www.icgst.com

The Evolution and Trend of Chain Code Scheme

[1]Lili Ayu Wulandhari, [2]Habibolah Haron
Department of Modelling and Industrial Computing
Faculty of Computer Science and Information Systems
Universiti Teknologi Malaysia
81310 UTM Skudai, Johor Bahru, Malaysia
[1]lili.wulandhari@gmail.com, [2] habib@utm.my

Abstract
Chain code is an image method representation based on region boundaries. The chain code of region is determined by specifying a starting pixel and the sequence of unit vectors obtained from going either left, right, up, or down in moving from pixel to pixel along the boundary. Chain code is widely used nowadays because it preserves information and allows considerable data reduction. The first approach for representing digital curves using chain code was introduced by Freeman in 1961, and it is known as Freeman Chain Code (FCC). This code follows the contour in counter clockwise manner and keeps track of the directions as we go from one contour pixel to the next. The codes involve 4–connected and 8– connected paths. Since it was introduced by Freeman, the development of chain code and its application increases rapidly. This paper explains some chain code concepts and their applications that are be the background of the development of vertex chain code cells algorithm. This algorithm is able to visualize and to transcribe a binary image into vertex chain code easily. Some examples are also presented.

Keywords: *chain code, region boundary*

1. Introduction
Image representation is one of important thing in image processing and pattern recognition. An image is [1] a natural visual object that is characterized by the two dimensional spatial variation of brightness or colour or both. It is objectively sensed by the normal human eye, and does not depend on the assignment of meaning for its definition. As example photograph, painting, and printed page. However in a system, representing of an image needs large storage capacity. An image represented as a 512 x 512 array of picture elements (pixel), with 8 bits of brightness (gray-scale) information, takes more than a quarter megabyte of storage [2]. The system can spend most of its time just for shuffling pictures between main memory and secondary storage devices. Even if the system has large capacity, raw vision data would still offer a serious drawback. It is not very convenient form for image understanding. Most image understanding strategies including the human brain work in series of successive stages. Each stage performs progressively intricate operations on a progressively smaller amount of more highly structured data. Because of that, it is important to find the way for representing an image efficiently.

One of the ways to represent an image efficiently is by using chain code. Chain code is one of simple image representing ways. Chain code represents an image based on its boundary. Representation through the boundary description of objects is very useful. Because this representation influences the information for some process like in digital image processing, pattern recognition and machine vision system. For binary image [3], two kinds of boundary description algorithm are frequently used: run-length based algorithm and chain code based algorithm. The run length list the consecutive "runs" of objects and background points and is usually used in image compression [4]. This method is simple, it just removing repetition of the same byte in a row continuously. This is the most useful an data that contains many such runs, for example relatively simple graphics image such as icons, line drawings and animation. A simple example, consider a screen containing plain black text on a solid white background. There will be many long runs of white pixel in the blank space, and many short runs of black pixels within the text. Let us take a hypothetical single scan line, with B representing a black pixel and W representing white:

WWWWWWWWWWWWBWWWWWWBBBWWWWBBW

If run-length based algorithm is applied to a hypothetical single scan above, we get following:

W12B1W6B3W4B2W1

The run-length code represents the original 29 characters in only 15. While chain code based algorithm is the topic that will be explained in this paper.

For processing an image to become a chain code, it is common to have binary image as input. A binary image is digital image that has only two possible values for each pixel. They are normally displayed as black and white. Numerically, the two values are often 0 for black and, either 1 or 255 for white. In the simplest case, an image may consist of a single object or several separated objects or relatively high intensity. This allows figure separation by thresholding. In order to create the two–valued binary image, a simple threshold may be applied so that all the pixels in the image plane are classified into object and background pixels. A binary image function can then be constructed such that pixels above the threshold are foreground ("1") and below the threshold are background ("0").

Binary image can be represented from gray scale image. Gray scale image is an image which the value of each pixel is a single sample. Displayed images of this sort are typically composed of shades of gray, varying from black at the weakest intensity to white at the strongest, though in principle the samples could be displayed as shades of any colour, or even coded with various colours for different intensities.

One of the important things before having the chain code of an image is edge detection process. Its purpose is to get a standard gray-level image that will be transformed to be binary image. Davis [5] has developed a technique in edge detection process. This technique has three steps, they are: (1) *smoothing*, is the first step in edge detection technique. It is removes isolated pixels whose gray-level radically different from those of its neighbours. (2) Calculate the brightness difference between each point and its neighbourhood. (3) Separate edge points from the rest of the image. Every point with edge intensity above this threshold would be set to "1", and the others set to "0". But this technique approach ignores variations in contrast over the image. In regions of high contrast, it would detect spurious edge. In regions of low contrast, it would miss edges. Instead, then, of setting just one threshold for the image, we use a function that sets a local threshold for each neighbourhood. When the local thresholding has been applied to every pixel, the output image is binary image map. Every edge point has a value of "1"; every non edge point has a value of "0".

This paper presents the evolution of the chain code. Section 2 will explain the development of chain code from 1961 until 2007. And the future works that is based on the development of chain code is presented in section 3. The last section is the conclusion of the previous section.

2. Chain Code Schemes

Since introduced at the first time, the evolution and improvement of chain code representation scheme has been widely used as a topic of research. It is because it preserves information and allows considerable data reduction; chain codes provide a very compact region representation, suitable for detecting such feature of a region as sharp corners, area, perimeter, moments, centres, eccentricity, projection and straight-line segments [3]. Thus it is more often used in shape based pattern recognition and image analysis.

First chain code scheme was introduced by Freeman in 1961 that is known as Freeman Chain Code (FCC) [6]. This code follows the boundary in counter clockwise manner and keeps track of the direction as we go from one contour pixel to the next. The codes involve 4-connected (Figure 1(a)) and 8-connected (Figure 1(b)) paths.

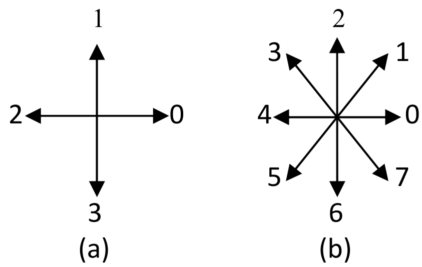


Figure 1. Neighbour Directions of FCC

If the codes involve 4-connected, it needs four values (two bits) per pixel to encode the direction to the next pixel, they are 0, 1, 2, and 3. While if the contour is 8-connected, we need eight numbers (three bits), they are 0, 1, 2, 3, 4, 5, 6, and 7. In the 8-connected FCC, each code can be considered as the angular direction, in multiples of 45^0 that we must move to go from one contour pixel to the next. Figure 2 shows the example of Freeman Chain Code using 8-connected path.

Freeman [1] states in general, a coding scheme for line structure must satisfy three objectives: (1) it must faithfully preserve the information of interest; (2) it must permit compact storage and convenient for display; and (3) it must facilitate any required processing. The three objectives are somewhat in conflict with each other, and any code necessarily involves a compromise among them

In 1973, Papert [7] presented one of the simplest chain codes. It just has two codes {0, 1}. Code "0" represents a right turn whereas symbol "1" represents a left turn when following the contour shape. The algorithm of the code is:

1. If you are in a front cell turn left and take a step
2. If you are in ground cell turn right and take a step
3. Terminate when you are within the starting point cell

Figure 3 shows the example of an image and its

Papert chain code

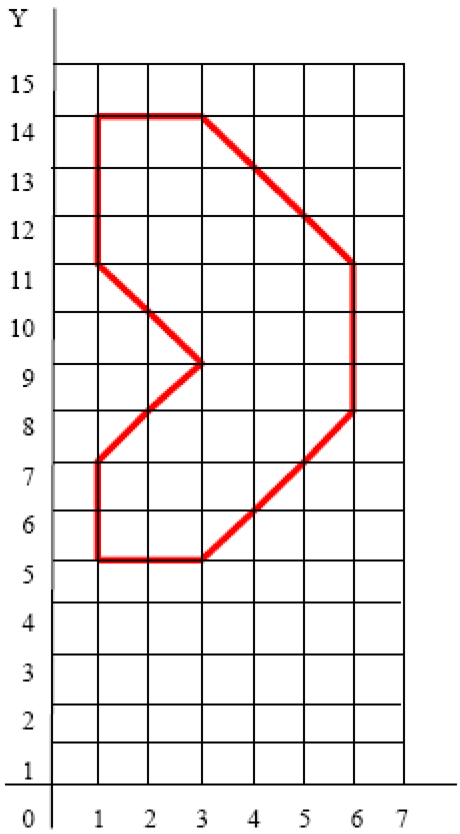


Figure 2. Example of Freeman Chain Code
Start from (1,5):00111222233344666775566

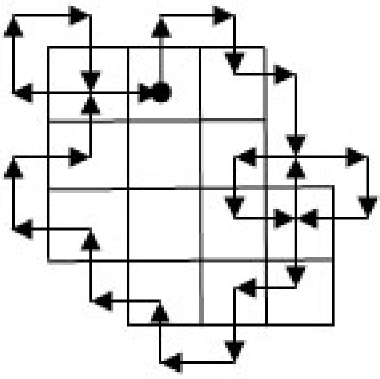


Figure 3. Papert chain code example.
Code: 1001001110001110010100110001

There are some disadvantages of Freeman chain code. It is very sensitive to noise as the errors cumulative, lack of the spatial information of the image content, and it is not invariant in starting point and scaling of the contour , and these are limited to image retrieval. Because of these laxities, the statistical method to solve these problems is proposed, namely Chain Code Histogram (CCH) [8]. This method is translation and scale invariant shape descriptor.

Chain Code Histogram (CCH) is calculated from the chain code of the contour of an object. For an eight – connected chain code, an 8 dimensional histogram, which shows the probability of each direction is obtained. CCH just give the approximation of the object's shape, so that similar object can be grouped together. The CCH has equation below

$$P(k) = \frac{n_k}{n}$$

where n_k is the number of chain code values k in chain code, and n is the number of links in a chain code. A simple example shows in Figure 4.

Chain Code: 00111222233344666775566

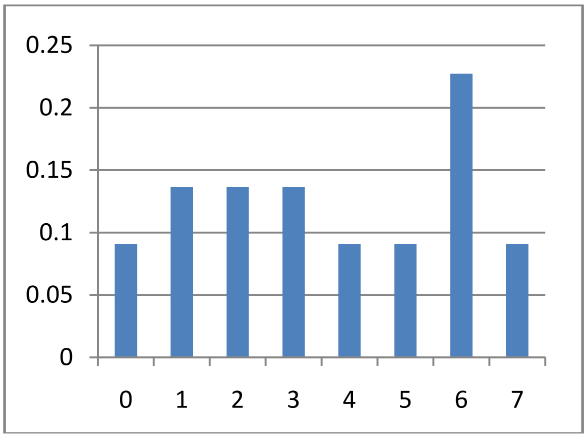


Figure 4. The Example of Chain Code Histogram (CCH)

The CCH is a method which just gives the approximation of object's shape. It will cause some mistakes in image retrieval process. So that Junding and Xiaosheng [9] proposed two new methods to solve problem in image retrieval process in 2006. They proposed Chain Code Coherence Vector (CCCV) and Chain Code Distribution Vector (CCDV).

Chain code's coherence is defined as the degree to which direction of that chain code are members of large similarly direction sequences. Coherence measure is classified as either coherent or incoherent. Coherent directions are a part of some sizable contiguous sequence while incoherent directions are not. A CCCV represent the classification for each direction. A direction is coherent if the size of its connected component exceeds a fixed value τ

$$\tau = {}^{n}/_{k}$$

Where n is the number of links in a chain code, and k is used as adjustive coefficient, otherwise the direction is incoherent. The CCCV for chain code consists of

$$< (\alpha_i, \beta_i) >$$

$$< (\alpha_0, \beta_0), (\alpha_1, \beta_1), \ldots, (\alpha_7, \beta_7) >$$

α_i shows number of coherent chain code values i in a chain code, β_i and is the number of incoherent chain code values i.

For example, according to two chain codes

$\{0011122233344666667755\}$
and
$\{00111222333446667755566\}$, suppose $\tau = 3$, so the CCCV of these two chain codes are
< (0,2), (3,0), (3,0), (3,0), (0,2), (0,2), (5,0), (0,2) >
and
< (0,2), (3,0), (3,0), (3,0), (0,2), (0,2), (3,2), (0,2) >
The Chain code distribution vector was supposed to extract the difference of the two chain codes by order. The CCDV can be defined as

$$< (h_i, \sigma_i) >$$

$$< (h_0, \sigma_0), (h_1, \sigma_1), \ldots, (h_7, \sigma_7) >$$

Where h_i denotes CCH of direction i, and σ_i denotes the distribution of direction i [9].

Most of the chain code which was proposed based on Freeman chain Code. In 1999 Bribiesca introduced a new chain code, namely Vertex Chain Code (VCC) [10]. And this chain code complied with three objectives that Freeman stated about coding scheme for line structure. Some important characteristic of VCC are: (1) The VCC is invariant under translation and rotation, and optionally may be invariant under starting point and mirroring transformation. (2) Using the VCC is possible to represent shapes composed of triangular, rectangular, and hexagonal cells (Figure 5). (3) The chain elements represent real values not symbol such as other chain codes, are part of the shape, indicate the number cell vertices of the contour nodes, may be operated for extracting interesting shape properties. (4) Using VCC it is possible to obtain relations between contour and interior of the shape.

In the Vertex Chain Code, the boundaries or contours of any discrete shape that are composed of regular cells can be represented by chains. Therefore, these chains represent closed boundaries. The minimum perimeter of closed boundary corresponds to the shape composed only of one cell. An element of a chain indicates the number of cell vertices, which are in touch with the bounding contour of the shape in that element position [10]. Figure 6 shows Vertex Chain Code of Rectangular –VCC cells which indicate the number of cell vertices, which are in touch with the bounding contour of the rectangle in that element position.

After Bribiesca proposed a new chain code that known as Vertex Chain Code (VCC) that is used to 2D images, Bribiesca proposed chain code for representing 3D curves in 2000 [11]. The study of 3D curve is very important because there are many natural objects that exist in 3D structure, like plants, tress, stone, and so on. 3D objects are digitalized and represented by constant orthogonal straight line segments, two contiguous straight line segments define a direction change and two direction changes define a chain element. The proposed chain code only considers relative direction changes, which allows us to have curve description invariant under translation and rotation. It may be starting point normalized and invariant under mirroring transformation.

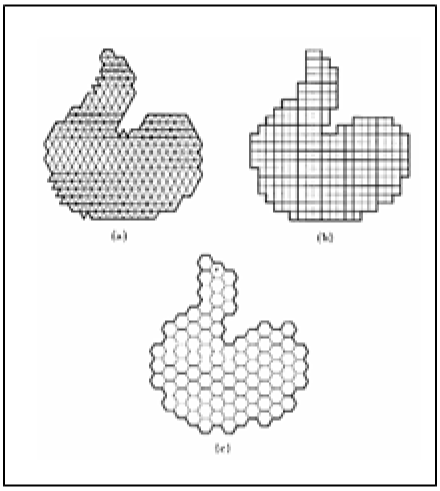


Figure 5. Example of VCC Cells: (a) Triangular cell (b) Rectangular cell, and (c) Hexagonal cell

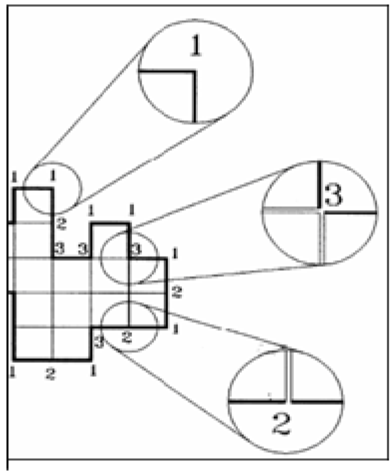


Figure 6. The Example of Rectangular Cells-VCC

There are only five possible direction changes for representing any 3D discrete curve which indicate relative direction changes. Figure 7 shows the five possible direction changes for representing 3D: (a) the element “0” represents the direction which goes straight through the contiguous straight-line segments following the direction of the last segment; (b) the element “1” which indicates a direction change to the right; (c) the element “2” which represents a direction change upward (stair case fashion); (d) the element “3” indicates the direction change to the left; and (e) the element “4” shows the going back direction.

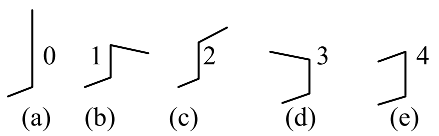


Figure 7. The five possible direction changes for representing 3D discrete curves

In 2005, a similar approach of Bribiesca 3D chain code was presented by Cruz and Dagnino [12]. It was for the representation of 2D binary shapes without holes, where only three of the five original symbols were used, namely 3OT. It is given by the set 3OT= {0,1,2}. By using this code any binary region could be represented by discrete curve. The element "0" represents no direction change which means to go straight, through the contiguous straight line segment following the direction of the last segment; the "1" indicates a direction change forward with regard to the basis segment; and the "2" means to go back with regard to the direction of the basis segment. The three directions of the chain code and its example are shown in Figure 8 and 9.

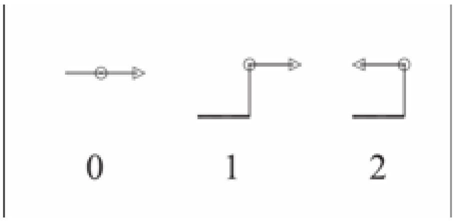


Figure 8. 3OT chain code direction

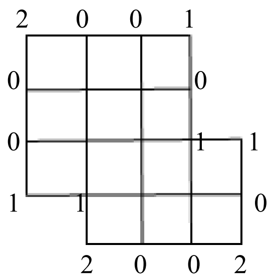


Figure 9. The example of 3OT chain code

Freeman, Papert, and Bribiesca has presented some chain code schemes. Nowadays there are some new chain codes that adopted from Freeman and Vertex Chain Code concept. One of them is the new chain code with Huffman coding [13]. This chain code is based on the most frequently used eight-directional Freeman chain code. This chain code is a simple one. The next chain code is often same as its immediate predecessor or the predecessor before that. It means when a chain moves in a direction defined by a code element the probability of sharp turns within one pixel distance is very low [13]. Yong Kui Liu and Borut Zalik [13] had analyzed the probability in 1000 curves, contour patterns and various shapes. Table 1 shows the probability results of various angle differences between two contiguous elements in a chain.

Table1.The probability of various angle differences

Angle differences	**±0°**	**±45°**	**±90°**	**±135°**	**±180°**
probability	0.453	0.488	0.044	0.012	0.003

This chain code uses Huffman coding concepts. The Huffman code is a widely used compression method that relies on the concept of entropy. Concept of entropy is the concept that measure uncertainty associated with the random variable. It quantifies the information in a message, it usually uses bit or bits per symbol. This concept also be a absolute limit of the best possible lossless in compression of communication. The Huffman coding has been proved requiring less one binary digit per symbol than the entropy. The construction of this algorithm is shown in Table 2 below.

Table 2. The construction of new chain code

New chain code	**Angle change**	**Probability**	**Huffman code**
C_0	0°	0.453	0
C_1	45°	0.244	10
C_2	-45°	0.244	110
C_3	90°	0.022	1110
C_4	-90°	0.022	11110
C_5	135°	0.006	111110
C_6	-135°	0.006	1111110
C_7	180°	0.003	1111111

The construction of the chain codes consists of the first code, which is the Freeman code in eight directions, and the remaining code which are coded as relative angle difference between the current and previous element. Table 3 shows the conversion of Freeman chain code into the new chain code.

Table 3. Conversion Freeman Chain Code into New Chain Code

Freeman Chain Code	0 0 1 1 2 2 2 3 3 3 4 4 6 6 6 7 7 5 5 6 6
New Chain Code	0 C_0 $C_1C_0C_1$ C_0 C_0 C_1 C_0 C_0 C_1 C_0 C_3 C_0 C_0 C_1 C_0 C_4 C_0 C_1 C_0

This chain code should have the ability to be used for any required processing.

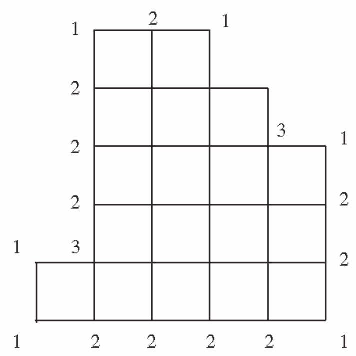
In the previous part, there is a new chain code that is based on Freeman chain code concept. In the next part, there are some new chain codes that enrol to vertex chain code concepts. They are extended vertex chain code, variable-length vertex chain code, and compressed vertex chain code.

Extended vertex chain code (E_VCC) is developed based on rectangular cells of vertex chain code. The rectangular cells of VCC have the equal code length of 2 bits. But it only uses three codes 1, 2, and 3, one element (0) can be added without increasing the code length. According to the experiments [14], the combination of 1-3 is the most often occurring combination. Then code 1-3 combination can be substituted by code 0. Table 4 shows the relationship between original VCC and extended VCC.

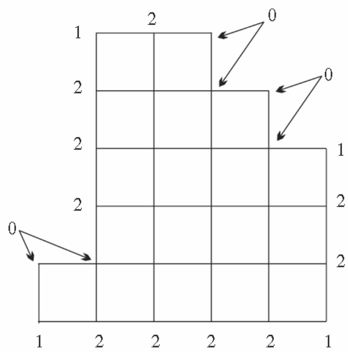
Table 4. Relationship between original VCC and E_VCC

VCC	1	2	3	1 and 3
E_VCC	1	2	3	0

Figure 10 below shows the example of E_VCC



(a) VCC:12212222113222121313



(b) E_VCC: 12212222102221200

Figure 10. Example of VCC and its substitution to E_VCC

From the example it is clear that length of the E_VCC code is not longer than the original VCC.
The second new chain code that based on vertex chain code is variable-length vertex chain code (V_VCC). This chain code also uses rectangular cells code of VCC. It has three elements 1, 2, and 3. These elements are represented by binary digits (01, 10, and 11). Variable-length VCC (V_VCC) code is defined by the probability of three code occurring. The experiment showed that the probability of code 2 is greater than the other two. Therefore, at V__VCC the binary digit **0** is used to represent code **2**, **10** for code **1**, and **11** for code **3** [14]. The relationship between the VCC and V_VCC is shown by Table 5 below.

Table 5. The relationship of VCC and V_VCC

VCC	1	2	3
Binary of VCC	01	10	11
V_VCC	10	0	11

Figure 11 shows the example of variable-length vertex chain code

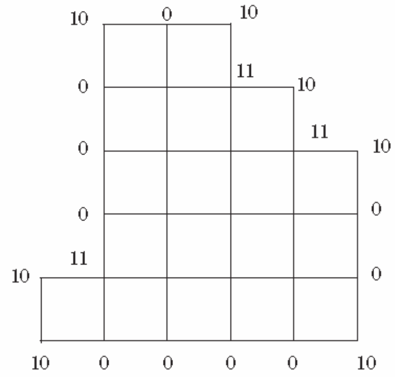


Figure 11. The example of V_VCC:
100010000010101100010010111011

The last chain code that related with vertex chain code is compressed vertex chain code (C_VCC). This chain code was constructing by taking account the E_VCC and V_VCC codes. C_VCC uses Huffman coding concept on its chain code. C_VCC consists of five codes. The probabilities of this code were obtained experimentally [14]. From experiment, it gets that the probability of a combination code 1 and 3 is the same with the probability of combination code 3 and 1. Then each of these combinations has their own code in Huffman code. Table 6 shows the VCC and its C_VCC.

Table 6. Code of VCC and C_VCC and its probability

C_VCC	Code 1	Code 2	Code 3	Code 4	Code 5
VCC	1	1,3	3,1	1	3
Probability	0.657	0.138	0.138	0.034	0.033
Huffman codes	0	10	110	1110	1111

All of the new chain codes that have been described above show that the development of chain code increases rapidly. It has been used widely as research topic. Some of them are extended code from existing code such as freeman and vertex chain code.

3. Future Trends

Based on the previous section in this paper, chain code is a part of image processing and pattern recognition that increases rapidly. There are many applications and new chain code method found. If we notice furthermore, the development of the chain code, most of them are based on Freeman chain code or Vertex chain code.
Most of the chain codes especially chain codes based on Freeman need to convert to y-axis representation. A region that is represented by sequence of chain codes some operations such as union, intersection and point membership, that is decide whether a point belonging to the region are difficult to process [15].

The erosion and dilation process of binary images by arbitrary structuring elements are easier by the y-axis representation [16]. But vertex chain code is a code that could be processed without going to y-axis representation [8].
Because of the predominance of VCC, some of the new chain codes are extended from vertex chain code. All of the new chain codes use rectangular cells of vertex chain code concepts. In 1999 Bribiesca introduced three cells of vertex chain code, namely rectangular, triangular, and hexagonal cells.
Then for future research, it will be interesting to use two others cells of vertex chain code. It is important to make an algorithm to visualize an image become triangular or hexagonal cells, and transcribe them into vertex chain code. Triangular and hexagonal cells have different code with rectangular cells. For triangular cells the codes are 1,2,3,4, and 5, while hexagonal cells the codes are 1 and 2.
Research about triangular and hexagonal cells of vertex chain code might become a new framework on development chain code generally, and especially for vertex chain code.

4. Conclusion

Chain code is one of the most interesting topics in pattern recognition and image processing. Since introduced by Freeman in 1961, chain code increases rapidly. There are many extended and applications of the chain code time by the time
Most of the new chain codes are extended from Freeman chain code and Vertex chain code that introduced by Bribiesca. The new chain codes need the binary image as the input, because chain code is the code based on boundary.
Experiment proves that the code of freeman chain code extended whose small angle has higher probability than the large one. And for the code of vertex chain code extended the combination code 1 and 3, or vice versa is the most occurring combination.
Chain code could be applied in many parts of pattern recognition and image processing. Then it is important to extend some algorithm about the chain code, especially vertex chain code.

5. Acknowledgement

The authors honorably appreciate Ministry of Science, Technology and Innovation (MOSTI) for the FRGS grant and Research Management Center (RMC), University of Technology Malaysia (UTM) for the support in making this projects success

6. References

[1] Freeman H, Computer Processing of Line-Drawing Images, ACM Computing Surveys 6, 1974, 57-97
[2] Wilf J M, Chain Code, Robotics Age, 1981
[3] Ren Mingwu, Yang Jingyu, Sun Han, Tracing Boundary Contours in Binary image, Image and Vision Computing, Vol 20, 2002, 125-131
[4] Cabrelli C A, Molter U M, Automatic Representation of Binary Images, IEEE Transactionon Pattern and machine Intelligence 12, 1990, 1190-1196
[5] Davis L S, A Survey of Edge Detection Techniques, Computer Graphics and Image Processing, Vol 4, 1975
[6] Freeman H, On The Encoding of Arbitrary Geometric Configurations. IRE Trans EC-10 (2), 1961, 260-268
[7] Papert S, Uses of Technology to Enhance Education, Technical Report 298, Al Lab, MIT, 1973
[8] Iivarinen J, and Visa A, Shape Recognition of irregular Objects, Intelligent Robots and Computer Vision XV: Algorithms, Techniques, Active Vision, and Material Handlings, SPIE, 1996, 25-32
[9] Junding S, and Xiaosheng W, Chain Code Distribution-Based Image Retrieval, Proceeding of The 2006 International Conference on Intelligent Information Hiding and Multimedia Signal Processing, 2006
[10] Bribiesca E, A New Chain Code. Pattern Recognition, Vol. 32, Issue 2, 1999, 235-251
[11] Bribiesca E, A Chain Code for Representing 3D Curves, Pattern Recognition, Vol 33, 2000, 755-765
[12] Cruz S H and Dagnino R M R, Compressing bi-Level Images by Means of a 3-bit Chain Code, SPIE Opt. Eng. 44, 2005, 1-8
[13] Liu Yong Kui, Zalik Borut, An Efficient Chain Code with Huffman Coding, Pattern Reognition, Vol 38, 2005, 553-557
[14] Liu Yong Kiu, Wei Wei, Wang Peng Jie, Zalik Borut, Compressed Vertex Chain Codes, Pattern Recognition, Vol 40, 2007, 2908-2913
[15] Ji L, Piper J, and Tang J Y, Erotion and Dilation of Binary Images by Arbitrary Structuring Elements Using Interval Coding, Pattern Recognization Letters, No 9, 1989, 201-209
[16] Chang Long-Wen and Leu Kuen-Long, A New method to Obtain Chain codes from Y-axis Representation of Region in A Binary Image, Multidimensional Systems and Signal Processing, 3, 1992, 79-87