martens, T. Naes, *Multivariate Calibration*, John Wiley & Sons Inc., 1989.
- [Mat93] *MATLAB. User's Guide*, The Math Works Inc., 1993.
- [Mat94] *Neural Networks Toolbox User's Guide*, The Math Works Inc., 1994.
- [McI92] Geoffrey J. McLachlan, *Discriminant Analysis and Statistical Pattern Recognition*, John Wiley & Sons Inc., 1992.
- [Mon82] D. C. Montgomery, E. A. Peck, *Introduction to Linear Regression Analysis*, John Wiley & Sons Inc., 1982.
- [Mon98] E. Montseny, P. Sobrevilla, "Application of Fuzzy Techniques to the Design of Algorithms in Computer Vision", *Mathware & Soft Computing*, vol. 5, 223-230, 1998.
- [Mur87] Fionn Murtagh, André Heck, *Multivariate Data Analysis*, D. Reidel Publishing Company, 1987.
- [Nav98] J. Navascués, L. Sánchez, "Localization and Fuzzy Classification of Manufacturing Defects in Sheets of Glass", *Mathware & Soft Computing*, vol. 5, 213-221, 1998.
- [Nor82] G. R. North, T. L. Bell, R. F. Callahan, "Sampling Errors in the Estimation of Empirical Orthogonal Functions", *Mon. Wea. Rev.*, vol. 110, 699-706, 1982.
- [Par93] J.R. Parker, *Practical Vision Using C*, Wiley Professional Computing, John Wiley & Sons Inc., 1993.
- [Per77] Eric Persoon, King-Sun Fu, "Shape Discrimination Using Fourier Descriptors", *IEEE Trans. on Systems, Man, and Cybernetics*, vol. 7(3), 170-179, 1977.
- [Pla89] Réjean Plamondon, Guy Lorette, "Automatic Signature and Writer Identification-The State of the Art", *Pattern Recognition*, vol. 22(2), 107-131, 1989.
- [Pre92] W.H. Press, S.A. Teukolsky, W.T. Vetterling, B.P. Flannery, *Numerical Recipes in C*, 2nd. ed., Cambridge University Press, 1992.
- [Qi94] Yingyong Qi, Bobby R. Hunt, "Signature Verification Using Global and Grid Features", *Pattern Recognition*, vol. 27(12), 1621-1629, 1994.
- [Rau79] S. J. Raudys, "Determination of Optimal Dimensionality in Statistical Pattern Recognition", *Pattern Recognition*, vol. 11, 263-270, 1979.
- [Rau91] S. J. Raudys, A. K. Jain, "Small Sample Size effects in Statistical Pattern Recognition: Recommendations for Practitioners", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, vol. 13(3), 252-264, 1991.
- [Ree80a] M. Reed Teague, "Image Analysis Via the General Theory of Moments", *J.Opt. Soc.Am.*, vol. 70, 920-930, 1980.

- [Ree80b] M.Reed Teague, "Optical Calculation of Image Moments", *Applied Optics*, vol. 19, 1353-356, 1980.
- [Rei91] T. H. Reiss, "The Revised Fundamental Theorem of Moment Invariants", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, vol. 13(8), 830-833, 1991.
- [Ren92] Alvin C. Rencher, "Interpretation of Canonical Discriminant Functions, Canonical Variates, and Principal Components", *The American Statistician*, vol. 46(3), 217-225, 1992.
- [Rog95] J.S. Roger Jang i C.T. Sun, "Neuro-Fuzzy Modelling and Control", *Proced. IEEE*, vol. 83 (3), 1995.
- [Rot96] Irene Rothe, Herbert Süsse, Klaus Voss, "The Method of Normalization to Determine Invariants", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, vol. 18(4), 366-375, 1996.
- [Rum86] D.E. Rumelhart, G.E. Hinton, R.J. Williams, *Learning Internal Representations by Error Propagation*, in *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*, vol. 1: Foundations, D.E. Rumelhart & J.L. McClelland (Eds.), MIT Press, 1986.
- [Sam70] John W. Sammon, JR, "An Optimal Discriminant Plane", *IEEE Trans. on Computers*, vol. C-19, 826-829, 1970.
- [San88] Eugenio Sánchez, Bruce R. Kowalski, "Tensorial Calibration: I. First-order Calibration", *Journal of Chemometrics*, vol. 2, 247-263, 1988.
- [Seb84] G.A.F. Seber, *Multivariate Observations*, John Wiley & Sons Inc., 1984.
- [She95] Lixin Sheng, Yunlong Sheng, "Noncentral Image Moments for Invariant Pattern Recognition", *Optical Engineering*, vol 34, 3181-3186, 1995.
- [She96] Alex Sherstinsky, Ronald W. Picard, "On the Efficiency of the Orthogonal Least Squares Training Method for Radial Basis Function Networks", *IEEE Trans. on Neural Networks*, vol. 7(1), 195-200, 1996.
- [Sim91] M.L. Simpson, R.L. Schmoyer, M.A. Hunt, "Moments Invariants for Automated Inspection of Printed Material" *Optical Engineering*, vol. 30(4), 424-430, 1991.
- [Sim96] Hans Ulrich Simon, "General Bounds on the Number of Examples Needed for Learning Probabilistic Concepts", *Journal of Computer and System Sciences*, vol. 52, 239-254, 1996.
- [Sjö79] M. Sjöström, B. R. Kowalski, "A Comparison of Five Pattern Recognition Methods Based on the Classification Results From Six Real Data Bases", *Analytica Chimica Acta*, vol. 112, 11-30, 1979.

- [Son93] M. Sonka, V. Hlavac i R. Boyle, *Image Processing, Analysis and Machine Vision*. Chapman & Hall Computing, 1st Edition, 1993.
- [Sta82] H. Stark, R. O'Toole, "Statistical Signal Processing", in *Applications of the Optical Fourier Transform*, H. Stark, Ed. Academic, New York, 1982.
- [Tea80] M.R. Teague, "Image Analysis Via the General Theory of Moments", *J. Opt. Soc. Am.*, vol. 70, 920-930, 1980.
- [Teh88] Cho-Huak Teh, Roland T. Chin, "On Image Analysis by the Methods of Moments", *IEEE Trans.on Pattern Analysis and Machine Intelligence*, vol. 10(4), 496-512, 1988.
- [Tri96] Øivind Due Trier, Anil K. Jain, Torfinn Taxt, "Feature Extraction Methods for Character Recognition- A Survey", *Pattern Recognition*, vol. 29(4), 641-662, 1996.
- [Vij86] B.V.K. Vijaya Kumar i C.A. Rahenkamp, "Calculation of geometric moments using Fourier plane intensities", *Applied Optics*, vol. 25(6), 997-1007, 1986.
- [Vij87] B.V.K. Vijaya Kumar i M.J. Zinnikas, "Geometric Moments from Optical Cosinoidal Transform" *Optics Communications*, vol. 62(4), 1987.
- [Wag71] T. J. Wagner, "Convergence of the Nearest Neighbor Rule", *IEEE Trans. on Inf. Theory*, vol. 17, 566-571, 1971.
- [Wak93] Ian N. Wakeling, Jeff J. Morris, "A Test of Significance for Partial Least Squares Regression", *Journal of Chemometrics*, vol. 7, 291-304, 1993.
- [Wal92] Beata Walczak, Wolfhard Wegscheider, "Non-Linear Methods of Chemical Data by Combinations of Linear and Neural Net Methods", *Analytica Chimica Acta*, vol. 283, 508-519, 1992.
- [Wan94] Shuenn-Shyang Wang, Po-Cheng Chen, Wen-Gou Lin, "Invariant Pattern Recognition by Moment Fourier Descriptors", *Pattern Recognition*, vol. 27(12), 1735-1742, 1994.
- [Web74] J. T. Webster, R. F. Gurst, R. L. Mason, "Latent Root Regression Analysis", *Technometrics*, vol. 16, 513-522, 1974.
- [Wol76] S. Wold, "Pattern Recognition by Means of Disjoint Principal Components Model", *Pattern Recognition*, vol. 8, 127-139, 1976.
- [Woo96] J. Wood, "Invariant Pattern Recognition: A Review", *Pattern Recognition*, vol. 29, 1-17, 1996.
- [Wu98] Quen-Zong Wu, Suh-Yin Lee, I-Chang Jou, "On-Line Signature Verification Based on Logarithmic Spectrum", *Pattern Recognition*, vol. 31(12), 1865-1871, 1998.

- [Wyt93] Barry J. Wythoff, "Backpropagation Neural Networks. A Tutorial", *Chemometrics and Intelligent Laboratory Systems*, vol. 18, 115-155, 1993.
- [Yan95] L. Yang, B. K. Widjaja, R. Prasad, "Application of Hidden Markov Models for Signature Verification", *Pattern Recognition*, vol. 28(2), 161-170, 1995.
- [Yen89] Peter W. Yendle, Halliday J. H. Macfie, "Discriminant Principal Components Analysis", *Journal of Chemometrics*, vol. 3, 589-600, 1989.
- [Zad65] L.A. Zadeh, "Fuzzy sets", *Inform. and Contr.*, vol 8, 338-353, 1965.
- [Zah72] Charles T. Zahn, Ralph Z. Roskies, "Fourier Descriptors for Plane Closed Curves", *IEEE Trans. on Comput.*, vol. 21(3), 269-281, 1972.
- [Zha84] Zhang T.Y., Suan C.Y, "A Fast Parallel Algorithm for Thinning Digital Patterns". *Communications of the ACM*, vol. 27(3), 236-239, 1984.