

**COMPARATIVE STUDY BETWEEN NEURAL NETWORK  
AND STATISTIC  
IN HANDWRITTEN DIGIT RECOGNITION**

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## ABSTRAK

Rangkaian neural merupakan salah satu teknik yang populer dalam bidang Kepintaran Buatan. Rangkaian ini telah diimplementasikan dalam pelbagai bidang dari bidang bukan teknikal sehingga ke bidang teknikal. Kebolehan rangkaian neural adalah bersandarkan model statistik seperti model regresi. Bidang pengecaman tulisan tangan adalah salah satu kebolehan atau keupayaan yang boleh dilakukan dalam rangkaian neural. Kebanyakan hasil kajian yang telah berjaya dalam bidang ini menggunakan rangkaian neural. Namun, didapati terdapat kurang kajian yang membandingkan rangkaian neural dan statistik. Oleh itu, kajian yang dilakukan ini bertujuan untuk membandingkan prestasi kebolehan rangkaian neural dan kebolehan model statistik dalam bidang pengecaman tulisan tangan. Hasil keputusan dibandingkan antara dua model tersebut. Multilayer Perceptron dipilih sebagai model bagi rangkaian neural, manakala Multiple Nonlinear Regression dipilih sebagai model statistik. Hasil keputusan (peratus ketepatan) menunjukkan rangkaian neural adalah lebih baik berbanding model statistik. Sejumlah 768 data digunakan untuk proses pembelajaran, rangkaian neural menghasilkan 94.98 % berbanding model statistik 78.7 %.

## **ABSTRACT**

Neural network is one of the most popular Artificial Intelligent techniques. It has been implemented in various applications ranging from non technical applications to highly technical applications. The ability of neural network was originally inherited from statistical models such as regression. Handwritten recognition is one of the promising domains for neural network. Many studies have shown the success and efficacy of neural network in handwritten recognition. Yet, less study compares the performance of neural network and statistical method. Hence, this study aims to compare the generalization performance of neural network and statistical model in handwriting recognition domain. The results obtained are compared and presented in this paper. Multilayer Perceptron is chose as neural network model and Multiple Nonlinear Regression as statistic model. The result (percentage of correctness) indicated that neural network model is better in generalization than the statistic model. A total of 768 datasets was used for training. Neural network has produced a higher generalization value if compared to statistic which is 94.98% and 78.7% respectively.

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# CHAPTER 1

## INTRODUCTION

One of the original aims of artificial neural networks (ANN) was to understand and shape the functional characteristics and computational properties of the brain when it performs cognitive processes such as sensorial perception, concept categorization, concept association and learning (Sordo *et al.*, 2001). Nowadays a great deal of effort is focused in the development of neural networks for applications such as pattern recognition and classification, data compression and optimization.

Neural networks are a wide class of flexible nonlinear regression and discriminant model, data reduction models, and nonlinear dynamical system (Sarle, 1994a). Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons (Stergiou and Siganos, 1996). A Neural Network is a system composed of many simple processing elements operating in parallel that function is determined by network structure, connection strength and the processing performed at computing elements or nodes (DARPA, 1998). NN is also defined as a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use (Haykin, 1999).

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# BIBLIOGRAPHY

- Adznan, B. J. and Tan, C.L. (2003). *Speech Recognition using Formant Analysis and Neural Network*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Ahmad, K. and Suradi, W. (2001). *Pengecaman Tulang Melalui Kaedah Rangkaian*. National Artificial Intelligent Seminar (AIS 2001), Malaysia.
- Aksela, M. (2000). *Handwritten Character Recognition: A Palm Top Implementation and Adaptive Committee Experiments*. Master's Thesis, Helsinki University of Technology.
- Alias, A.J., Ahmad, I., and Muad, A.M. (2000). *Pendekatan Rangkaian Neural di dalam Pengesanan Kekacatan Bagi Teknik Tanpa Musnah*. Prosiding Simposium Teknologi Maklumat (ITSim'2K), Malaysia, pp. 29-37
- Alimoglu, F. (1994). *Combining Multiple Representation and Classifiers Pen-based Handwritten Digit Recognition*. M.Sc Thesis, Bogazici University, Turkey.
- Al-Jumaily, A. A., Taib, M.Z., and Shahrim, M. R. (2002). *Neural Network Based Recognition Engine for Car Plate Recognition System*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia, pp. 298-304.
- AlNaqeeb A.A (2001). *Color Recognition Using Neural Network*. National Artificial Intelligent Seminar (AIS 2001), Malaysia.
- Arjunan, S., Deris, S., Illias, R.M., and Mohamad, M.S. (2003). *A Parallelizing Interface for K-Means Type Clustering Algorithms and Neural Network Batch Training (I)*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Bahlmann, C., Bockhorn, D., Triebel, R. and Simon, K. (2003). *Frog On Hand*. Online: <http://lmb.informatik.uni-freiburg.de/people/bahlmann/frog.en.html>. Accessed date: 13<sup>th</sup> November, 2003.
- Breuel M. T. (1993). *Recognition of Handprinted Digits using Optimal Bounded Error Matching*. International Conference on Document Analysis and Retrieval (CDAR), Tsukuba Science City, Japan.
- Chan, K., F., and Yeung, D., Y.. (1999). *Recognizing on-line handwritten alphanumeric characters through flexible structural matching*. Pattern Recognition, 32(7). pp. 1099-1114.

- Chan, K., F., Yeung, D., Y. (2001). *PenCalc: a novel application of on-line mathematical expression recognition technology*. Proceedings of the Sixth International Conference on Document Analysis and Recognition. pp.774-778.
- Cheung, K., W., Yeung, D., Y., and Chin. R., T. (2002). *Bidirectional deformable matching with application to handwritten character extraction*. IEEE Transactions on Pattern Analysis and Machine Intelligence, 24(8). pp. 1133-1139.
- Cheung, K., W., Yeung, D., Y., and Chin. R., T., (1998). *A Bayesian framework for deformable pattern recognition with application to handwritten character recognition*. IEEE Transactions on Pattern Analysis and Machine Intelligence, 20(12). pp. 1382-1388.
- Duin, P., W., R., and Pekalska, E. (2001). *Automatic Pattern Recognition By Similarity Representations A Novel Approach*. Online: <http://citeseer.ist.psu.edu/pekalska01automatic.html>. Accessed date 12<sup>th</sup> January 2004.
- Dyer, C., C., and Ip, S., S., P. (2000). *An Elementary Introduction to Scientific Computing*. Online: [http://pathfinder.scar.utoronto.ca/~dyer/csca57/book\\_P/book.html](http://pathfinder.scar.utoronto.ca/~dyer/csca57/book_P/book.html). Accessed date: 15<sup>th</sup> January 2004.
- Elfadil N., Salami, M., J., E., Khalil., M., Nor, M., S. (2002). *Disk Performance Recognition Using Kohonen Self-Organizing Neural Networks & Expert System*. International Conference 2002, Malaysia.
- Hanafi, D. and Rahmat, M.F. (2003). *System Identification of Nonlinear Model of A Quarter Car Passive Suspension with Backpropagation Neural Network*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Hinton, G. E., Dayan, P., and Revow, M. (1995). *Recognizing Handwritten Digits Using Mixtures of Linear Models*. Advances in Neural Information Processing Systems Vol (7) MIT Press, Cambridge University, pp. 1015-1022.
- Hinton, G. E., Dayan P., and Revow, M. (1997). *Modeling the Manifolds of Images of Handwritten Digits*. IEEE Transactions on Neural Networks Vol (8). Toronto, Canada, pp. 65-74.
- Hitam, M.S., Muslan, M.Y.H., and Deris, M. M. (2003). *Image Texture Classification Using GLCM, Projection and Neural Network*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.

- Husin, S. S. F., Khalid, M., and Yusof, R. (2002). *Design of and Intelligent License Plate Recognition System : VISIONPLATE II*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia, pp. 305-310.
- Hani, A. F. M. and Irfan, A. R. (2003). *Face Recognition using MYKAD Security(I)*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Haykin, S. (1999). *Neural Networks: A Comprehensive Foundation*, 2nd Edition, New Jersey: Prentice Hall.
- Ishak, W., H., W., and Rahman, A., S. (2003). *Neural Network in Handwritten Recognition System: A Survey*. Seminar ICT Kebangsaan, Arau, pp. 132-140.
- Janahiraman, T., Tay, Y. H., Khalid, M., and Yusof, R. (2002). *Classification of Handwritten Digits Using Geometrical and Topological Feature Extraction Technique And Neural Network*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia, pp. 291-297.
- Junoh, M.Z.H.M. and Siraj, F. (2001). *Evaluating Multilayer Perceptron and Multiple Regression On Breast Cancer*. National Artificial Intelligence Seminar (AIS 2001), Malaysia.
- Kaastra, I. and Boyd, M. (1996) Designing a Neural Network for Forecasting Financial and Economic Time Series. *Neurocomputing* 10: 215-236. Elsevier Science B.V.
- Khalid, M.A., Muad, A.M., Muhamad, A.A., Hamzah, A.R., and Ghazali, A.B. (1999). *Recognition of Welding Defects on Radiographic Films Using Image Processing and Neural Network*. Proceedings of The First National conference on Artificial Intelligence In Industry (AIAI'99), Kuala Lumpur, pp.16-25.
- Kuan, M., M., Lim, C.P., Ismail, O., Yuvaraj, R.M., and Singh, I. (2002). *Application of Artificial Neural Network to Diagnose of Acute Coronary Syndrome*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia.
- Lay, C.B., Khalid, M., and Yusof, R. (1999). *Intelligent Database by Neural Network and Data Mining*. Proceedings of The First National conference on Artificial Intelligence In Industry (AIAI'99), Kuala Lumpur. pp.201-219.
- Laaksonen, J., Aksela, M., Oja, E., and Kangas, J. (1999) *Dynamically Expanding Context as Committee Adaptation Method in On-line Recognition of Handwritten Latin Characters*. Proceedings of ICDAR '99, India. pp. 489-497.

- Laaksonen, J., Hurri, J., Oja, E., and Kangas, J. *Comparison of Adaptive Strategies for On-Line Character Recognition*. Proceedings of ICANN'98. pp. 245-250.
- Laaksonen, J., Hurri, J., Oja, E., and Kangas, J. (1998). *Experiments with a Self-Supervised Adaptive Classification Strategy in On-Line Recognition of Isolated Handwritten Latin Characters*. Proceedings of IWFHR98, Korea. pp. 475-484.
- Lazim, M.M., Sap, M.N.M., and Mohamad, D. (1990). *Pengecaman Tulisan Tangan: Keperluan Sistem dan Satu Pendekatan Terhadap Penyelesaian Deterministik*. Jurnal Teknologi Maklumat 1(1), pp. 44-53.
- LeCun, Y., Jackel, L., Bottou, L., Brunot, A., Cortes, C., Denker, J., Drucker, H., Guyon, I., Muller, U., Sackinger, E., Simard, P., and Vapnik V. (1995). *Comparison of Learning Algorithm For Handwritten Digit Recognition*. Holmdel, USA.
- LeCun, Y., Boser, B., Denker, J.S., Henderson, D., Howard, R.E, Hubbard, W., and Jackel, L.D. (1990). *Handwritten Digit Recognition with a Back-Propagation Network*. Holmdel, USA, pp. 396-404.
- Lee, N. K., Wang, D. H., and Tan, K. W. (2003). *Protein Classification Using Neural Networks : A Review*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Liam, L.W., Chekima, A., Dargham, J.A., and Fan, L.C. (2002). *Iris Recognition Using Self-Organizing Neural Network*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia.
- Lim, P.C., Woo, S. C., and Osman, R. (2002). *Classification of Speech Signals using Supervised ART-Based Neural Networks*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia.
- LiminFu (1994). *Knowledge discovery based on neural networks*. Neural Network In Computer Intelligence, New York. pp.47-50.
- Phokaratkul, P., Suedsanit, T., Pantaragphong, P., Pinngern, O., and Kimpan, C. (2002). *Printed Thai Characters Recognition Using Rough Classification*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia, pp. 284-290.
- Pofahl, W.E., Walczak, S.M., Rhone, E., and Izenberg, S.D. (1998) *Use of an artificial neural network to predict length of stay in acute pancreatitis*. American Surgeon, pp. 868-872.

- Ramachandram, D. and Rajeswari, M. (2003). *A Short Review of Neural Network Techniques in Visual Servoing of Robotic Manipulators*. Malaysia – Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Rashid, R., Jamaluddin, H., and Amin, N.A. S. (2003). *Application of Multi-Layer Perceptron in Modeling Tapioca Starch Hydrolysis*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Saxena, I., Moerland, P., Fiesler, E., and Pourzand, A. (1997). *Handwritten Digit Recognition with Binary Optical Perceptron*. Proceedings of the International Conference on Artificial Neural Networks (ICANN'97). Online: [http://www.alltheweb.com/r?ck\\_sm=3379f3&rpos=1&rpage=1&ref=200320086&r=http://www.idiap.ch/~perry/saxena-97.3.bib.abs.html](http://www.alltheweb.com/r?ck_sm=3379f3&rpos=1&rpage=1&ref=200320086&r=http://www.idiap.ch/~perry/saxena-97.3.bib.abs.html). Accessed date: 13<sup>th</sup> November, 2003.
- Sarle, W.S. (1994a). *Neural Network and Statistical Models*. Proceedings of the Nineteenth Annual SAS Users Group International Conference, Cary, NC :SAS Institute, pp. 1538-1580.
- Sarle, W.S. (1994b). *Neural Network Implementation in SAS Software*. Proceedings of the Nineteenth Annual SAS Users Group International Conference, Cary, NC :SAS Institute.
- Stergiou, C., and Siganos, D., (1996) *Neural Networks, Volume 4*.
- Seni, G. (1995). *Large Vocabulary of on-line Handwritten Cursive Word*. Ph.D. Dissertation, Cambridge University.
- Siraj, F., Zakaria, A., Aziz, A. A., and Abas, Z. (2003). *WEBIC: A Web Based Business Insolvency Classifier Using Neural Networks (I)*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Sordo, M., Fox, J., Blum, C., Taylor, P. Lee, R. and Alberdi, E. (2001). *Combining decision support and image processing: a PROforma model*. Proceedings of the Tenth World Congress on Health and Medical Informatics (medinfo2001), London.

- Sulaiman, S., Osman, M. R., and Ahmad, M.M.H.M. (2003). *Development of a Knowledge-based Feature Recognition System for Mechanical Parts*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Tsoukalas, L. H., and Uhrig R. E., (1997) *Fuzzy and Neural Approaches in Engineering*, John Wiley & Sons, Inc.
- Turban, E., (1993) *Decision Support and Expert Systems: Management Support Systems*, Macmillan Publishing Company.
- Vuori, V. (2002). *Adaptive Method for On-Line Recognition of Isolated Handwritten Characters*. Doctoral Thesis, Helsinki University of Technology.
- Vuori, V., Laaksonen, J., Oja, E., Kangas, J. (2001). *Speeding up On-line Recognition of Handwritten Characters by Pruning the Prototype Set*. Proceedings of ICDAR'01, pp. 501-505, Seattle, USA.
- Vuori, V. and Oja, E. (2000). *Analysis of Different Writing Styles with Self-Organizing Map*. Proceedings of the ICONIP2000, volume (2), pp. 1243-1247, Taejon, South Korea.
- Vuori, V., Aksela, M., Laaksonen, J., Oja, E. and Kangas, J. (2000). *Adaptive character recognizer for hand held device: implementation and evaluation setup*. Proceedings of the IWFHR2000. Amsterdam, Netherlands. pp. 13-22.
- Vuori, V., Laaksonen, J., Oja, E., Kangas, J. (1999). *On-line Adaptation in Recognition of Handwritten Alphanumeric Characters*. Proceedings of ICDAR '99, India.
- Wahap, A. R., Khalid, M., Ahmad, A. R., and Yusof, R. (2002). *A Neural Network Based Bank Cheque Recognition system for Malaysian Cheques*. International Conference on AI in Engineering and Technology (ICAIET-2002), Malaysia, pp. 273-279.
- Yusof, K. M., Idris, A., and Morad, N. A. (2003). *Artificial Neural Network Modeling of Steady-state Chemical Engineering Systems*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.
- Zin, Z. M., Salleh, S.H.S., and Sulaiman, M.D. (2003). *Classifications of Mitral Regurgitation and Normal Heart Sounds based on Artificial Neural Network and Wavelet*. Malaysia - Japan Seminar on Artificial Intelligence Applications in Industry (AIAI 2003), Kuala Lumpur.