IMPROVED CLUSTERING APPROACH FOR JUNCTION DETECTION OF MULTIPLE EDGES WITH MODIFIED FREEMAN CHAIN CODE

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This thesis is dedicated to:

My lovely wife Zaharah
whose love and support

and

for my children
Mohd Daniel Haziq, Nurhanisah Zakirah and Nur Awadah Zahirah

Thank you for always being there for me, supporting me and encouraging me to be the best that I can be

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ABSTRACT

Image processing framework of two-dimensional line drawing involves three phases that are detecting junction and corner that exist in the drawing, representing the lines, and extracting features to be used in recognizing the line drawing based on the representation scheme used. As an alternative to the existing frameworks, this thesis proposed a framework that consists of improvement in the clustering approach for junction detection of multiple edges, modified Freeman chain code scheme and provide new features and its extraction, and recognition algorithm. This thesis concerns with problem in clustering line drawing for junction detection of multiple edges in the first phase. Major problems in cluster analysis such as time taken and particularly number of accurate clusters contained in the line drawing when performing junction detection are crucial to be addressed. Two clustering approaches are used to compare with the result obtained from the proposed algorithm: self-organising map (SOM) and affinity propagation (AP). These approaches are chosen based on their similarity as unsupervised learning class and do not require initial cluster count to execute. In the second phase, a new chain code scheme is proposed to be used in representing the direction of lines and it consists of series of directional codes and corner labels found in the drawing. In the third phase, namely feature extraction algorithm, three features proposed are length of lines, angle of corners, and number of branches at each corner. These features are then used in the proposed recognition algorithm to match the line drawing, involving only mean and variance in the calculation. Comparison with SOM and AP clustering approaches resulting in up to 31% reduction for cluster count and 57 times faster. The results on corner detection algorithm shows that it is capable to detect junction and corner of the given thinned binary image by producing a new thinned binary image containing markers at their locations.

ABSTRAK

Rangka kerja pemprosesan imej lukisan garis dua dimensi melibatkan tiga fasa iaitu pengesanan simpang dan sudut yang wujud dalam lukisan, mewakilkan garisan, dan penyarian sifat-sifat untuk digunakan dalam pengecaman lukisan garis berdasarkan skema perwakilan yang digunakan. Sebagai pilihan kepada rangka kerja sedia ada, tesis ini mencadangkan rangka kerja yang melibatkan pembaikan dalam pendekatan pengelompokan untuk mengesan simpang berbilang pinggir, skema kod rantaian Freeman terubahsuai dan menyediakan sifat-sifat baru dan penyariannya, dan algoritma pengecaman. Tesis ini menumpukan kepada masalah di dalam pengelompokan lukisan garis bagi mengesan simpang berbilang pinggir dalam fasa pertama. Masalah utama dalam analisa kelompok adalah seperti masa yang diperlukan, dan penentuan bilangan kelompok yang tepat di dalam lukisan garis semasa melaksanakan pengesanan simpang adalah amat penting untuk ditangani. Dua pendekatan kelompok yang digunakan bagi membandingkan keputusan dengan algoritma yang dicadangkan adalah peta swa-organisasi (SOM) dan rambatan afiniti (AP). Kaedah-kaedah ini dipilih berdasarkan kesamaan mereka sebagai kelas pembelajaran tidak diselia dan tidak memerlukan nilai awal bilangan kelompok untuk melaksanakannya. Dalam fasa kedua, skema kod rantaian baru dicadangkan bagi digunakan untuk mewakili arah tuju bagi garisan dan ia mengandungi beberapa siri kod berarah dan label selekoh/simpang yang dijumpai di dalam lukisan. Manakala fasa ketiga di kenali sebagai algoritma penyarian sifat, tiga sifat yang telah di cadangkan adalah panjang garis, sudut bagi simpang dan bilangan cabang bagi setiap simpang. Sifat-sifat ini kemudiannya digunakan dalam algoritma pengecaman yang dicadangkan bagi pemadanan lukisan garis, ia melibatkan hanya nilai min dan varians dalam pengiraan. Perbandingan keputusan dengan pendekatan pengelompokan SOM dan AP menunjukkan 31% pengurangan bilangan kelompok dan 57 kali lebih pantas. Keputusan ini menunjukkan algoritma pengesanan simpang mampu mengesan simpang bagi suatu imej binari ternipis dengan menghasilkan imej binari ternipis baru yang mengandungi tanda pada lokasi simpang. .

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LIST OF ABBREVIATION

CAD	-	Computer Aided Design
CCW	-	Counter-clockwise
CEDAR	-	Center of Excellence for Document Analysis and Recognition
CW	-	Clockwise
FCC	-	Freeman Chain Code
IDRI	-	Imaging Database Resources Initiative
JPEG	-	Joint Photographic Experts Group
MFCC	-	Modification Freeman Chain Code
NIST	-	National Institute of Standards and Technology
PDL	-	Picture Description Language
PNG	-	Portable Network Graphics format
TBI	-	Thinned Binary Image
TIFF	-	Tagged Image File Format
VCC	-	Vertex Chain Code

CHAPTER 1

INTRODUCTION

1.1 Introduction

Recognition of line drawing involves image processing and pattern recognition that includes procedural automation on a computer system to execute a specific task. Some of the famous examples are handwritten recognition for postal address and cheque receipt, corner and edge detection, and object recognition (Xue et al., 2012; Boodoo and Baichoo, 2013). Four fields related to recognition of line drawing include image processing, line drawing interpretation, picture description language, and feature extraction and recognition (Haron, 2004; Varley and Martin, 2000; Durand 2012).

Image processing is a technique to convert an image into digital form by analyzing and manipulating images using a computer. This operation is necessary for image visualization, image sharpening and restoration, image retrieval, measurement of pattern and image recognition (Durand, 2012; Eitz, 2012).

Line drawing in the recognition process can be categorised into a few types such as single still image or in sequence (video), and the output is recognised items contained in the image such as edges, characters and paths (Yazdi and Toussi, 2011). In this thesis, the object of interest is structure outline in form of line drawing converted into a chain code representation. The comparison of two structures will include the information or features, extracted from each chain code. The differences between the two will show whether the input structures have been subjected to any rotation and sizing operations. The process will conclude the result based only on the given chain code which acts as the sole structure information source, reflecting the chain code properties for efficient image data storage.

The initial step in the pre-processing stage is binarization. In binarization, the image is converted into 0 and 1. 0 is equal to background and 1 is equal to foreground (Pitas, 1995). Next, skeletonization or thinning procedure is performed to the input structure line drawing to ensure that the line thickness to be exactly 1 pixel (Lee and Wang, 1994), except where the connected line meets. Such location will be found by clustering method in subsequent stage.

Pixel clustering searches for groups of pixels located closely together and assigned them as members to unique clusters. Additionally, the process finds cluster gates, which are the line ends connecting between clusters. By applying a set of rules to every foreground pixel in the image, the method prepares the image for further processing in junction detection stage.

Junction detection stage includes corner detection and junction located in groups of pixels called cluster. A corner is defined as locations where two line edges with different slopes meet (Park and Gravel, 2013; Gopal et al., 2010) while junctions in a cluster connect all edges pointing into the cluster. The process hugely depends on line vector concept, making use of gradient to locate the most suitable junction position for a particular place. After all junctions in the structure have been recognized, binary image will be updated with their location marked with special character as preparation for chain code extraction.

Chain code style used in this thesis is a modification of Freeman chain code (MFCC) to include junction marker in the chain code string as indicator for edge's starting and end junction. The string formatting is also developed to adapt this edge source-destination requirement by recording junction marker occurrence. Junction label used as the marker is positioned along the traversal of the structure, prioritizing the junction situated at the outer loop before completing the line drawing trip in the inner loop. The output for this chain code extraction stage is the MFCC representing the line drawing structure. By extracting features from two MFCC of different structures and comparing them in recognition stage, it is possible to see whether the line drawings have any matching properties or not.

An algorithm is developed to handle the task of recognising the line drawing based on the MFCC. Connection between junctions and their corresponding vector attributes such as slope and length are all constructed from the chain code by parsing through the string and storing the information accordingly into the data structure. This information would be used in two contexts: junction matching and geometrical fitting. The operation sequence is done repeatedly until a match is found or no more alternative pattern is available which marks the end of the process. The result is either the line drawing is identical; the structure orientation is varied or completely different.

This thesis proposes a framework that performs the recognition of line drawing involving five fields mentioned above, using line drawing input. By applying existing image processing function and algorithm, a new clustering method, corner detection algorithm, chain code scheme and lastly features for the recognition process are introduced.

1.2 Problem Statement

Clustering is an approach used in many applications such as information retrieval, image analysis, machine learning, pattern recognition and bioinformatics (Jain, 2010; Yang et al, 2010). Due to unsupervised nature of clustering approach, number of cluster is an unknown parameter in most cases, and user knowledge in terms of relationship between data is limited. Therefore, assessment of different clustering algorithms and determining the number of clusters are significant research issues in cluster analysis (Rokach, 2010; Luxburg, 2007).

Problem in clustering line drawing for junction detection of multiple edges usage is the main concern of this thesis. Only two clustering techniques, SOM and AP are chosen for benchmarking purpose since other methods needs initial cluster count as mandatory parameter before processing can start. Even though SOM and AP could generate junction clusters automatically, the area suggested is imprecise and takes a considerable amount of time. Issues such as time taken and particularly number of accurate clusters contained in the line drawing are crucial when performing junction detection. These two issues are resolved using proposed clustering method by marking the image pixels as cluster members and gates with special characters.

Chain code scheme is one of the techniques in computer vision field. It is commonly used in image representation to symbolize a series of line drawing with predefined movement direction and length (Freeman, 1961). This representation can be used in image processing field such as image compression, feature extraction and pattern recognition (Siddiqi and Vincent, 2009). This thesis proposes a new chain code series that combines standard FCC format with additional character as marker to indicate any junction or corner exists in the thinned binary image (TBI). This is done by producing only a single series of chain code even though there are multiple junctions occurring in the line drawing. This new chain code is also introduced for feature extraction and later, in image recognition implementation.

1.3 Objectives

The main objectives of this thesis are shown below:

i. To develop a new clustering method for image pixels to assist in corner detection stage.
ii. To develop a new corner detection algorithm based on line vector.
iii. To introduce modified Freeman chain code and its chain code generator algorithm.
iv. To develop feature extraction and recognition algorithm based on modified Freeman chain code.

1.4 Scope

The scopes of this study are as listed below:

i. The studied image is line drawing with closed loop taken from publication, internet and self-drawn.
ii. For thinning line drawing, thinning function in standard commercial software and manual pixel deletion is applied for pre-processing.
iii. The rotation and scaling of images are performed by standard commercial image editor function.
iv. The corner detection algorithm covered a variable number of junctions, along with possibility of having multiple junctions in a single cluster.

1.5 Thesis Organization

This thesis is divided into seven chapters. This chapter gives introduction and motivation of the thesis. Chapter 2 presents literature review of four fields related to the thesis, followed by the research methodology in Chapter 3. Chapter 4 explains the pixel clustering and corner detection of the line drawing by using examples for better understanding. Chapter 5 presents chain code generation algorithm by providing 3 pseudo codes used in generating the MFCC. Chapter 6 presents features of the recognition process and its feature extraction algorithm. The explanation of the algorithm is supported by examples for easy understanding. The thesis ends with conclusion and future work in Chapter 7.

REFERENCES

Amerijckx, C., Verleysen, M. and Legat, J. D. (1998). Image compression by self-organized Kohonen map. *IEEE Transactions on Neural Networks*, 9(3), 503–507.

Arrebola, F., Bandera, A, Camacho, P. and Sandoval, F. (1997). Corner Detection by Local Histograms of Contour Chain Code. *Electronics Letters,* 33(21), 1769-1771.

Arrebola, F., Bandera, A, Camacho, P. and Sandoval, F. (1999). Comer Detection and Curve Representation by Circular Histograms of Contour Chain Code. *Electronic Letters,* 35(13), 1065-1067.

Banerjee, A., Merugu, S., Dhillon, I.S and Ghosh, J. (2005). Clustering with Bregman divergences. *The Journal of Machine Learning Research*, 6,1705–1749.

Blumenstein, M., Verma, B. and Basli, H. (2003). A novel feature extraction technique for the recognition of segmented handwritten characters. *Proceedings of the Seventh International Conference on Document Analysis and Recognition* (ICDAR '03), Edinburgh, Scotland, 137-141.

Boodoo-Jahangeer, N. and Baichoo, S. (2013). Face Recognition Using Chain Codes. *Journal of Signal and Information Processing*, 4(3B), 154-157.

Bribiesca, E. (1999). A New Chain Code. *Pattern Recognition*, 32. 235-251.

Bribiesca, E. (2000). A Chain Code for Representing 3D Curves. *Pattern Recognition*, 33, 755-765.

Bribiesca, E. (2003). Scanning-curves Representation for the Coverage of Surfaces Using Chain Code. *Computer & Graphics*, 27(1), 123-132.

Bribiesca, E. (2004). 3D-Curve Representation by Means of a Binary Chain Code. *Mathematical and Computer Modelling*, 40, 285-295.

Chiou, Y. C. and Liang, Y. T. (2010). An effective corner detection method using subpixel edge detector and Gaussian filter. *Sensor Review*. 30(1), 51–61.

Corridoni, J.M., Del Bimbo, A. and Landi, L. (1996). 3D object classification using multi-object Kohonen networks.

Cowan, T. M. (1977). Organizing the Properties of Impossible Figures. *Perception*, 6, 41-56.

Dey, N., Nandi, P. and Barman, N. (2011). A Novel Approach of Harris Corner Detection of Noisy Images using Adaptive Wavelet Thresholding Technique. *International Journal of Computer Science & Technology*, (IJCST), 2(4), 380-384.

Dueck, D. (2009). *Affinity propagation: clustering data by passing messages.* PhD Thesis, University of Toronto.

Durand, F. (2012). Technical Perspective: Where Do People Draw Lines? *Magazine -Communications of the ACM*, 55(1), 106.

Eitz, M., Richter, R., Boubekeur, T., Hildebrand, K. and Alexa, M. (2012). Sketch-based shape retrieval. *ACM Transactions on Graphics (TOG)* - SIGGRAPH 2012 Conference Proceedings, 31(4).

Figueiredo, M.A. and Jain, A.K. (2002). Unsupervised learning of Finite Mixture Models. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 24(3), 381–396

Fodeh, S. J., Punch, W.F. and Tan, P. N. (2009). Combining statistics and semantics via ensemble model for document clustering. *In Proc. of the 2009 ACM symposium on Applied Computing*. 1446–1450.

Freeman, H. (1961). On the Encoding of Arbitrary Geometric Configurations. *Electronic Computers, Institute of Radio Engineers, Transactions on Electronic Computers*, EC-10 (2), 260-268.

Freeman, H., Glass, J. M. (1969). On the Quantization of Line Drawing Data. *Systems Science and Cybernetics, IEEE Transactions on.* 5(1), 70-79.

Freeman, H. (1974). Computer Processing of Line-Drawing Images. *ACM Computing Surveys*, 6(1), 57-97.

Frey, B. J. and Dueck, D. (2006). Mixture modeling by affinity propagation. *Advances in neural information processing systems,* 18**,** 379-386.

Frey, B. J. and Dueck, D. (2007). Clustering by passing messages between data points. *science,* 315**,** 972-976.

Friedberg, S. A. (1986). Finding Axes of Skewed Symmetry. *Computer Vision, Graphics and Image Processing*, 134, 138-155.

Fujiwara, Y., Irie, G. and Kitahara, T. (2011). Fast algorithm for affinity propagation. *In:* IJCAI *Proceedings-International Joint Conference on Artificial Intelligence,* 2238.

Gráfová, L., Jan Mareš, J., Aleš Procházka A. and Konopásek P. (2013). Edge Detection in Biomedical Images Using Self-Organizing Maps. *In Artificial Neural Networks - Architectures and Applications. InTech*, 125–143.

Gopal, A., Patil, S. and Nikam, A. (2010). A Parallel Algorithm for Image Edge Detection using Difference Chain Encoding. *International Journal of Computer Science and Application Issue 2010.* 66-69.

Grimstead, I. J. and Martin, R. R. (1995). Creating Solid Model From Single 2D Sketches. *Proceedings Third Symp. On Solid Modelling Applications*, ACM SIGGRAPH, 323-337.

Grimstead, I. J. (1997). *Interactive Sketch Input of Boundary Representation Solid Models.* PhD Thesis, University of Cardiff, UK.

Hanmandlu, M. and Murthy (2007). Fuzzy model based recognition of handwritten numerals. *Pattern Recognition*, 40(6), 1840-1854.

Haron, H. (2004). *Enhanced Algorithms for Three-Dimensional Object Interpreter*. PhD Thesis. University Teknologi Malaysia.

Haron, H., Shamsuddin, S. M. and Mohamed, D. (2004). Chain Code Algorithm In Deriving T-Junction And Region Of A Freehand Sketch. *Jurnal Teknologi*, 40(D), 25-36.

Hermann, S. and Klette, R. (2005). Global Curvature Estimation for Corner Detection. *Communication and Information Technology Research Technical Report*, (171).

Hong, Z. Q. (1991). Algebraic feature extraction of image for recognition. *Pattern Recognition*, 24(3), 211-219.

Huffman, D. A. (1971). Impossible Objects as Nonsense Sentences. *Machine Intelligence*, 6, New York, American Elsevier, 295-323.

Jaffe, A., Naaman, M., Tassa, T. and Davis, M. (2006). Generating summaries and visualization for large collections of georeferenced photographs. *In Proc. of the 8th ACM international workshop on Multimedia information retrieval*. 89–98.

Jain, A.K. (2010). Data clustering: 50 years beyond K-means, *Pattern Recognition Letters* 31(8), 651–666.

Jain, A. K., Murty, M. N. and Flynn, P. J. (1999). Data clustering: a review. *ACM computing surveys* (CSUR). 31(3), 264–323.

Jordan, J. and Angelopoulou, E. (2011). Edge Detection In Multispectral Images Using The N-Dimensional Self-Organizing Map. *In 18th IEEE International Conference on Image Processing* (ICIP). IEEE, 3181–3184.

Joutsiniemi, S. L., Kaski, S. and Larsen, T. A. (1995). Self-Organising Map in Recognition of Topographic Patterns of EEG Spectra. *IEEE Transactions on Biomedical Engineering*. 42(11), 1062–1068.

Kanade, T. (1981). Recovery of the Three-Dimensional Shape of an Object from a Single View. *Artificial Intelligence*, 17, 409-460.

Kangas, J. (1991). Time-Dependant Self Organising Maps for Speech Recognition. *Artificial Neural Networks*. 1591–1594.

Kinnunen, T., Sidoroff, I., Tuononen, M. and Fränti, P. (2011). Comparison of clustering methods: a case study of text independent speaker modeling. *Pattern Recognition Letters*. 32(13), 1604–1617.

Koh, J., Suk, M. and Bhandarkar, S. M. (1993). A multi-layer Kohonen's self-organizing feature map for range image segmentation. *In IEEE International Conference on Neural Networks*. 1270–1275.

Kohonen, T., Oja, E., Simula, O., Visa, A. and Kangas, J., (1996). Engineering Applications of the Self-Organising Map. *Proceedings of the IEEE*, 84(10). 1358–1384.

Kohonen, T. (2001). *Self-Organizing Maps* (3rd ed), Springer.

Laganière, R. (1998). Morphological Corner Detection. *Proceedings of the Sixth International Conference on Computer Vision* (ICCV), 4-7 Jan 1998, 280-285.

Le, X. and Gonzalez, R. (2009). Pattern-Based Corner Detection Algorithm. *International Symposium on Image and Signal Processing and Analysis* (ISPA 2009). 238-243

Leclerc, Y. G. and Fischler, M. A (1992). An Optimisation-Based Approach to the Interpretation of Single Line Drawing as 3D Frames. *International Journal of Computer Vision*, 9(2), 113-136.

Lee, C. L. and Wang, P. S. P. (1994). A New Thinning Algorithm, *Proc*. *12th IAPR Int. Conf. On Compo Vision & Image Processing, Patten Recognition*, 1, 546-548.

Leeuwenberg, E. (1971). A perceptual coding language for visual and auditory patterns. *American Journal of Psychology*, 84, 307-349.

Li, M., Wang, J. Z., Li, L. L. and Li, C. H. (2009). Curvature statistic corner detection. *Power Electronics and Intelligent Transportation System* (PEITS), 1, 309-312.

Lipson, H. and Shpitalni, M. (1996). Optimisation-based Reconstruction of a 3D Object from a Single Freehand Line Drawing. *Computer Aided Design*, 28(8), 651-663.

Liu, C. L., Nakashima, K., Sako, H., and Fujisawa, H. (2004). Handwritten digit recognition: investigation of normalization and feature extraction techniques. *Pattern Recognition*, 37(2), 265-279,

Liu, H. C. and Srinath, M. D. (1990). Corner detection from chain-code. *Journal Pattern Recognition.* 23(1-2), 51-68.

Liu, Y. K. and Zalik, B. (2005). An Efficient Chain Code with Huffman Coding, *Pattern Recognition*, 38, 553-557.

Luxburg, U. (2007). A tutorial on spectral clustering. *Statistics and computing*, 17(4), 395–416.

MacQueen, J. (1967). Some methods for classification and analysis of multivariate observations. *In Proceedings of the fifth Berkeley symposium on mathematical statistics and probability*. 281–297.

Mangiameli, P., Chen, S. K. and West, D. (1996). A comparison of SOM neural network and hierarchical clustering methods. *European Journal of Operation Research*, 93(2), 402–417.

Marill, T. (1991). Emulating the Human Interpretation of Line Drawing as Three Dimensional Objects. *International Journal of Computer Vision*, 6(2), 147-161.

Matondang, M. Z., Samah, A. A., Haron, H. and Majid, H. A. (2011). Graph Colouring Algorithm for Validating Labelled 2D Line Drawing Objects. *International Journal of Computer Science Issues*, 8(5), 1-7.

Maung, P. P. (2012). Augmented Reality using a Neural Network, *Midwest Instruction and Computing Symposium* (MICS).

McLachlan, G. and Peel, D. (2005). *Finite mixture models*, Wiley Series in Probability and Statistics.

Noulas, A., Scellato, S., Mascolo, C. and Pontil, M. (2011). Exploiting semantic annotations for clustering geographic areas and users in location-based social networks. *In Fifth International AAAI Conference on Weblogs and Social Media*, 32–35.

Ozkan, K., Topal, C. and Akinlar, C. (2011). Corner detection via trilateral filtering of chain codes. *Innovations in Intelligent Systems and Applications* (INISTA), 168-172.

Okamoto, N., Chen, W., Iida, N. and Minami, T. (1997). Automatic Extraction of Contour Lines and Feature Points from Profile Images. *Electrical and Computer Engineering, 1997. Engineering Innovation: Voyage of Discovery*. IEEE. 2, 831-834.

Papari, G. and Petkov, N. (2011). Edge and line oriented contour detection: State of the art. *Image and Vision Computing*, 29**,** 79-103.

Papert, S. (1973). Uses of Technology to Enhance Education, *Technical Report*. AIM-298, Al Lab, MIT.

Parks, D. and Gravel, J. P. (2013). http://uc-kinect-research.googlecode.com/svn/trunk/Papers and Presentations/RGB Algorithms/ Corner Detection Introduction.pdf (August 2014)

Pitas, I. (1995). *Digital Image Processing Algorithm*, University Press Cambridge, Prentice Hall.

Rattarangsi, A., Chin, R. T. (1992). Scale-based detection of corners of planar curves. *Pattern Analysis and Machine Intelligence*, IEEE Transactions on , 14(4), 430-449.

Rokach, L. (2010). A survey of clustering algorithms. *In Data Mining and Knowledge Discovery Handbook. Springer*. 269–298.

Scheunders, P. (1997). A comparison of clustering algorithms applied to color image quantization. *Pattern Recognition Letters*, 18(11), 1379–1384.

Schomaker, L. (1993). Using Stroke or Character Based Self Organising Maps in the Recognition of On-line, Connected Cursive Scripts. *Pattern Recognition*, 26(3), 443–450.

Sekita, I., Toraichi, K., Mori, R., Yamamoto, K. and Yamada, H.(1988). Feature extraction of handwritten Japanese. *Pattern Recognition* 21(1), 9-17.

Siddiqi, I. and Vincent, N. (2009). A Set of Chain Code Based Features for Writer Recognition, *Document Analysis and Recognition*, ICDAR., 9, 981-985.

Sun, Y. X., Zhang, C. M., Liu, P. Z. and Zhu, H. M. (2007). Shape feature extraction of fruit image based on chain code. *Wavelet Analysis and Pattern Recognition*, 3, 1346-1349.

Toivanena, P. J., Ansamäkib, J., Parkkinenc, J. P. S and Mielikäinena, J. (2003). Edge detection in multispectral images using the self-organizing map. *Pattern Recognition Letters*. 24(16), 2987–2994.

Trahanias, P. E. and Venetsanopoulos, A.bN. (1993). Color edge detection using vector order statistics. *IEEE Transactions on Image Processing*. 2(2), 259–264.

Tsai, D. M., Hou, H. T. and Su, H. T. (1999). Boundary-based corner detection using eigenvalues of covariance matrices. *Journal Pattern Recognition Letters*. 20(1), 31-40.

Ugbaga, I. N., Sulong, G. (2013). Human Ear Classification Scheme Based On Lobule Chain Code And Helix Dimensionality. *European Scientific Journal November 2013 edition*, 9(33),286-298.

Ultsch, A. (1992). Knowledge Acquisition with Self-Organising Neural Networks. *Artificial Neural Networks*. 735–739.

Varley, P. A. C. and Martin, R. R. (2000). A System for Constructing Boundary Representation Solid Models from a Two-Dimensional Sketch. *IEEE Proc. Geometric Modelling and Processing*, 13-32.

Vicent, A. P., Calleja, P. C. and Martin, R. R (2003). Skewed Mirror Symmetry in the 3D Reconstruction of Polyhedral Models. *Journal of WSCG*, 11(1), 1-8.

Vidal, R. (2010). A tutorial on subspace clustering. *IEEE Signal Processing Magazine*. 28(2), 52–68.

Wang, C., Sun, G., Wang, Y. and Xu, L. (2010). An Improved Corner Detection Algorithm Based on Gaussian Smoothing. *In: Intelligent Computation*

Technology and Automation (ICICTA), International Conference on, 2010. IEEE, 536-539.

Wang, K., Zhang, J., Li, D., Zhang, X. and Guo, T. (2008). Adaptive affinity propagation clustering. *arXiv preprint arXiv:0805.1096*.

Wenzhi, L. and Youguo, P. (2009). Corner Detection of the Chinese Characters Based on First-Order Difference. *International Conference on Computational Intelligence and Natural Computing,* 2, 349-352.

Wesemann, S. and Fettweis, G. (2012). Decentralized formation of uplink CoMP clusters based on affinity propagation. *In: Wireless Communication Systems* (ISWCS), International Symposium on, 2012. IEEE, 850-854.

Wulandhari, L. A. and Haron, H. (2008). The Evolution and Trend of Chain Code Scheme. *ICGST International Journal on Graphics, Vision and Image Processing,* GVIP, 8, 17-23.

Würtz, R. P. and Lourens, T. (1997). Corner detection in color images by multiscale combination of end-stopped cortical cells. *International Conference of Artificial Neural Networks* (ICANN '97). 901-906.

Xiang, T. and Gong, S. (2008). Spectral clustering with eigenvector selection. *Pattern Recognition,* 41**,** 1012-1029.

Xu, R. and Wunsch, D. (2005). Survey of clustering algorithms. *IEEE Transactions on Neural Networks*, 16(3), 645–678.

Xue, T., Liu, J. and Tang, X. (2012). Example-based 3D object reconstruction from line drawings. *Computer Vision and Pattern Recognition* (CVPR), 2012 IEEE Conference on , 16-21 June, 302-309.

Yang, J. and Byun, H. (2008). Feature extraction method based on cascade noise elimination for sketch recognition. *Pattern Recognition, 19th International Conference on Pattern Recognition* (ICPR), 8-11 Dec, 1-4.

Yang, Y., Xu, D., Nie, F., Yan, S. and Zhuang, Y. (2010). Image clustering using local discriminant models and global integration. *IEEE Transactions on Image Processing*. 19(10), 2761–2773.

Yazdi, H. S. and Toussi, S. A. (2011). Edge/Corner Programming. *International Journal of Signal Processing, Image Processing and Pattern Recognition*, 4(2), 51-64.

Yu, D., Ma, L. and Lu, H. (2007). Lottery Digit Recognition Based on Multi-features. *Systems and Information Engineering Design Symposium*, 2007. SIEDS 2007. IEEE, 27 April, 1-4.

Zhang, X. H., Wang, H. X., Smith, A. W. B., Ling, X., Lovell, B. C. and Yang, D. (2010). Corner detection based on gradient correlation matrices of planar curves. *Pattern Recognition*, 43(4), 1207-1223.

Zheng, H. T., Kang, B. Y. and Kim, H. G. (2009). Exploiting noun phrases and semantic relationships for text document clustering. *Information Sciences*. 179(13), 2249–2262.

Zhu, M., Meng, F. and Zhou, Y. (2013). Semisupervised clustering for networks based on fast affinity propagation. *Mathematical Problems in Engineering*, 2013.

Zhu, Q., Wang, Y. and Liu, H. (2010). Auto-Corner Detection Based on the Eigenvalues Product of Covariance Matrices over Multi-Regions of Support. *Journal of Software*, 5(8), 907-914.