Experimental Study Of Multi-level Regional Voting Scheme And Its Application In Human Face Recognition

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ABSTRACT

By extending from two-level voting scheme model to multi-level voting scheme model, we use the Monte Carlo approach in studying the stability of the multi-level regional voting scheme with respect to region sizes and levels. Then we implement one face recognition system using two-level regional voting scheme and multi-level regional voting scheme, and apply it in FERET human face database. We verify again that the regional voting scheme is always more stable than the national voting scheme. We find that the stability of multi-level regional voting scheme is not as good as two-level regional voting scheme when the region size is within a certain range. Out of this range, the multi-level regional voting scheme may compete with the two-level voting scheme. We conclude that the multi-level regional voting scheme may be comparable to the two-level regional voting scheme and prove our conclusion in the face recognition application.

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INTRODUCTION

As a biometrics technique, face recognition recently has received significant attention because of its ability to meet commercial and security needs [1, 2]. Zhao et al. define face recognition problem as follows: "given still or video images of a scene, identify or verify one or more persons in the scene using a stored database of faces" [2].

Because face recognition is sensitive to image quality and other factors such as lighting conditions, poses, and facial expressions, the field of face recognition is still full of challenges [1, 2].

Decision making is involved in the face recognition stage. As one important decision making procedure, voting method is also used in the face recognition system.

Among different voting methods, national voting and regional voting have received attention and study [6, 25]. Differences between national voting and regional voting include how votes are counted and how winners are selected. National voting selects the winner by counting the votes of the entire voting population. Regional voting selects the winner by dividing a nation into voting regions, then counting the votes on these regions [6]. Considering the robustness of voting systems, progress was made in stability analysis on national and regional voting [6, 25].

Based on the previous noise-and-voting model of regional voting [6], we extend the study to the multi-level voting scheme. For the multi-level voting scheme, we keep recursively dividing regions into smaller sub-regions. Then we select the winner of each region by the votes from sub-regions.

After setting up a multi-level voting scheme model and an experimental analysis of its stability nature, we conclude that the multi-level voting scheme has stability characteristics comparable to the two-level voting scheme in some degree. Also, we apply this multi-level voting scheme model to the face recognition problem and confirm our conclusion. In our face recognition problem study, we find that region shifting procedure plays an important role in face recognition system performance.

Portions of the research in this paper use the FERET database of facial images collected under the FERET program, sponsored by the DOD Counterdrug Technology Development Program Office [5, 26].

CHAPTER 1 LITERATURE SURVEY

Usually there are three steps in a face recognition system: face detection, facial feature extraction, and face identification [2]. In this chapter, we will give a brief review of several face detection, facial feature extraction, and face identification methods. Also, in the end of this chapter, we will review face image database we use and different voting schemes.

1.1 Face Detection

Face detection can be considered the first stage in face recognition system. In this stage, the task is to find all faces in an image, where there can be multiple or no faces in the image [3]. Yang et al. state, "to build fully automated systems that analyze the information contained in face images, robust and efficient face detection algorithms are required" [3].

There are over 150 reported approaches to face detection and they can be classified into four categories: knowledge-based methods, feature invariant approaches, template matching methods, and appearance-based methods [3].

Face detection is with full of challenges as well. For example, how to make a robust face detection system under different lighting conditions and how to apply face detection algorithms in live video are all interesting topics.

1.2 Facial Feature Extraction

The facial feature extraction problem considers how to represent facial data, usually using lower dimensional feature vectors [9]. Geometrical features extraction, Fourier transform, and Gabor Filter are several common methods used in the facial feature extraction stage [4].

1.2.1 Geometrical Features Extraction

In the geometrical feature extraction method, the face is represented by facial features instead of local features [2]. For example, nose width and length, mouth position, distance from eyes to the mouth, et al.

The accuracy in measuring the numeric values and number of features will affect the performance of this method, so it may need higher resolution images. The advantages of this strategy over techniques based on template matching are essentially compact representation and high matching speed [11].

1.2.2 Fourier Transform

The Fourier transform is still one of the powerful tools used for facial feature extraction. Zana and Cesar introduced a new face recognition algorithm based on Polar frequency descriptors which are extracted from face images by Fourier-Bessel Transform (FBT) [12]. Jing et al. implemented a face recognition system based on discriminant fractional Fourier feature extraction, and their results show that their approach outperforms four representative discrimination methods [13].

1.2.3 Gabor Filters

Gabor filters are also widely used in facial feature extraction. The dynamic link architecture (DLA) framework, founded on a Gabor wavelet-based face recognition system, was introduced by Lades et al. [14]. Wiskott et al. developed a Gabor wavelet-based elastic bunch graph matching (EBGM) method [15].

One of disadvantages of the Gabor filter-based feature extraction method is its computational expenses, due to its high dimensional Gabor features [16].

1.3 Face Identification

In this stage, face identification compares the input image with the image database and decides if there is a match [3]. Template Matching, Artificial Neural Network, and Eigenfaces are several face identification methods.

1.3.1 Template Matching

Basic template matching in the face recognition problem computes the distance between the input image and the database images. This computation is time-consuming, so people start to use more than one template with different scales and rotations [17, 18].

Karungaru uses two kinds of templates for each face. One is based on edge detection and the other depends on the YIQ color information from the face [17]. Lao uses template matching in 3D face recognition problems by introducing a sparse depth map [18].

1.3.2 Artificial Neural Network

An artificial neural network is a kind of mathematical model which processes technical information methods in a way similar to biological systems. It is a powerful tool in face recognition and classification, like the fault tolerance and the ability to learn from examples.

The back-propagation learning algorithm is one of the most important learning algorithms used to train artificial neural networks system to recognize face images. But the difficulty for the neural network is that a simple network can be very complex and difficult to train [22].

1.3.3 Eigenfaces

By reducing the image to an eigenvector, a system can compare a candidate's eigenvector against the gallery in a database. Sirvovick and Kirby first proposed this algorithm, and it was refined by Turk and Pentland [20].

1.4 Face Database

One of the basic requirements to evaluate the face recognition system is the facial image database [5]. The FERET database is one of the largest and most famous face databases introduced recently. There are 14,126 images from 1,199 individuals in the FERET database [5].

Phillips mentioned, "The main goals of the FERET evaluation were to assess the state-of-the-art and feasibility of automatic face recognition" [5]. In our face recognition system, we use one subset of FERET image database.

1.5 Local Voting Scheme vs. National Voting Scheme

Voting is one of important decision-making procedures. Two voting schemes, national voting and regional voting, have received attention and study for their stability natures [6, 25].

Considering stability characteristics, which is its robustness nature to noise, the previous study shows that the regional voting scheme is more stable than the national voting scheme against concentrated noise, and the stability of regional voting should increase as the size of subdivided regions decreases [6, 25].

As one decision making method, the voting scheme has also been introduced into the face recognition field. T. Faltemier selected multiple regions of the face in order to reduce the effects caused by variations in expression [27]. Artiklar proposed that the system use voting methods for classification experiments, false positive experiments, and temporal experiments [7]. The research in the face recognition field and the previous stability study on regional voting schemes make us believe that it is an interesting topic about the stability nature of the multi-level regional voting scheme and its application in face recognition.

1.6 Summary

A face recognition system has three stages: face detection, facial feature extraction, and face identification. This chapter gives a brief introduction of each stage and several well-known methods used. Also, FERET face image database is described. Finally we briefly introduce the previous stability study about local voting scheme and national voting scheme.

CHAPTER 2 MULTI-LEVEL VOTING SCHEME MODEL

Previous analysis demonstrates that regional voting is always more stable than national voting [6]. We extend regional voting to the multi-level regional voting scheme by dividing partitioned regions into sub-regions, and we study its stability characteristics by comparison of the national voting scheme and two-level regional voting scheme.

To extend national voting and regional voting models to a multi-level voting scheme, we set up a multi-level voting scheme model. Also we use this multi-level voting scheme to do experimental analysis. From the analysis and a comparison study with both the two-level regional voting scheme and national voting scheme, we collect our observations into a summary of characteristics for multi-level voting scheme. Based on previous studies of national voting scheme model and regional voting scheme model [6, 25], we supply the multi-level voting scheme model with the following details:

2.1 Multi-level Voting Scheme Model

(1) Like the regional voting scheme model [6], the multi-level voting scheme model has two candidates, A and B. The nation is represented as a rectangular area which has $l \times w = N$ (l and w being positive integers) unit cells. One cell has one vote and will cast its vote by selecting either A or B.

(2) For two-level regional voting purposes, the nation is divided into equal shaped rectangles, call regions of size $r_{1,l}$ x $r_{1,w}$ ($r_{1,l}$ and $r_{1,w}$ being integers), where l and w are divisible by $r_{1,l}$ and $r_{1,w}$ independently.

(3) For multi-level regional voting purposes, the rectangular region divided in upper level is then recursively divided into equal shaped sub-rectangles, called sub-regions, of size $r_{n,l}$ x $r_{n,w}$ ($r_{n,l}$ and $r_{n,w}$ being integers), where $r_{n,l}$ and $r_{n,w}$ are divisible by $r_{n+1,l}$ and $r_{n+1,w}$ independently (here n represents the division level).

(4) We keep recursively dividing the sub-region which is the result from upper-level division operation, until the size of sub-region $r_{n,l}$ x $r_{n,w}$ is equal to one unit cell.

(5) Like the regional voting scheme model [6], national voting is implemented over the entire nation, with a winner decided by a simple majority of the two votes throughout the nation. A winner in the two-level regional voting is decided by the "winner-take-all" principle, namely by a majority of the winning regions, where the winner of each region is determined by a simple majority. In multi-level regional voting, a winner is decided by the "winner-take-all" principle, namely by a majority of the winning top-level regions, where the winner of each top-level region is determined by a simple majority of votes within the sub-region, and the winner of each sub-region is determined by simple majority within the lower level regions recursively.

(6) Like the regional voting scheme model [6], noise is defined as a change of environment that enforces a change of voting result. The noise that influences votes to change from A to B or B to A is called anti-A noise or anti-B noise, respectively.

(7) Like the regional voting scheme model [6], there are two types of noise: concentrated noise and white noise. Concentrated noise influences the votes within a block(s) of cells, and white noise is distributed uniformly and randomly over the whole nation. There are anti-A white noise or anti-B white noise, as well as anti-A concentrated noise or anti-B concentrated noise.

(8) Because we are interested in computing the lower bounds of voting stability throughout this paper [6], we consider only the anti-B noise in the analysis. Thus anti-B noises, anti-B concentrated noise, anti-B white noise are referred to as noise, and concentrated noise, and white noise hereinafter respectively.

(9) In the experimental model of the multi-level regional voting scheme, we divide a nation into regions, and then divide each region into sub-regions. This is one special case of multi-level voting scheme due to the computational complexity.

(10) In the experimental model of the multi-level regional voting scheme, noise generation and original distribution of vote will be generated by the Monte Carlo method.

2.2 Monte Carlo Method

In this section, we introduce the Monte Carlo method, and the random number generator Mersenne Twister algorithm which we use in the study.

The Monte Carlo method is used widely to simulate various physical and mathematical systems' behavior. It usually uses random numbers or pseudo-random numbers. A Monte Carlo algorithm and the Monte Carlo method are used when problems have many variables and can not easily be solved.

The complexity of analysis of multi-level regional voting schemes and the uncertainty in inputs, such as the random distribution of concentrated noise and white noise, make us believe that using the Monte Carlo method is an efficient way to understand the properties of the multi-level voting scheme.

The 1997 invention of the Mersenne Twister algorithm [21], by Makoto Matsumoto and Takuji Nishimura, avoids many of the problems with earlier pseudorandom number generators. It has the colossal period of 2^{19937}-1, is proven to be equidistributed in 623 dimensions up to 32-bit values accuracy, and runs faster than all but the least statistically reasonable generators.

Because of these advantages, in our experimental model, we choose the Mersenne Twister algorithm as the random number generator for distribution of initial votes, concentrated noise and white noise.

2.2.1 Pseudocode for MT19937 Algorithm

The following generates uniformly 32-bit integers in the range [0, 232 − 1] with the MT19937 algorithm [23]:

```
// Create a length 624 array to store the state of the generator
 int[0..623] MT
 int index = 0

// Initialize the generator from a seed
 function initializeGenerator(int seed) {
    MT[0] := seed
    for i from 1 to 623 { // loop over each other element
        MT[i] := last 32 bits of(1812433253 * (MT[i-1] xor (right shift by 30 bits(MT[i-1]))) +
i) // 0x6c078965
    }
 }

// Extract a tempered pseudorandom number based on the index-th value,
// calling generateNumbers() every 624 numbers
 function extractNumber() {
    if index == 0 {
        generateNumbers()
```

```
    }
    int y := MT[index]
    y := y xor (right shift by 11 bits(y))
    y := y xor (left shift by 7 bits(y) and (2636928640)) // 0x9d2c5680
    y := y xor (left shift by 15 bits(y) and (4022730752)) // 0xefc60000
    y := y xor (right shift by 18 bits(y))

    index := (index + 1) mod 624
    return y
}

// Generate an array of 624 untempered numbers
function generateNumbers() {
    for i from 0 to 623 {
        int y := 32nd bit of(MT[i]) + last 31 bits of(MT[(i+1) mod 624])
        MT[i] := MT[(i + 397) mod 624] xor (right shift by 1 bit(y))
        if (y mod 2) == 1 { // y is odd
            MT[i] := MT[i] xor (2567483615) // 0x9908b0df
        }
    }
}
```

In our study, we use MT19937 C# version developed by CenterSpace Software as our random number generator (http://www.centerspace.net).

CHAPTER 3 AUTOMATED FACE RECOGNITION SYSTEM

After setting up the experimental multi-level voting scheme model, we are able to use this model to build a face recognition system.

3.1 Face Recognition System

The design of our face recognition system consists of the face image database, face detection, face feature extraction and normalization, and face identification.

3.2 Face Image Database

We use one subset of the FERET database as our face recognition system benchmark. FERET database consists of monochrome images taken in different frontal views and in left and right profiles [5].

There are four evaluation tasks which employed frontal images gathered between 1993 and 1996 [5]: Duplicate I or T1, Duplicate II or T2, fafb and fafc. The evaluation task of fafb is Facial Expression. We choose Facial Expression (fafb) as our image database. There are 1196 gallery images and 1195 probe images. Each probe image is matched against those in the gallery, and the vote can be analyzed to produce recognition performance measures.

3.3 Face Detection

Because we are using the FERET database, its subset and each image in FERET database will have one face, so face detection will not be our focus.

3.4 Face Feature Extraction and Normalization

In this stage, the system is given facial images with the coordinates of the centre of the eyes. This can be called a partially automatic algorithm, as compared to a fully automatic algorithm, which is only given facial images [5].

In our test, there are 1196 gallery images and 1195 probe images. Since these face images are stored as rasters of varying resolutions, a normalization procedure is needed. We use the following formula to normalize:

(PixelAsGreyScale – Arithmetic Average) / stddev

In this stage, we modify one program called face2norm to take a text file containing the names of images and the (x, y) coordinate of the eyes within those images, and produce one elementary file containing identically 74 x 64 floating point values corresponding to zero mean, unit variance values from each image with 74 rows and 64 columns. (The original face2norm source code is contained in The Facial Recognition Technology (FERET) database CDROM).

Then the test images were cropped to a size of 60 x 60. We cropped the images at the fixed position from the upper left corner (3, 8). This step can be called pre-processing.

3.5 Face Identification

After preprocessing, the face identification stage is needed to map the input image to proper output. Because we are using a multi-level regional voting scheme model, there are two main computational steps: second-level local voting, then first-level local voting.

3.5.1 Multi-Level Regional Voting Scheme

For the multi-level regional voting scheme, we partition both the probe images and gallery images into non-overlapping regions. Furthermore, we partition these regions into sub-regions (see Figure 3.1 for an example).

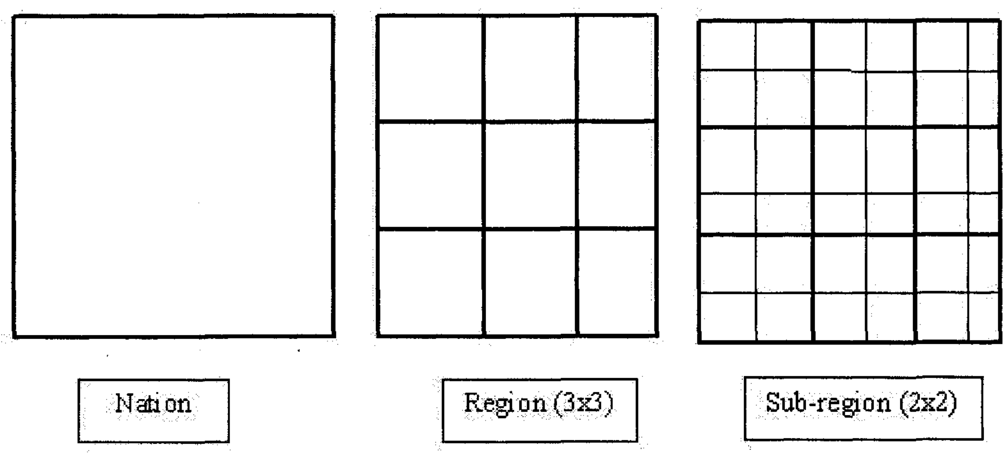


Figure 3.1 Image partition: nation, region and sub-region

On the sub-regional level, matching is determined locally between corresponding sub-regions. Here we calculate the city block distance between one sub-region of the probe image and corresponding sub-regions of the gallery images. The city block distance between one sub-region in the probe image and corresponding sub-regions in gallery images is the sum of absolute differences between corresponding pixels in those sub-regions. In these corresponding sub-regions of the gallery images, one sub-region which has the smallest distance will be cast a vote. We repeat this process for the entirety of the sub-regions and record the votes received by each regions in each image in the gallery.

Then we sum up the total votes from the sub-regions by region. After we repeat this process for all regions, we can obtain the total vote for the each region in the gallery. For the corresponding regions of each gallery image, we apply the "winner takes all" principle and cast a vote for the region with max vote.

Then we sum the total votes from region by each gallery images. After obtaining the total vote for the each gallery image, the system will find the matched image which has the max vote. Comparing the names of the probe image and the gallery images, the system considers this match successful if names are matched, and failed if names are not matched. We repeat the above steps for each probe image and keep track of both successful matches and mismatches. Then we are able to calculate the system performance by the matching percentage. For example, if we have X probe images matched, and then system performance will be calculated to be X/1195 (1195 is the total number of probe images).

Considering the occasion of a tie, for example, for one probe image, if two or more gallery images are matched, then we sum up the average. For example, if we have 1000 successful matches, one 2-candidate tie and one 3-candidate tie, we would calculate system performance as (1/2+1/3+1000)/1195 = 83%.

3.5.2 Shifting Procedure

In order to provide robustness to small amounts of shift, normally the shift process is applied when computing the distance between a probe sub-region and gallery images sub-region.

In our study, we use one-step shifting or a no-shift policy. Using one-step shifting, we simply shift the input window by 1 pixel in 4 directions, and then record the smallest distance. The reason for two policies is that we want to compare differences in system performance with or without shifting process.

Although we are able to configure our face recognition system by varied maximum steps, for example, we can use two shift steps or five shift steps and record the smallest distance, we notice that when the sub-region size is relatively small (for example, 2x2 or 3x3), one-step shifting is enough for our comparison study between two-level regional voting scheme and multi-level regional voting scheme.

3.6 Example

Here we give an example to facilitate understanding:

We divide probe image into 4 regions (we do the same with the gallery images, assuming we have 5 images), then we divide the 4 regions into 16 sub-regions (doing the same with gallery images) and we get results as seen below after shifting was used:

Table 3.1 Voting on the sub-region level

	1	**2**	**3**	**4**	**5**
Region 1(sum of vote)	3	0	1	0	1
Sub-region 1.1:	1	0	0	0	1
Sub-region 1.2:	0	0	1	0	0
Sub-region 1.3:	1	0	0	0	0
Sub-region 1.4:	1	0	0	0	0
Region 2(sum of vote)	4	0	0	1	0
Sub-region 2.1:	1	0	0	0	0
Sub-region 2.2:	1	0	0	0	0
Sub-region 2.3:	1	0	0	0	0
Sub-region 2.4:	1	0	0	1	0
Region 3(sum of vote)	3	1	1	1	0
Sub-region 3.1:	0	1	1	0	0
Sub-region 3.2:	1	0	0	1	0
Sub-region 3.3:	1	0	0	0	0
Sub-region 3.4:	1	0	0	0	0

Region 4(sum of vote)	1	1	1	1	1
Sub-region 4.1:	0	0	1	0	0
Sub-region 4.2:	0	0	0	0	1
Sub-region 4.3:	0	1	0	0	0
Sub-region 4.4:	1	0	0	1	0

Table 3.2 Voting on the region level

	1	2	3	4	5
Region 1:	3 1	0 0	1 0	0 0	1 0
Region 2:	4 1	0 0	0 0	1 0	0 0
Region 3:	3 1	1 0	1 0	1 0	0 0
Region 4:	1 0.2	1 0.2	1 0.2	1 0.2	1 0.2
Sum of Vote	3.2	0.2	0.2	0.2	0.2

Finally image 1 gets 3.2 votes, thus image 1 matches the most. Since we observe that there are several ties during voting, we give them equal portion of votes.

3.7 Summary

By choosing FERET database fafb evaluation task, we set up the face recognition system by using the multi-level regional voting scheme. Through face detection, facial feature extraction and normalization, and face identification stages, we are able to verify conclusions from multi-level regional voting scheme experimental model. As the multi-level voting scheme is also sensitive to image shift, in order to provide robustness to small amounts of shift, we apply the process of shifting. During our test, we find that for different sub-region sizes, shifting is one of important factors to system performance.

Chapter 4 Experiment Implementation and Results for Multi-level Regional Voting Scheme

In this chapter, we will summarize testing details and results for the multi-level regional voting scheme experiment. Implementation details and results for face recognition system will be presented in chapter five.

4.1 Multi-level Regional Voting Scheme Experiment Setup and Different Voting Schemes Comparison Study

To compare the multi-level regional voting scheme with the two-level voting scheme and the national voting scheme, we implement an experimental model to simulate multi-level regional voting scheme. In the implementation model, the nation area is composed of a constant number of unit cells, represented by N (Width x Length = 129600). For each unit cell, there is one vote for candidate A or candidate B. Regions and sub-regions with different sizes are used to divide the nation. Two types of noise, white noise and concentrated noise, are applied to the nation. Also, to understand the nature of the multi-level regional voting scheme and to compare it with other voting schemes, we form different test sets with varied input parameters, such as size of region, size of sub-region, and type and size of noise block. We use Monte Carlo method to generate original distribution of votes and noise distribution in order to understand the stability characteristics of the multi-level voting scheme. We define the initial percentage of votes for A as P_A and the initial percentage of votes for B as P_B and we have $P_A + P_B = 1$, $P_B > P_A$ and $P_B - P_A = u$ (positive number, we choose u = 0.04

for the initial test setup). Gradually we add anti-B concentrated noise or anti-B white noise or both until candidate A wins out. We record the percentage of votes for A in nation as P_A' when A wins out in each voting scheme. The difference $P_A' - P_A$ is caused by noise (white noise or concentrated noise or both) added to the nation. We use $(P_A' - P_A) \times N$ as the measurement for the stability value; we compare them and discuss the stability nature for each voting scheme when they are manipulated using different noise types, noise levels, and region and sub-region sizes as input parameters. By deeply understanding its stability nature, we are able to apply the multi-level voting scheme on a real and interesting application: face recognition.

To understand the different types of voting schemes, we compare the national voting scheme, two-level regional voting scheme and multi-level voting scheme in the following example (Figure 4.1)

A	A	A		A	A	A		A	A	A					
A	A	A		A	A	A		A	A	A					
A	A	A		A	A	A		A	A	A					
A	A	A		A	A	A									
A	A	A		A	A	A									
A	A	A		A	A	A									
A	A	A		A	A	A									
A	A	A		A	A	A									
A	A	A		A	A	A									
A	A	A		A	A	A									
A	A	A		A	A	A									
A	A	A		A	A	A									

Figure 4.1 Nation with 256 unit elements

This nation has 256 (16 by 16) unit elements (we may think of each unit element as corresponding to a sub-region in the multi-level voting scheme or a unit cell in the two-level voting scheme). Each element can vote for candidate A or candidate B. For A to win in the national voting scheme, A should have at least 129 votes, with B receiving a maximum of 127 votes. A situation with 128 votes for A and 128 votes for B is considered a special case which we call a tie.

In the two-level voting scheme, we consider each unit element as one unit cell. We divide the nation into 16 voting regions. For A to win, it must win the votes of at least 9 regions (8:8 is a tie). That means, for each winning region which has 16 unit cells, at least 9 unit cells must vote for A. Under this very special distribution of votes, if there are 81 unit cells in total voting for A, A wins. The total number of elements in the nation is 256. Thus, although candidate A only wins 81 / 256 = 31.64% of the total unit cells, A still wins with the two-level regional voting scheme. But if we apply the national voting scheme, B would be the winner.

In the multi-level voting scheme, we consider each unit element one sub-region. So we have 256 sub-regions and 16 regions. For each sub-region, for example, there are 16 (4 x 4) unit cells. In order for A to win, it requires the support of at least 9 regions. For each region which supports A, at least 9 sub-regions must support A. For each sub-region which supports A, at least 9 unit cells must support A. Thus, candidate A requires 9 x 9 x 9 = 729 supporting unit cells and if unit cells are distributed in this fashion, candidate A will win in the multi-level voting scheme. But from the view of a national voting scheme, A only receives 729 / 4096 = 17.80% supporting percentage in total.

This is only one special scenario in which we consider the national voting scheme, two-level voting scheme, and multi-level voting scheme together. In reality, candidate A should not be so lucky. But it raises the concern that under different distributions of votes and under different distributions of noise, a comparison study on the stability characteristics of the national voting scheme, two-level voting scheme, and multi-level voting scheme can become quite complex. Since the purpose of our research is to study and compare the stability characteristics of three different voting schemes, we describe the details to set up experimental model based on the Monte Carlo method in section 4.3.

In the following section, we introduce stability value as the stability measurement in our multi-level voting scheme analysis and other possible measures.

4.2 Stability Value

The stability nature of one voting scheme can be viewed as its system robustness to noise. To measure the robustness, we use $S = (P_A' - P_A) \times N$ as the measurement of the stability value. P_A is the initial percentage of votes for candidate A and P_A' is percentage of votes for candidate A when A wins out. A wins out because concentrated noise or white noise are gradually added to nation. The difference $P_A' - P_A$ is caused by noise (white noise or concentrated noise or both) added to the nation. So we use the minimum amount of noise that causes the voting system to reverse the original winner selection as the stability value measurement.

Another possible measure of stability can be the maximum amount of noise that a voting system could accommodate before the original winner selection is reversed. From the implementation's view, we have to keep recording previous votes' percentage for candidates before the winner selection reverses. Two measures represent different paths to approximate the robustness nature but with similar results. So we choose the first one in our stability analysis.

4.3 Implementation Details and Noise Types

Our implementation (named as flag application) details for the multi-level regional voting scheme model is as following: the nation includes 360 x 360 = 129,600 unit cells. Initially there are 48% unit cells voting for A (represented by 1) and 52% unit cells voting for B (represented by 0).

Also we apply two types of noise, white noise and concentrated noise, on the nation. For white noise, there are two options: either we add no white noise or we add a small portion gradually so that each round 0.1% of total unit cells in nation will be affected by this white noise and vote for A (originally it votes for A or B). For concentrated noise, there are two types also: Type 1 concentrated noise has a noise block of size of less than 1% of total unit cells in the nation, and the noise block width and length is less than 36. Type 2 concentrated noise has a noise block size of less than then 0.25% of total unit cells in the nation and its width and length is less than 18. Type 1 and type 2 concentrated noises will affect the unit cells in noise block and vote for A.

So there are four noise combinations we use in the test sets:

1. Gradually adding no white noise but type 1 concentrated noise (represented by WN0CN0.01)
2. Gradually adding white noise and type 1 concentrated noise (represented by WN0.001CN0.01)
3. Gradually adding no white noise but type 2 concentrated noise (represented by WN0CN0.0025)
4. Gradually adding white noise and type 2 concentrated noise (represented by WN0.001CN0.0025)

We record the number of unit cells voting for candidate A in the entire nation when A wins in each voting scheme and calculate the stability value. Using the Monte Carlo method, for each region and sub-region size configuration, we repeat our tests, varying by initial vote distribution, concentrated noise size and position, and with/without white noise. After a satisfactory number of tests, we are able to find the stability nature behind the tests.

4.4 Number of Tests and Error Range

Since we use the Monte Carlo method, how many tests we need for each configuration is one of our considerations when we set up the multi-level regional voting scheme model. So we use the multi-level regional voting scheme model to validate the previous study on two-level regional voting scheme model and do the comparison study between tests 100 times and 1000 times (see test result table and chart in 4.3.1). The mean and standard deviation are as in the following table (Table 4.1):

Table 4.1 Mean and standard deviation of two-level voting scheme (100 tests vs. 1000 tests)

Two-level voting scheme (test 100 times)	**WN0 CN0.01(100)**	**WN0.001 CN0.01(100)**	**WN0 CN0.0025(100)**	**WN0.001 CN0.0025(100)**
mean	8357.71	6857.66	5903.82	4359.06
stddev	3123.56	2031.29	2200.35	895.51
Two-level voting scheme (test 1000 times)	**WN0 CN0.01(1000)**	**WN0.001 CN0.01(1000)**	**WN0 CN0.0025(1000)**	**WN0.001 CN0.0025(1000)**
mean	8457.25	6816.90	5931.71	4398.61
stddev	3240.50	2036.87	2184.73	933.68

According to the mean, standard deviation, and the chart, we observe that both can satisfy our test purpose and verify the stability nature of the two-level regional voting scheme. So in most of our test cases, we choose 100 test times.

Another consideration is error range. To explain the data we get, we have to consider the error range and, for different test results for each test set, if the difference is within the error range, we can tolerate the error and consider that the data represent the same observation.

Since we add concentrated noise blocks gradually, before applying the last concentrated noise block that causes candidate A to win out, candidate A may just need one more vote for A or need one whole concentrated anti-B noise block. For the WN0CN0.01 noise combination, the average error range will be $\sum i^2/ 36(i = 1, 2, \ldots, 36) = 450.17$. Also for WN0CN0.0025, the error range will be $\sum i^2/ 18(i = 1, 2, \ldots, 18) = 117.17$. If the test result difference is under the error range, we think it satisfies our test requirements.

In the following, we will summarize our test results. We call each test configuration a test set. Under each test set, we will list its purpose, input parameters, result table, result graph, and brief discussion. In the end, we will be able to compare the stability nature of the national voting scheme, two-level regional voting scheme, and multi-level regional voting scheme.

4.5 Test Sets and Test Results

4.5.1 Two-Level Regional Voting Scheme

Purpose: To study the stability nature of the multi-level regional voting scheme, we have to compare it with the two-level voting scheme. Here we apply the two-level regional voting scheme to the nation. Since in this test and following tests, we have to choose a reasonable number of tests for Monte Carlo analysis, we repeat two-level regional voting scheme test 100 times and 1000 times and compare the difference.

Parameters: Use varied region sizes from 1 x 1 to 180 x 180.

The following table is obtained by 100 test times:

Table 4.2 Two-Level Regional Voting Scheme (100 tests)

Length of Region	**WN0CN0.01(100)**	**WN0.001 CN0.01(100)**	**WN0 CN0.0025(100)**	**WN0.001 CN0.0025(100)**
1	2806.77	2933.72	2679.01	2707.32
2	3970.85	3795.89	3696.17	3325.48
3	5795.69	5047.26	5277.65	4046.16
4	6773.96	5658.27	5953.66	4290.49
5	7794.53	6406.12	6848.43	4570.46
6	8607.07	6777.43	7255.06	4811.01
8	9859.96	7618.78	7977.39	5001.02
9	10491.31	7867.25	8390.94	5040.14
10	10806.70	8130.00	8501.14	5162.64
12	11177.30	8273.40	8463.15	5167.06
15	11745.53	8763.06	8534.19	5177.64
18	12488.02	8876.72	8383.24	5292.05
20	12288.26	9007.14	7964.83	5169.76
24	11710.19	8820.26	7541.28	5108.27
30	10893.81	8649.82	6702.30	4982.32
36	10352.07	8675.67	5926.28	4822.36
40	9808.80	8433.81	5658.06	4745.33
45	9123.04	8207.50	5028.13	4578.68
60	7451.17	7018.99	3696.72	4127.11
72	6514.59	6793.70	2968.62	3653.53
90	4901.72	5311.32	2744.34	3011.74
120	4265.10	4208.12	3055.68	2969.25
180	2600.85	2451.85	2541.62	2498.47

The following table is obtained by 1000 test times:

Table 4.3 Two-Level Regional Voting Scheme (1000 tests)

Length of Region	WN0 CN0.01(1000)	WN0.001 CN0.01(1000)	WN0 CN0.0025(1000)	WN0.001 CN0.0025(1000)
1	2946.84	2948.52	2685.36	2695.67
2	3946.45	3796.85	3694.66	3346.97
3	5930.96	5031.21	5220.75	4036.33
4	6843.40	5736.64	5964.74	4411.44
5	8002.66	6440.78	6789.91	4773.91
6	8875.16	6841.20	7269.63	4836.54
8	10152.07	7561.97	8072.14	5016.85
9	10478.43	8253.68	8500.37	5129.81
10	10918.84	8071.16	8384.32	5188.15
12	11666.53	8221.33	8460.51	5247.75
15	12198.30	8487.97	8544.36	5340.35
18	12110.20	8707.67	8325.17	5335.88
20	12271.72	8934.18	8117.13	5359.56
24	12108.02	9073.56	7564.12	5147.67
30	11367.93	8723.54	6686.30	5109.54
36	10521.93	8461.49	5925.09	4887.16
40	10185.45	8187.00	5773.54	4710.18
45	8951.21	8034.14	5033.12	4522.18
60	7449.30	7216.10	3624.23	3951.13
72	6436.18	6615.06	3505.32	3552.96
90	5043.07	5019.49	2739.07	2914.90
120	3872.54	4070.65	3005.97	3201.98
180	2239.44	2354.59	2543.63	2451.23

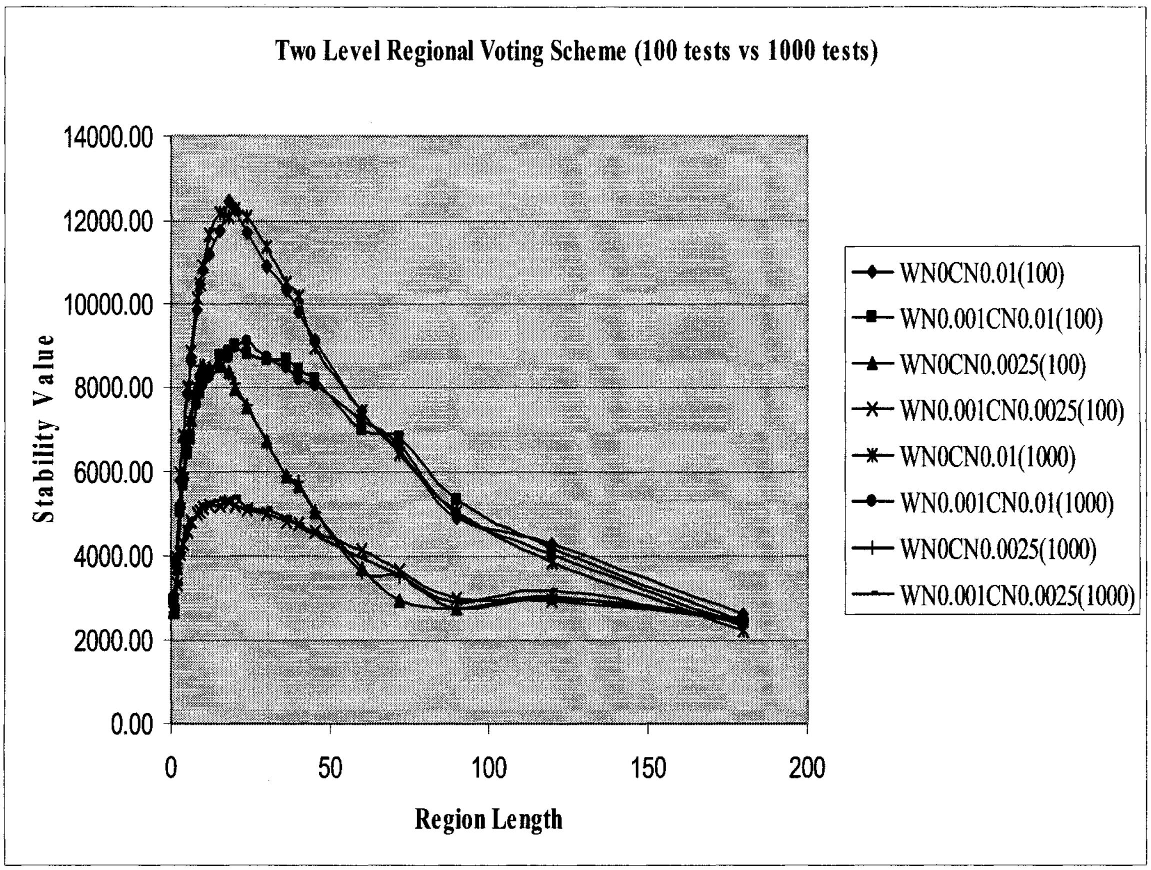


Figure 4.2 Two level regional voting scheme (100 tests vs. 1000 tests)

Discussion:

The stability value reaches maximum when we add the larger concentrated noise block without adding white noise. The stability value reaches the highest point when the region size is around 15 x 15 to 20 x 20, and beyond this region, stability nature decreases. With white noise added, the stability nature of the two-level voting scheme is worse than without white noise. This result verifies the previous conclusion about two-level regional voting scheme.

4.5.2 Multi-level Voting Scheme Test Set 1:

Purpose: Using the multi-level voting scheme, when region size (the first level window) is constant and sub-region size (the second level window) is variable, what is the stability nature of the system? In this test set, the width and length of the first level window is 180. The number of the first level window is 4.

Parameters: The size of a sub-region (the second level window) ranges from 1 x 1 to 90 x 90. So each region (the first level window) has 180 x 180 to 4 number of sub-regions (the second level windows). Each region (the first-level window) has a constant number of unit cells (180 x 180 unit cells per first level window). We repeat the test 100 times.

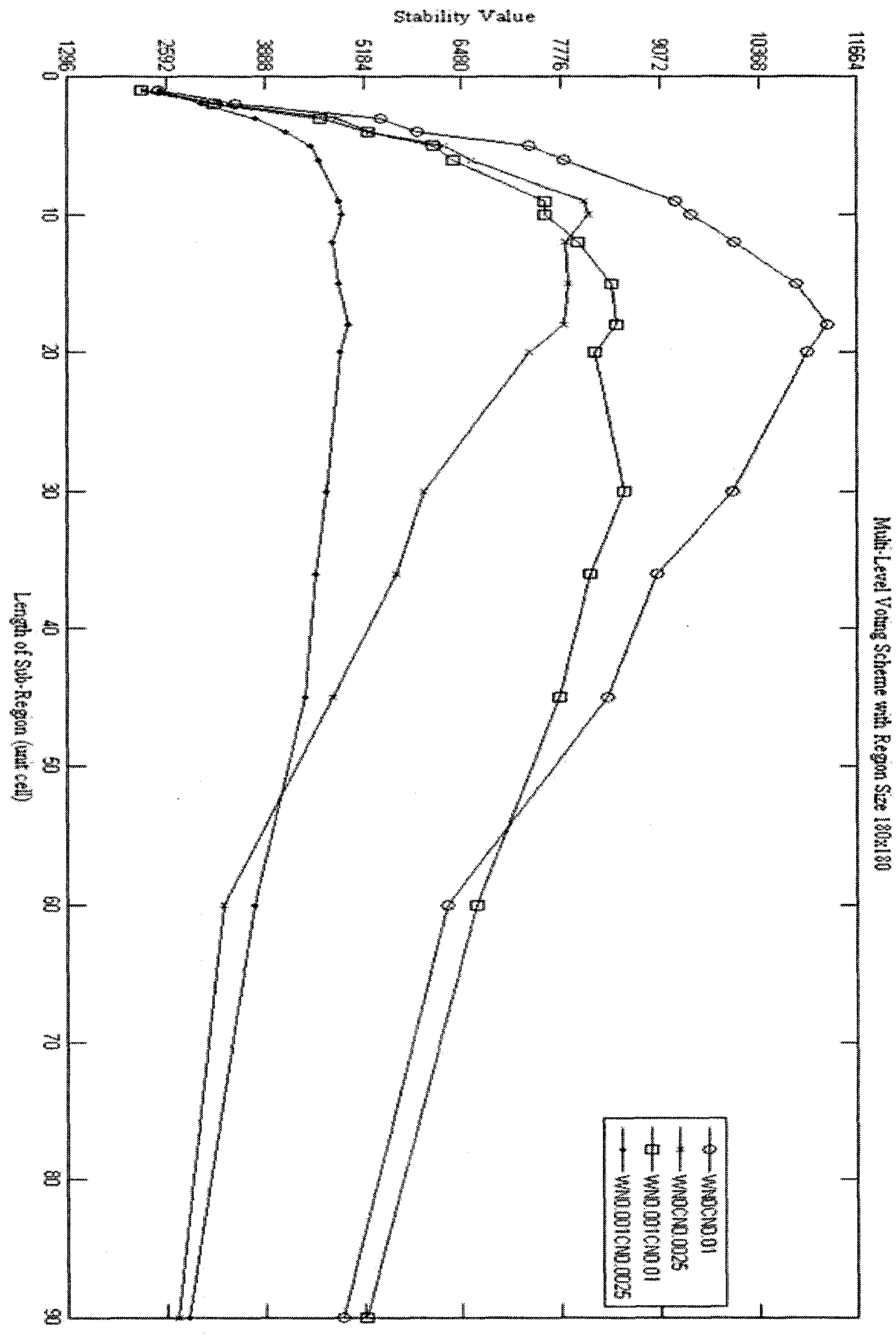
Also we notice that when the sub-region size is equal to one unit cell, this is equivalent to applying the two-level voting scheme to the nation: dividing the nation into regions with size 180 x 180.

Table 4.4 Multi-level voting scheme with region size 180 x180

Length of Sub-Region	WN0CN0.01	WN0.001CN0.01	WN0CN0.0025	WN0.001CN0.0025
1	2488.03	2251.66	2299.09	2502.63
2	3504.38	3214.84	3297.98	3049.29
3	5415.39	4619.60	4842.75	3771.40
4	5900.05	5253.92	5279.55	4180.25
5	7367.98	6096.47	6253.52	4507.35
6	7803.88	6364.84	6618.35	4590.38
9	9284.01	7558.36	8085.42	4863.21
10	9471.21	7575.66	8129.13	4896.64
12	10044.83	7985.96	7829.69	4781.86
15	10862.55	8451.58	7865.63	4866.13
18	11269.21	8510.91	7815.90	4978.27
20	11009.90	8218.25	7361.54	4879.79

30	10037.61	8598.93	5988.78	4706.83
36	9024.13	8150.70	5624.87	4562.14
45	8386.66	7754.93	4775.75	4410.26
60	6291.96	6663.89	3348.95	3745.32
90	4900.29	5205.85	2735.18	2869.27

Figure 4.3 Multi-level voting scheme with region size 180 x180


Multi-Level Voting Scheme with Region Size 180x180
Stability Value
1296
2592
3888
5184
6480
7776
9072
10368
11664
Length of Sub-Region (unit cell)
0
10
20
30
40
50
60
70
80
90
WN0CN0.01
WN0CN0.0025
WN0.001CN0.01
WN0.001CN0.0025

Discussion:

We can see the stability value reach maximum when we only add the larger concentrated noise block without adding white noise. Maximum value is reached when the sub-region size is around 18 x 18. When white noise is added, the stability nature of the multi-level voting scheme is worse than without adding white noise.

4.5.3 Multi-level Voting Scheme Test Set 2

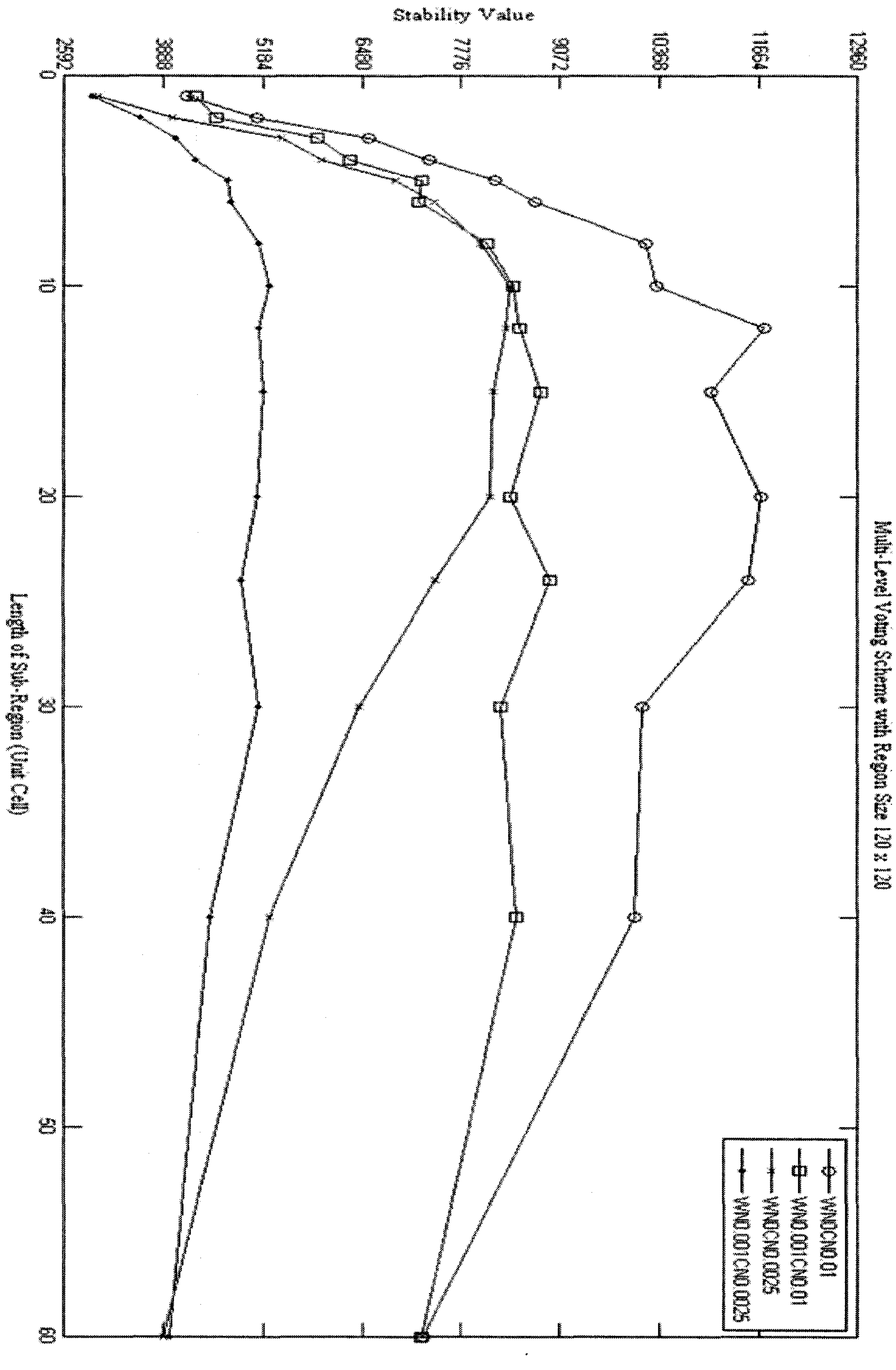
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 120 x 120. The number of first level windows is 9.

Table 4.5 Multi-level voting scheme with region size 120 x 120

Length of Sub-Region	**WN0CN0.01**	**WN0.001CN0.01**	**WN0CN0.0025**	**WN0.001CN0.0025**
1	4194.54	4301.79	3031.36	2954.45
2	5095.68	4565.12	3996.55	3581.59
3	6566.64	5900.07	5436.80	4052.15
4	7357.74	6315.14	5954.06	4318.21
5	8203.85	7264.02	6917.34	4709.59
6	8733.65	7213.67	7411.66	4750.22
8	10185.68	8118.90	8019.98	5123.94
10	10318.56	8465.55	8425.13	5260.59
12	11740.14	8539.54	8364.82	5122.27
15	11030.90	8828.03	8191.82	5189.79
20	11687.55	8416.92	8160.15	5100.24
24	11530.95	8946.79	7439.39	4907.62
30	10141.37	8291.94	6454.38	5113.89
40	10042.81	8488.24	5262.19	4495.97
60	7283.75	7254.57	3889.71	3969.17

Figure 5.4 Multi-level voting scheme with region size 120 x 120



Multi-Level Voting Scheme with Region Size 120 x 120
Stability Value
Length of Sub-Region (Unit Cell)
2592
3888
5184
6480
7776
9072
10368
11664
12960
0
10
20
30
40
50
60
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025

Discussion:

We can see the stability value reach maximum when we add the larger concentrated noise block without adding white noise. Maximum value is reached when the sub-window size is around 12. The stability nature of the multi-level voting scheme is worse with white noise added.

4.5.4 Multi-level Voting Scheme Test Set 3

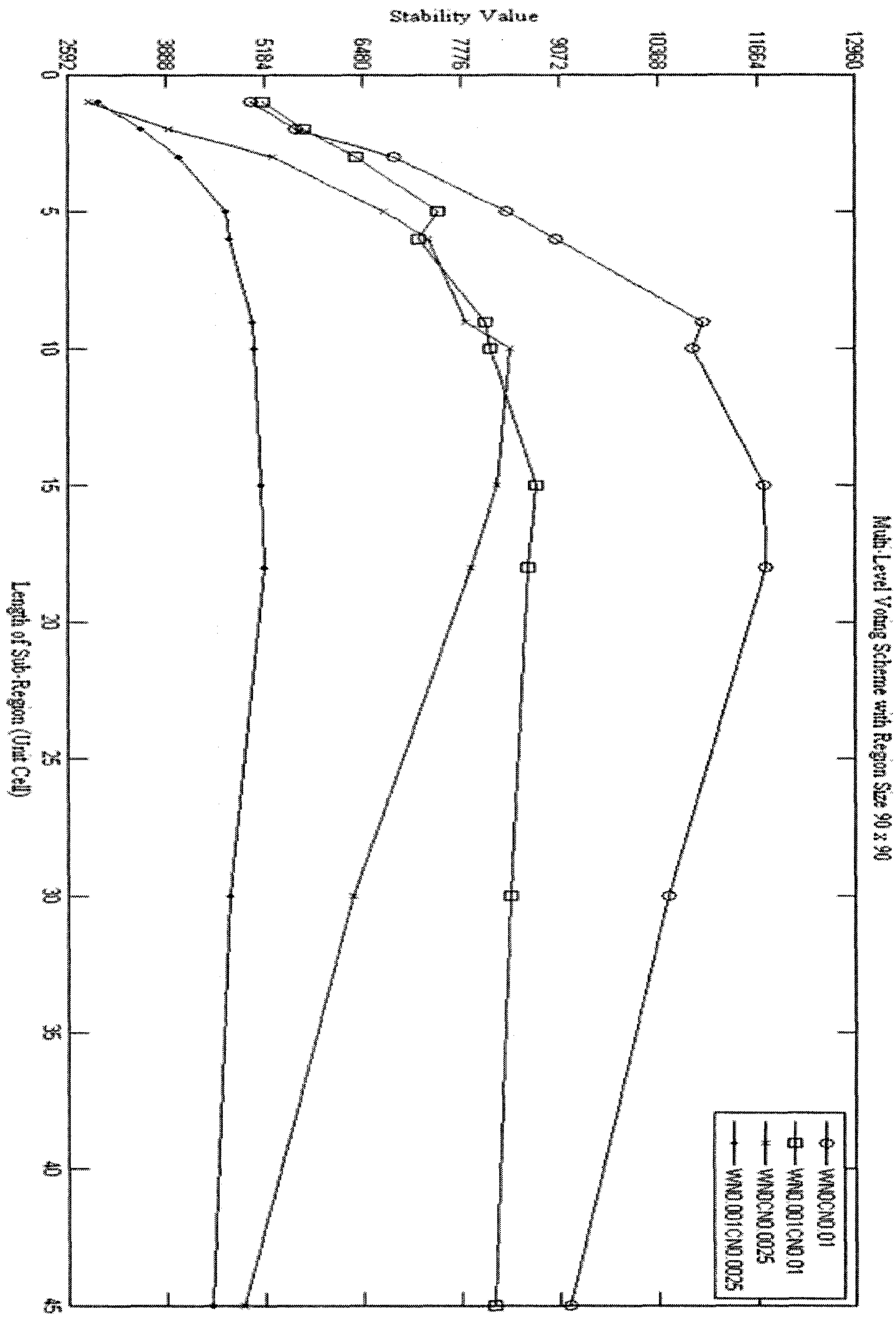
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 90 x 90. The region number is 16.

Table 4.6 Multi-level voting scheme with region size 90 x 90

Length of Sub-Region	**WN0CN0.01**	**WN0.001CN0.01**	**WN0CN0.0025**	**WN0.001CN0.0025**
1	5000.05	5154.24	2863.99	3002.70
2	5594.15	5704.33	3922.46	3548.66
3	6887.44	6398.53	5287.47	4057.72
5	8379.61	7474.07	6759.87	4678.38
6	9035.03	7214.90	7345.18	4727.03
9	10951.26	8101.31	7840.22	5018.63
10	10822.24	8161.20	8435.69	5042.85
15	11763.39	8780.05	8249.29	5141.54
18	11781.42	8663.53	7905.26	5172.53
30	10500.27	8435.43	6339.49	4716.96
45	9195.25	8204.34	4902.47	4486.61

Figure 4.5 Multi-level voting scheme with region size 90 x 90


Multi-Level Voting Scheme with Region Size 90 x 90
Stability Value
2592
3888
5184
6480
7776
9072
10368
11664
12960
Length of Sub-Region (Unit Cell)
0
5
10
15
20
25
30
35
40
45
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025

Discussion:

We can see the stability reach maximum when we add the larger concentrated noise block without adding white noise. The maximum value is reached when the sub-window size is around 18. The stability nature of the multi-level voting scheme is worse when white noise has been added.

4.5.5 Multi-level Voting Scheme Test Set 4

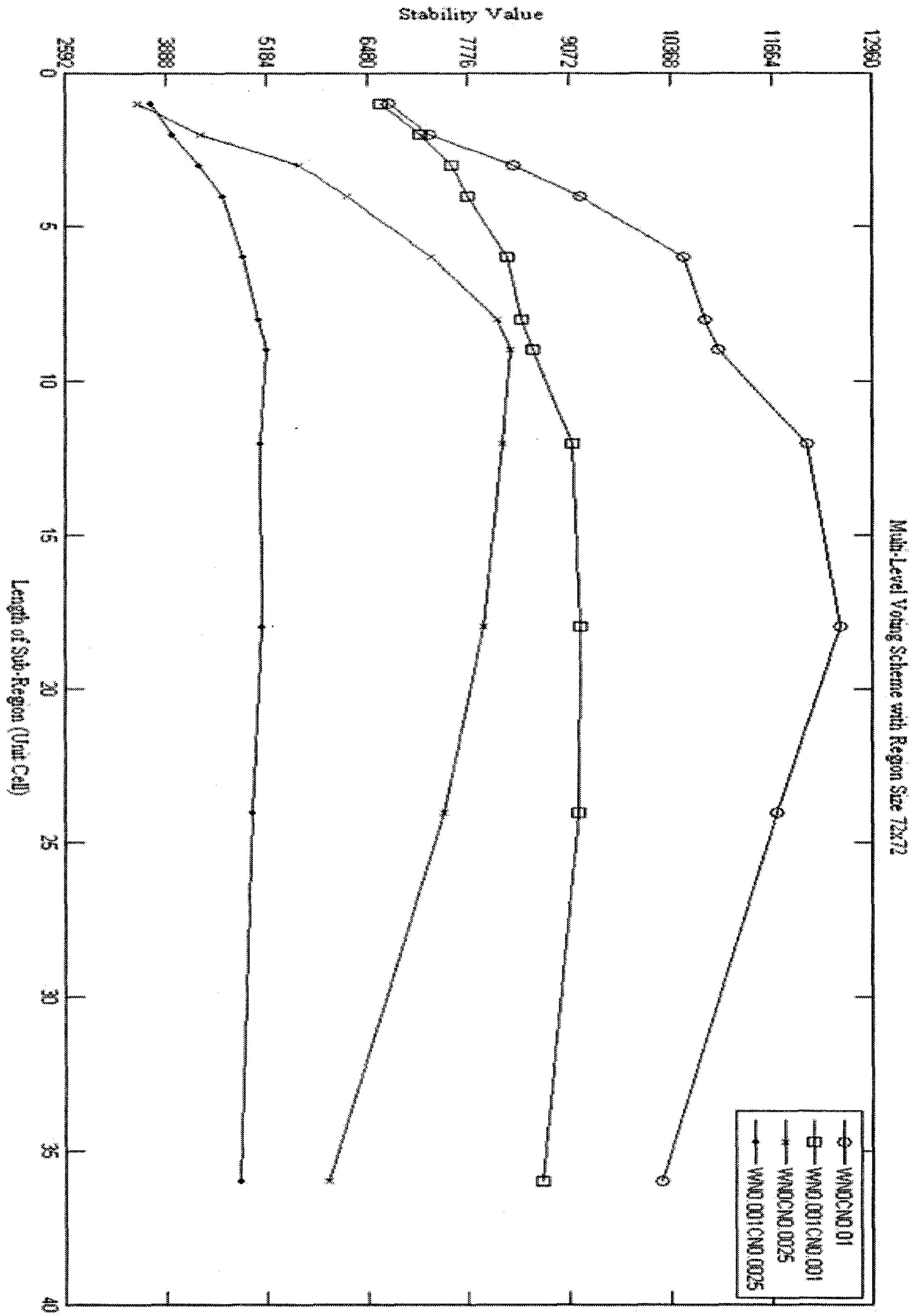
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 72. The number of region is 25.

Table 4.7 Multi-level voting scheme with region size 72 x 72

Length of Sub-Region	WN0CN0.01	WN0.001CN0.01	WN0CN0.0025	WN0.001CN0.0025
1	6742.03	6648.99	3520.67	3685.44
2	7278.83	7159.99	4325.63	3969.86
3	8352.21	7566.97	5614.88	4313.13
4	9209.10	7771.70	6216.73	4609.81
6	10538.33	8284.01	7307.11	4874.84
8	10822.58	8466.73	8142.15	5086.75
9	10972.55	8599.17	8320.18	5174.01
12	12114.77	9111.09	8209.67	5105.94
18	12542.22	9212.47	7973.39	5123.18
24	11735.22	9190.32	7469.22	4994.67
36	10252.29	8730.71	5973.19	4832.32

Figure 4.6 Multi-level voting scheme with region size 72 x 72


Multi-Level Voting Scheme with Region Size 72x72
Stability Value
2592
3888
5184
6480
7776
9072
10368
11664
12960
Length of Sub-Region (Unit Cell)
0
5
10
15
20
25
30
35
40
WN0CN0.01
WN0.001CN0.001
WN0CN0.0025
WN0.001CN0.0025

Discussion:

We can see the stability value reach maximum when we add the larger concentrated noise block, without adding white noise. The maximum value is reached when the sub-region size is around 18. The stability nature of the multi-level voting scheme is worse when white noise has been added.

4.5.6 Multi-level Voting Scheme Test Set 5

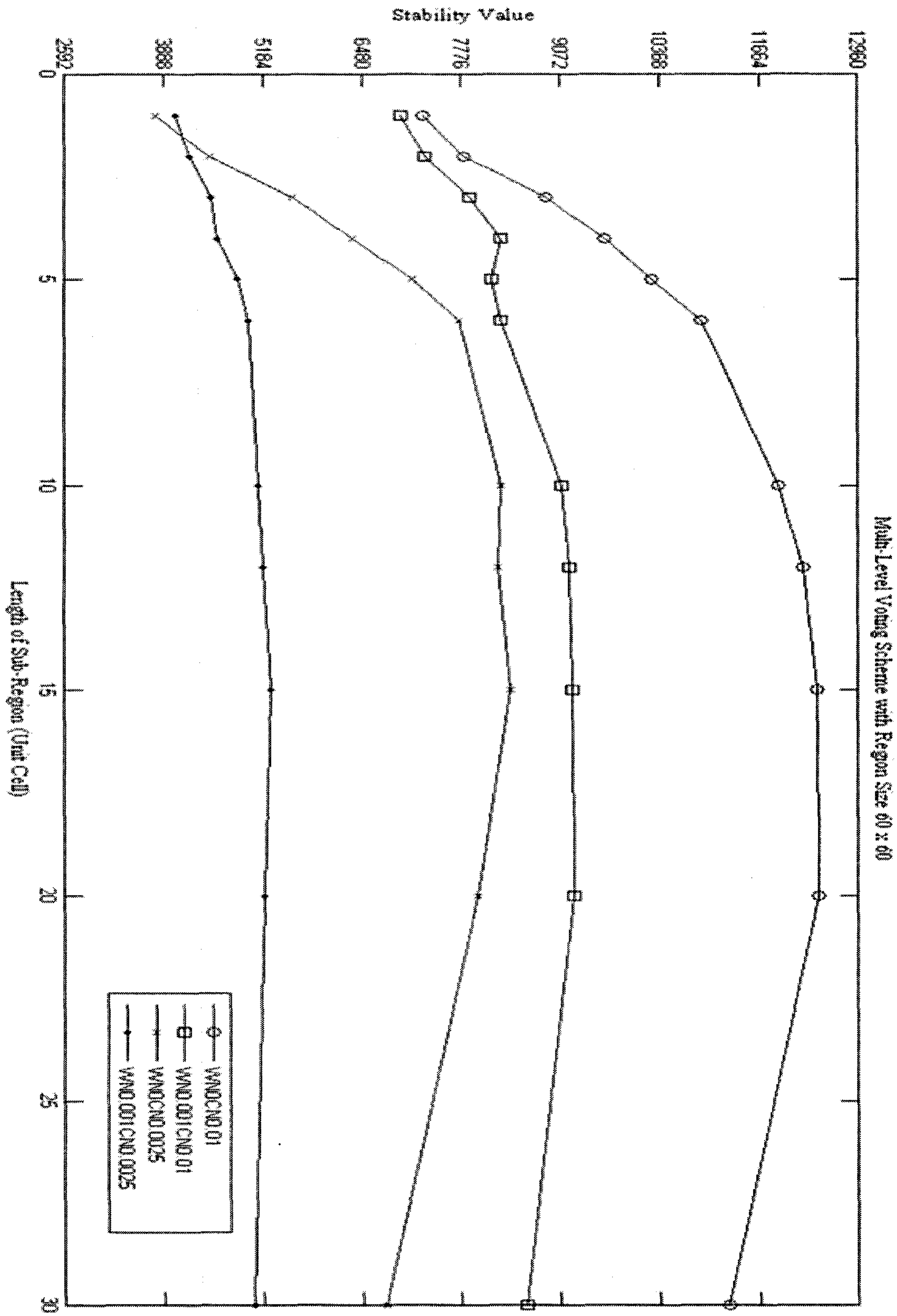
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 60. The number of regions (the first level window) is 36.

Table 4.8 Multi-level voting scheme with region size 60 x 60

Length of Sub-Region	WN0CN0.01	WN0.001CN0.01	WN0CN0.0025	WN0.001CN0.0025
1	7286.01	6993.81	3788.86	4046.23
2	7813.67	7294.32	4501.29	4237.22
3	8887.28	7881.69	5573.05	4516.81
4	9646.94	8289.40	6360.31	4591.87
5	10271.60	8178.67	7134.44	4859.38
6	10925.81	8303.20	7741.55	4998.34
10	11906.86	9086.17	8301.49	5127.90
12	12239.27	9186.38	8263.11	5178.27
15	12418.25	9239.46	8425.44	5291.13
20	12444.81	9246.60	7994.10	5206.97
30	11269.34	8628.07	6789.23	5066.14

Figure 4.7 Multi-level voting scheme with region size 60 x 60


Multi-Level Voting Scheme with Region Size 60 x 60
Stability Value
2592
3888
5184
6480
7776
9072
10368
11664
12960
Length of Sub-Region (Unit Cell)
0
5
10
15
20
25
30
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025

Discussion:

The stability value reaches maximum when we add the larger concentrated noise block without adding white noise. The maximum value is reached when the sub-region size is around 20. The stability nature of the multi-level voting scheme is worse when adding white noise.

4.5.7 Multi-level Voting Scheme Test Set 6

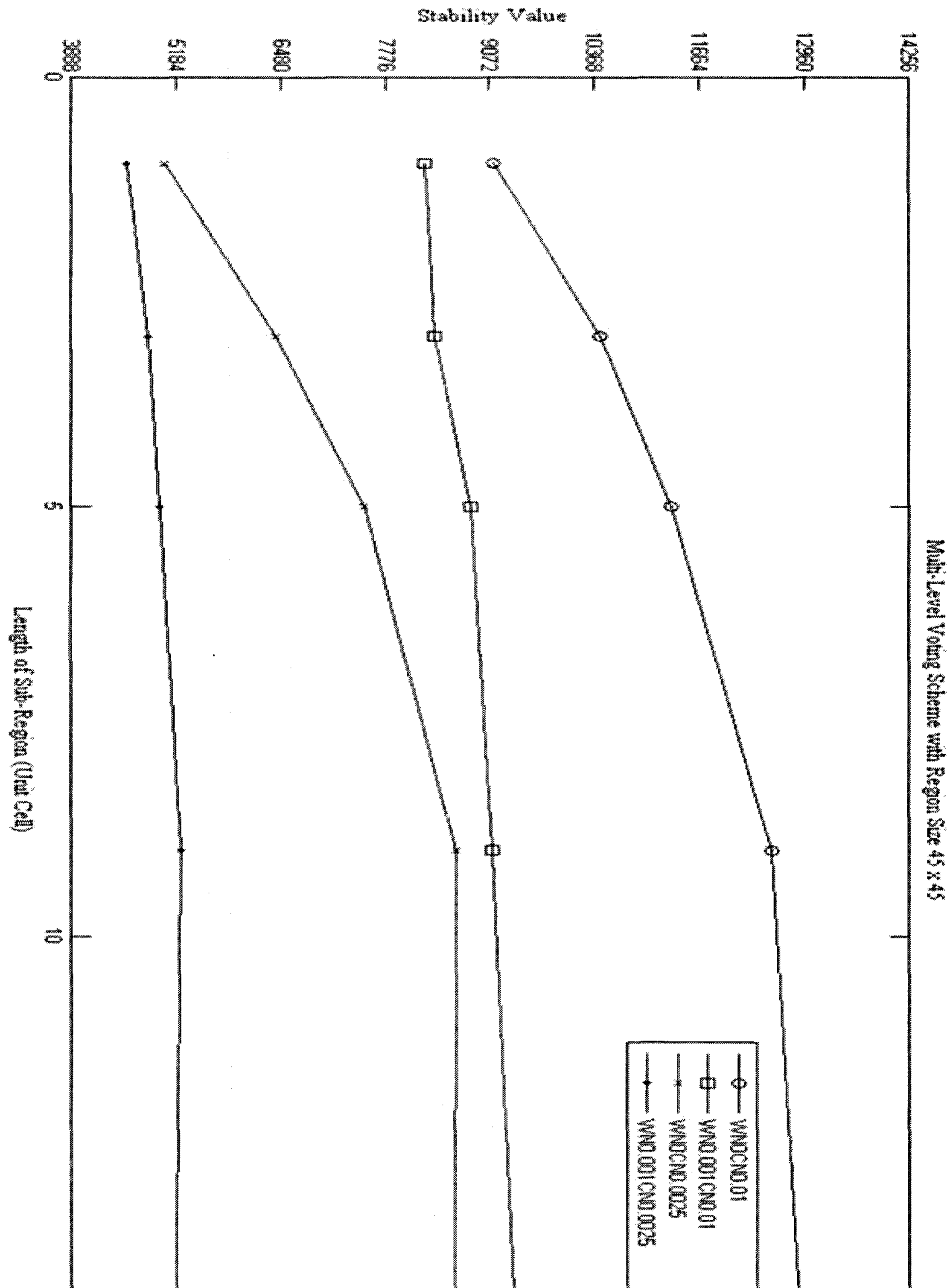
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 45. The number of regions (the first level window) is 64.

Table 4.9 Multi-level voting scheme with region size 45 x 45

Length of Sub-Region	**WN0CN0.01**	**WN0.001CN0.01**	**WN0CN0.0025**	**WN0.001CN0.0025**
1	9120.47	8267.64	5032.47	4559.11
3	10444.81	8381.40	6410.88	4825.84
5	11318.11	8843.99	7513.61	4978.45
9	12567.42	9094.14	8654.33	5247.54
15	12943.09	9404.97	8632.75	5168.71

Figure 4.8 Multi-level voting scheme with region size 45 x 45


Multi-Level Voting Scheme with Region Size 45 x 45
Stability Value
3888
5184
6480
7776
9072
10368
11664
12960
14256
0
5
10
15
Length of Sub-Region (Unit Cell)
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025

Discussion:

The stability value reaches the maximum when we just add larger concentrated noise block without adding white noise. Maximum value is reached when the sub-region size is around 15. The stability nature of the multi-level voting scheme is worse with white noise added.

4.5.8 Multi-level Voting Scheme Test Set 7

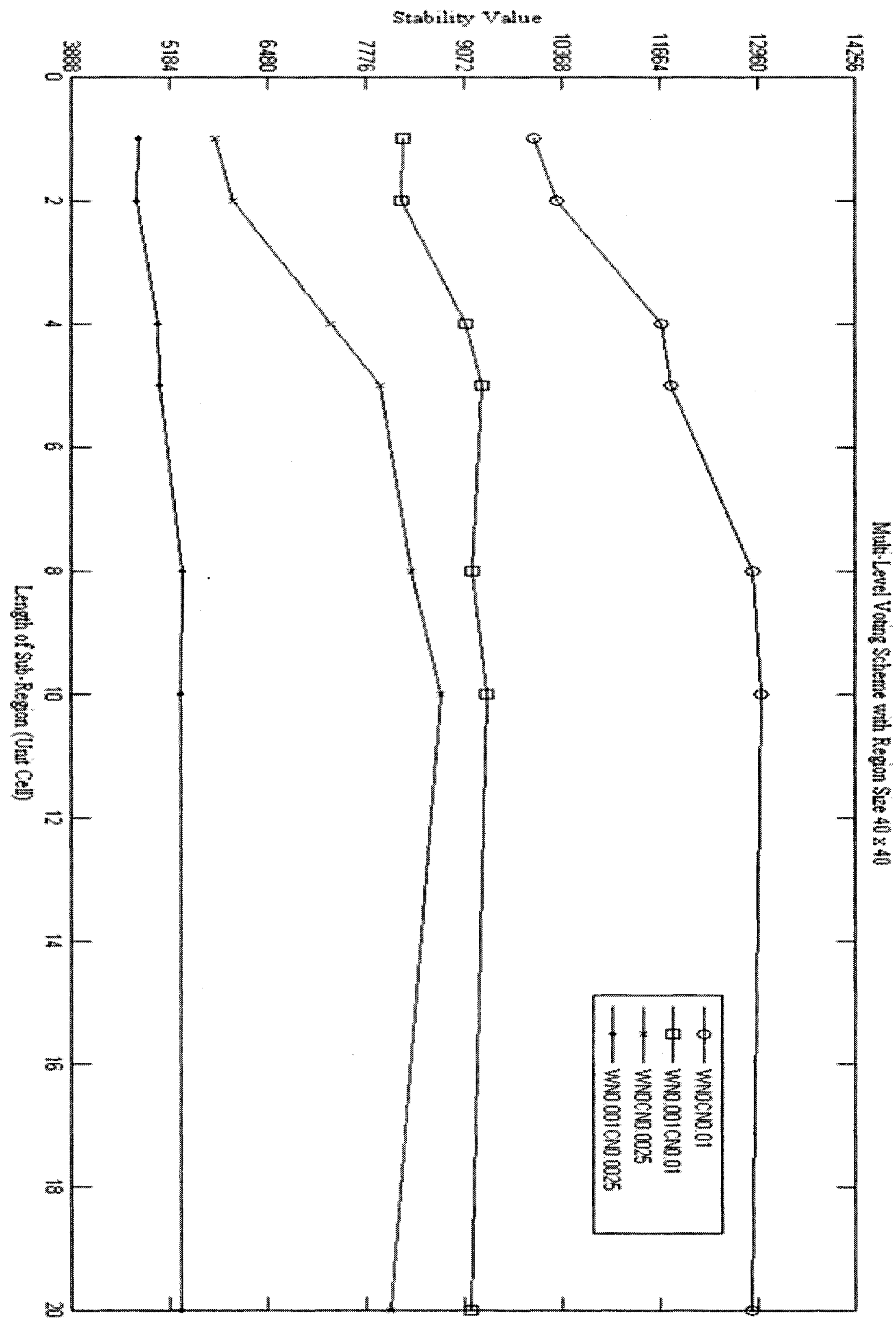
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 40. The number of regions (the first level window) is 81.

Table 4.10 Multi-level voting scheme with region size 40 x 40

Length of Sub-Region	WN0CN0.01	WN0.001CN0.01	WN0CN0.0025	W0.001CN0.0025
1	10010.12	8272.52	5780.82	4759.16
2	10296.95	8253.58	6017.90	4749.50
4	11693.64	9098.68	7323.50	5016.69
5	11817.19	9302.36	7959.10	5042.68
8	12913.75	9173.08	8379.57	5343.16
10	13016.93	9385.15	8761.82	5329.51
20	12880.19	9151.73	8097.25	5336.05

Figure 4.9 Multi-level voting scheme with region size 40 x 40


Multi-Level Voting Scheme with Region Size 40 x 40
Stability Value
3888
5184
6480
7776
9072
10368
11664
12960
14256
Length of Sub-Region (Unit Cell)
0
2
4
6
8
10
12
14
16
18
20
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025

Discussion:

The stability value reaches maximum when we add larger concentrated noise block, without white noise. The maximum value is reached when the sub-region size is around 10. The stability nature of the multi-level voting scheme is worse when white noise is added than when it is not.

4.5.9 Multi-level Voting Scheme Test Set 8

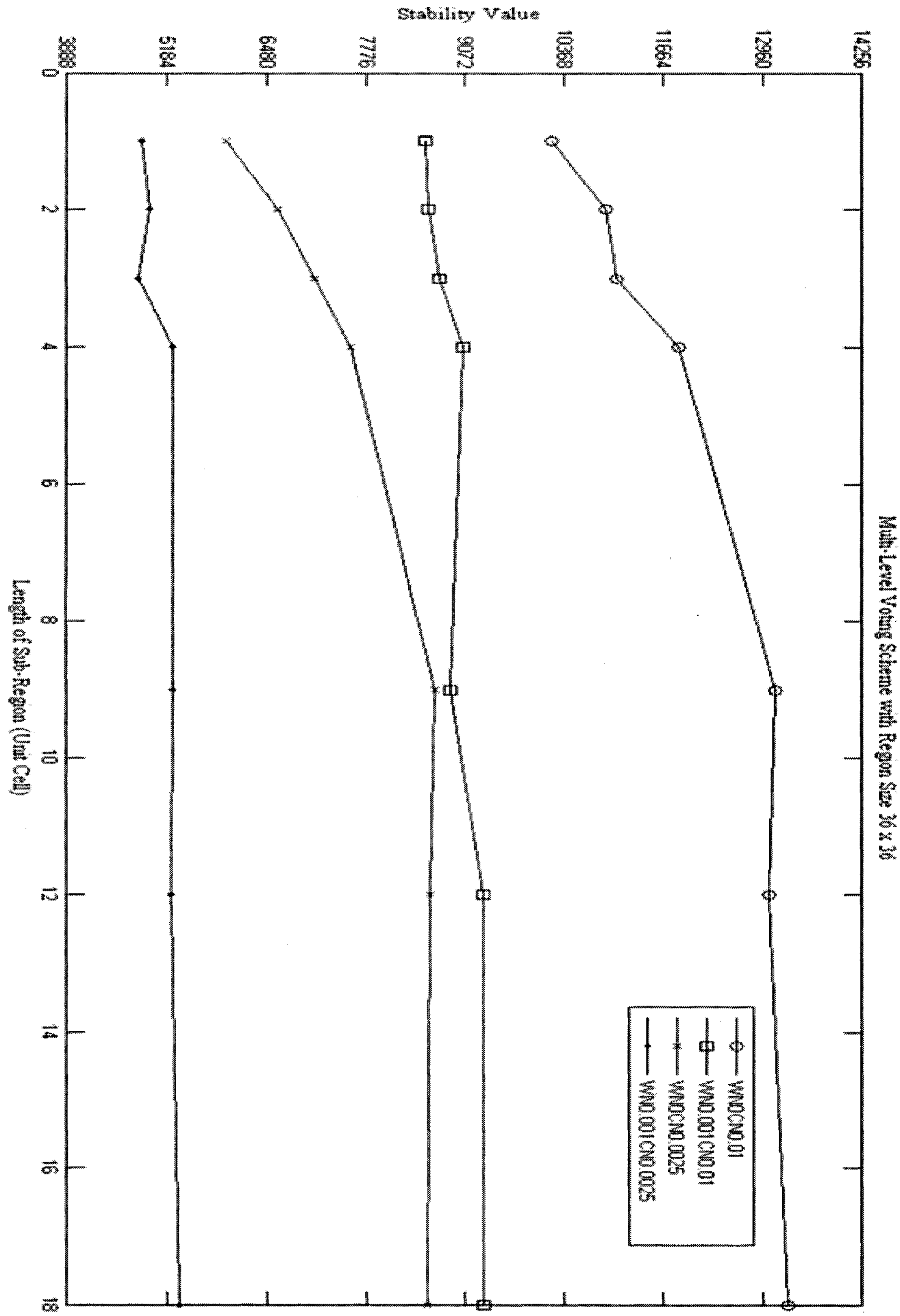
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 36. The number of regions (the first level window) is 100.

Table 4.11 Multi-level voting scheme with region size 36 x 36

Length of Sub-Region	**WN0CN0.01**	**WN0.001CN0.01**	**WN0CN0.0025**	**WN0.001CN0.0025**
1	10198.35	8549.72	5959.81	4845.83
2	10916.42	8595.89	6622.20	4950.58
3	11047.19	8729.20	7117.87	4819.31
4	11867.41	9032.72	7570.16	5258.38
9	13122.10	8883.61	8673.29	5262.10
12	13042.36	9305.80	8606.62	5241.27
18	13294.85	9298.01	8568.17	5342.20

Figure 4.10 Multi-level voting scheme with region size 36 x 36


Multi-Level Voting Scheme with Region Size 36 x 36
Stability Value
3888
5184
6480
7776
9072
10368
11664
12960
14256
0
2
4
6
8
10
12
14
16
18
Length of Sub-Region (Unit Cell)
WN0CN0.01
WN0.001CN0.01
WN0CN0.025
WN0.001CN0.025

Discussion:

The stability value reaches maximum when we only add the larger concentrated noise block without adding white noise. The maximum value is reached when the sub-region size is around 18 x 18. The stability nature of the multi-level voting scheme is worse with white noise added.

4.5.10 Multi-level Voting Scheme Test Set 9

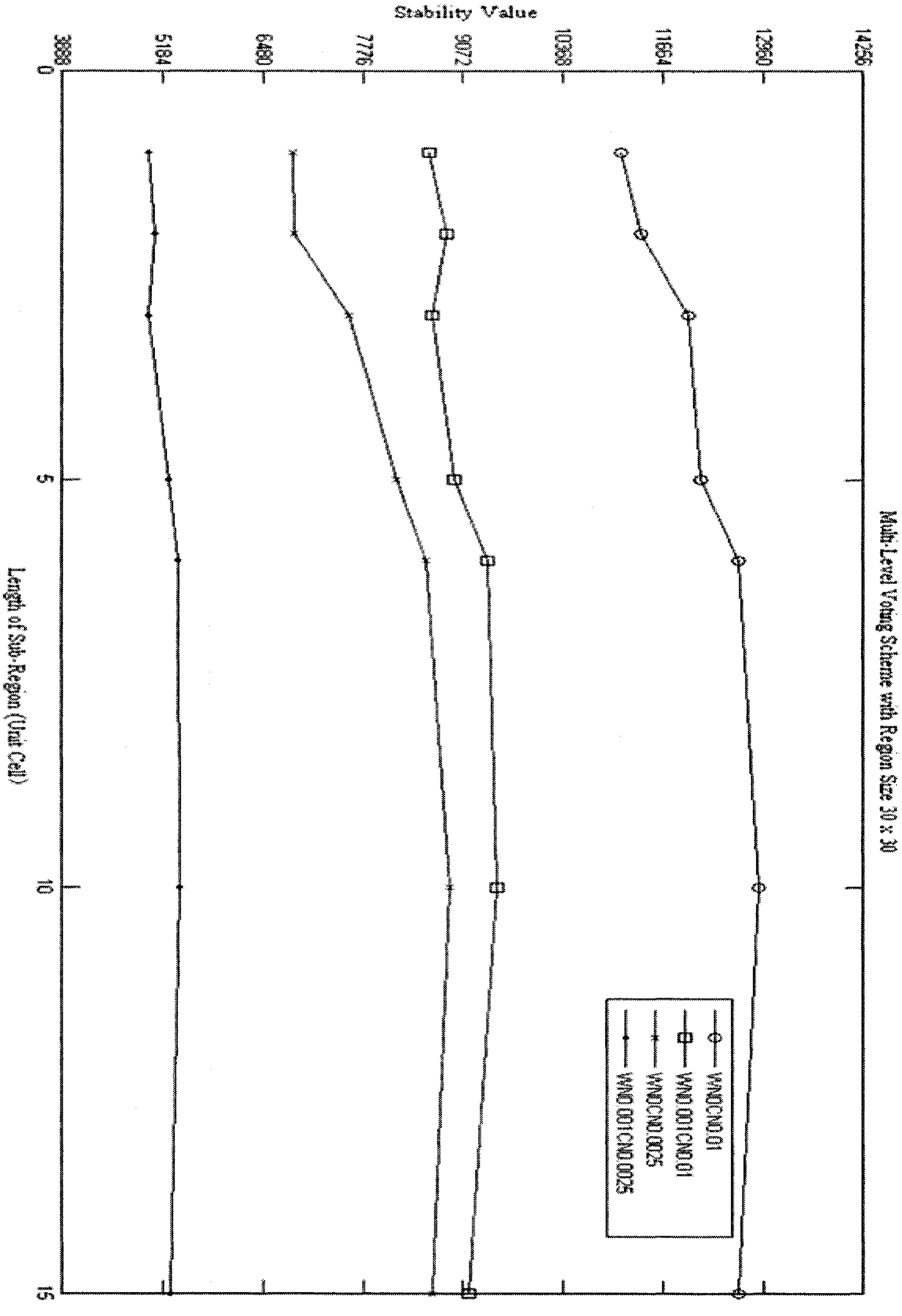
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The size of region (the first level window) is 30. The number of first level window is 144.

Table 4.12 Multi-level voting scheme with region size 30 x 30

Length of Sub-Region	**WN0CN0.01**	**WN0.001CN0.01**	**WN0CN0.0025**	**WN0.001CN0.0025**
1	11112.69	8631.94	6857.33	4990.08
2	11369.63	8853.60	6876.43	5068.45
3	11981.04	8667.06	7603.01	4990.78
5	12153.30	8953.10	8205.73	5264.57
6	12632.60	9381.39	8590.46	5389.36
10	12897.22	9516.80	8894.89	5399.23
15	12645.21	9146.68	8673.99	5289.86

Figure 4.11 Multi-level voting scheme with region size 30 x 30


Multi-Level Voting Scheme with Region Size 30 x 30
Stability Value
3888
5184
6480
7776
9072
10368
11664
12960
14256
Length of Sub-Region (Unit Cell)
0
5
10
15
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025

Discussion:

The stability value reaches maximum when we add the larger concentrated noise block without adding white noise. The maximum value is reached when the sub-region size is around 10 x 10. The stability nature of the multi-level voting scheme is worse with white noise added.

4.5.11 Multi-level Voting Scheme Test Set 10

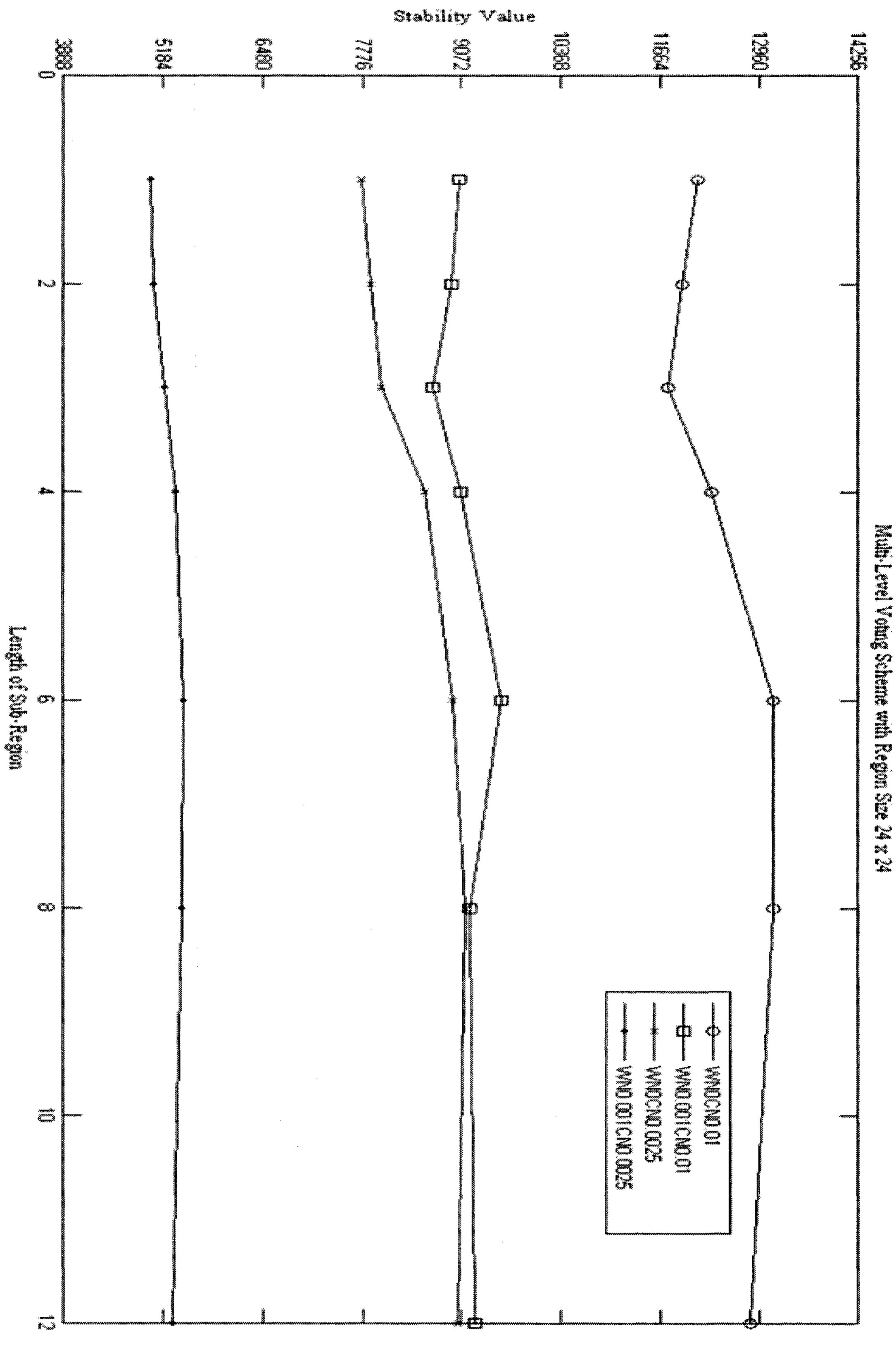
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 24. The number of regions (the first level window) is 225.

Table 4.13 Multi-level voting scheme with region size 24 x 24

Length of Sub-Region	**WN0CN0.01**	**WN0.001CN0.01**	**WN0CN0.0025**	**WN0.001CN0.0025**
1	12158.00	9037.10	7768.15	5025.47
2	11953.16	8940.43	7888.23	5064.28
3	11766.62	8693.48	8034.63	5201.06
4	12339.50	9071.36	8603.90	5339.73
6	13151.00	9599.23	8952.37	5442.47
8	13151.55	9191.13	9127.46	5430.91
12	12838.55	9249.75	9028.62	5292.94

Figure 4.12 Multi-level voting scheme with region size 24 x 24



Multi-Level Voting Scheme with Region Size 24 x 24
Stability Value
Length of Sub-Region
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025
3888
5184
6480
7776
9072
10368
11664
12960
14256
0
2
4
6
8
10
12

Discussion:

The stability value reaches maximum when we add the larger concentrated noise block without adding white noise. The maximum value is reached when the sub-region size is around 8 x 8. The stability nature of the multi-level voting scheme is worse with white noise added.

4.5.12 Multi-level Voting Scheme Test Set 11

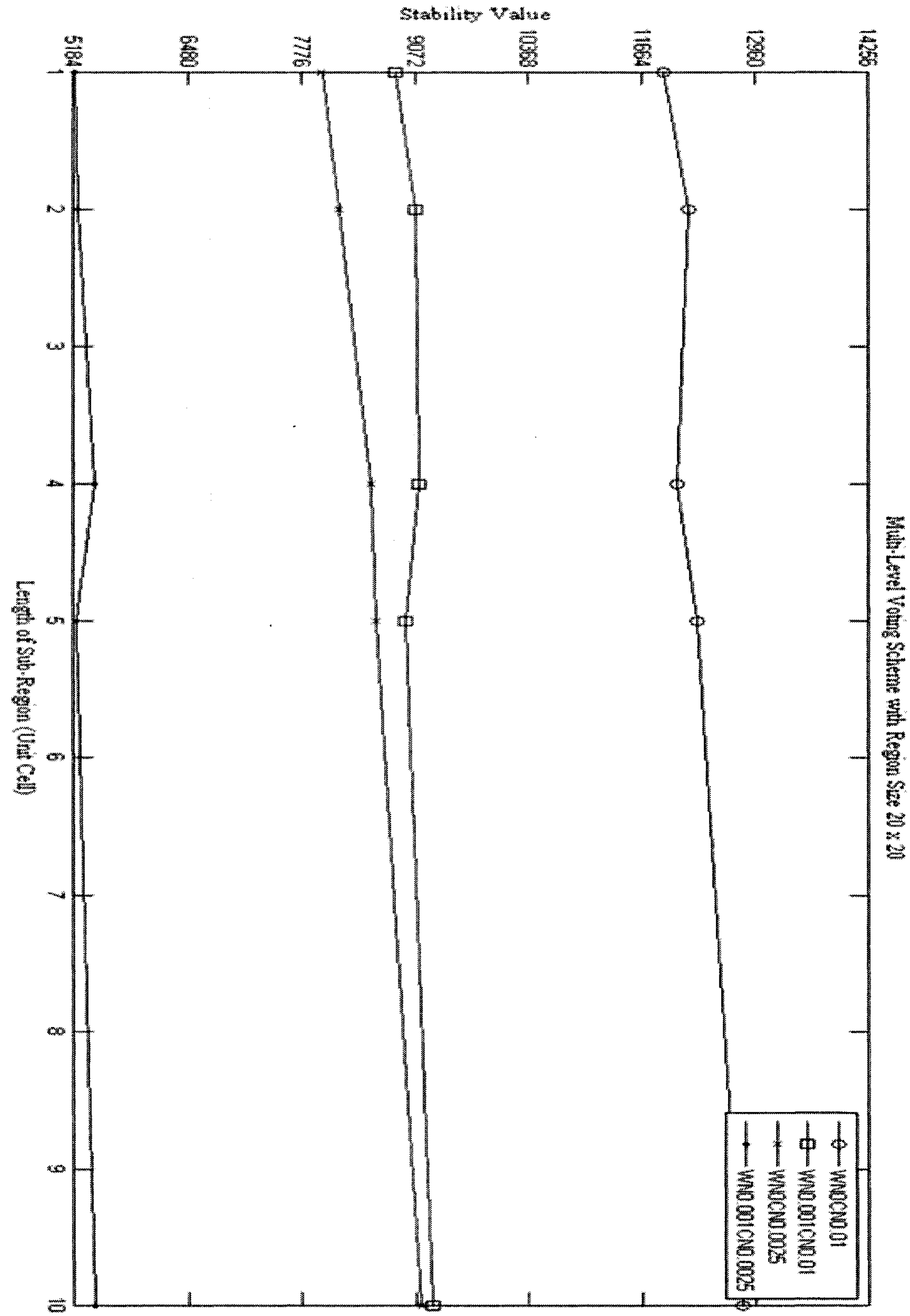
Purpose: Same as Multi-level regional voting scheme Test Set 1.

Parameters: The region size (the first level window) is 20 x 20. The number of regions (the first level window) is 324.

Table 4.14 Multi-level voting scheme with region size 20 x 20

Length of Sub-Region	WN0CN0.01	WN0.001CN0.01	WN0CN0.0025	WN0.001CN0.0025
1	11916.06	8855.02	8005.31	5197.04
2	12197.67	9077.78	8203.12	5222.04
4	12070.37	9121.60	8571.72	5418.49
5	12289.03	8954.53	8622.11	5209.19
10	12800.29	9256.90	9126.76	5420.69

Figure 4.13 Multi-level voting scheme with region size 20 x 20


Multi-Level Voting Scheme with Region Size 20 x 20
Stability Value
5184
6480
7776
9072
10368
11664
12960
14256
1
2
3
4
5
6
7
8
9
10
Length of Sub-Region (Unit Cell)
WN0CN0.01
WN0.001CN0.01
WN0CN0.0025
WN0.001CN0.0025

Discussion:

The stability value reaches maximum when we add the larger concentrated noise block without adding white noise. Maximum value is reached when the sub-region size is around 10. The stability nature of the multi-level voting scheme is worse with concentrated noise than without.

4.5.13 Comparison Study for Multi-Level Regional Voting Scheme and Two-Level Regional Voting Scheme with Larger Concentrated Noise Block

Purpose: We will compare the multi-level regional voting scheme with the two-level voting scheme when the first-level window size is less than 20. Here we use the same nation, repeating the test 100 times. The reason we emphasize that in this testing set the first-level window size is around or less than 20 is because, in our face recognition problem, the size of probe and gallery image is 60 x 60. Also we note that when the sub-region size is 1 x 1, we can think of it as two-level regional voting scheme.

Parameters: we will consider two kinds of noise mode, WN0CN0.01 and WN0.001CN0.01. In the previous study, we know that the stability nature of a multi-level regional voting scheme is worse when the concentrated noise type is type 2 (CN0.0025) rather than type 1 (CN0.01), and we want to know if there is any chance that the multi-level voting scheme can be more robust than the two-level voting scheme so we do not consider WN0CN0.0025 and WN0.001CN0.0025 two configurations.

4.5.13.1 WN0CN0.01:

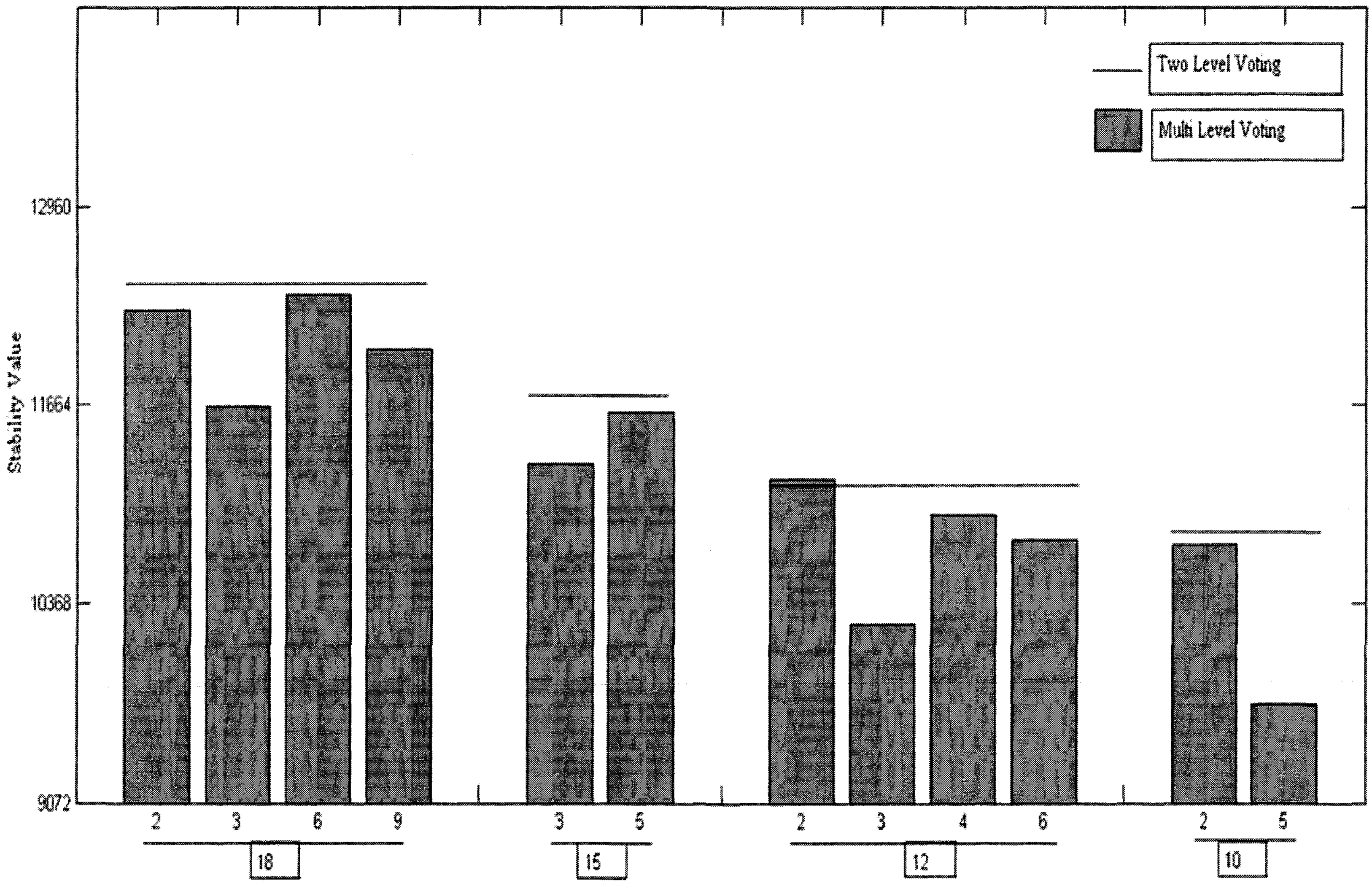
- When region size (the first-level window) is 18 x 18, we divide the region (the first-level window) further into sub-regions with size 2 x 2, 3 x 3, 6 x 6 , 9 x 9
- When region size (the first-level window) is 15 x 15, we divide the region (the first-level window) further into sub-regions with size 3 x 3 , 5 x 5
- When region size (the first-level window) is 12 x 12, we divide the region (the first-level window) further into sub-regions of size 2 x 2, 3 x 3, 4 x 4, 6 x 6
- When region size (the first-level window) is 10 x 10, we divide the region (the first-level window) further into sub-regions of size 2 x 2, 5 x 5

Table 4.15 Multi-level voting scheme vs. two-level voting scheme (WN0CN0.01)

Length of Region	**Length of Sub Region**	**Stability Value**
18	1	12483.85
18	2	12289.85
18	3	11663.75
18	6	12387.98
18	9	12032.70
15	1	12114.72
15	3	11285.83
15	5	11622.00
12	1	11153.15
12	2	11178.41
12	3	10239.33
12	4	10943.57
12	6	10785.49
10	1	10853.92
10	2	10755.04
10	5	9713.62

Figure 4.14 Multi-level voting scheme vs. two-level voting scheme (WN0CN0.01)

Multi-Level Voting Scheme vs Two-Level Voting Scheme (WN0CN0.01)



Discussion:

When there is no white noise and the concentrated noise block size is less than 0.01 of the nation size, we can see the multi-level voting scheme is comparable, but not as good as the two-level voting scheme when region size is between 18 and 10.

4.5.13.2 WN0.001CN0.01

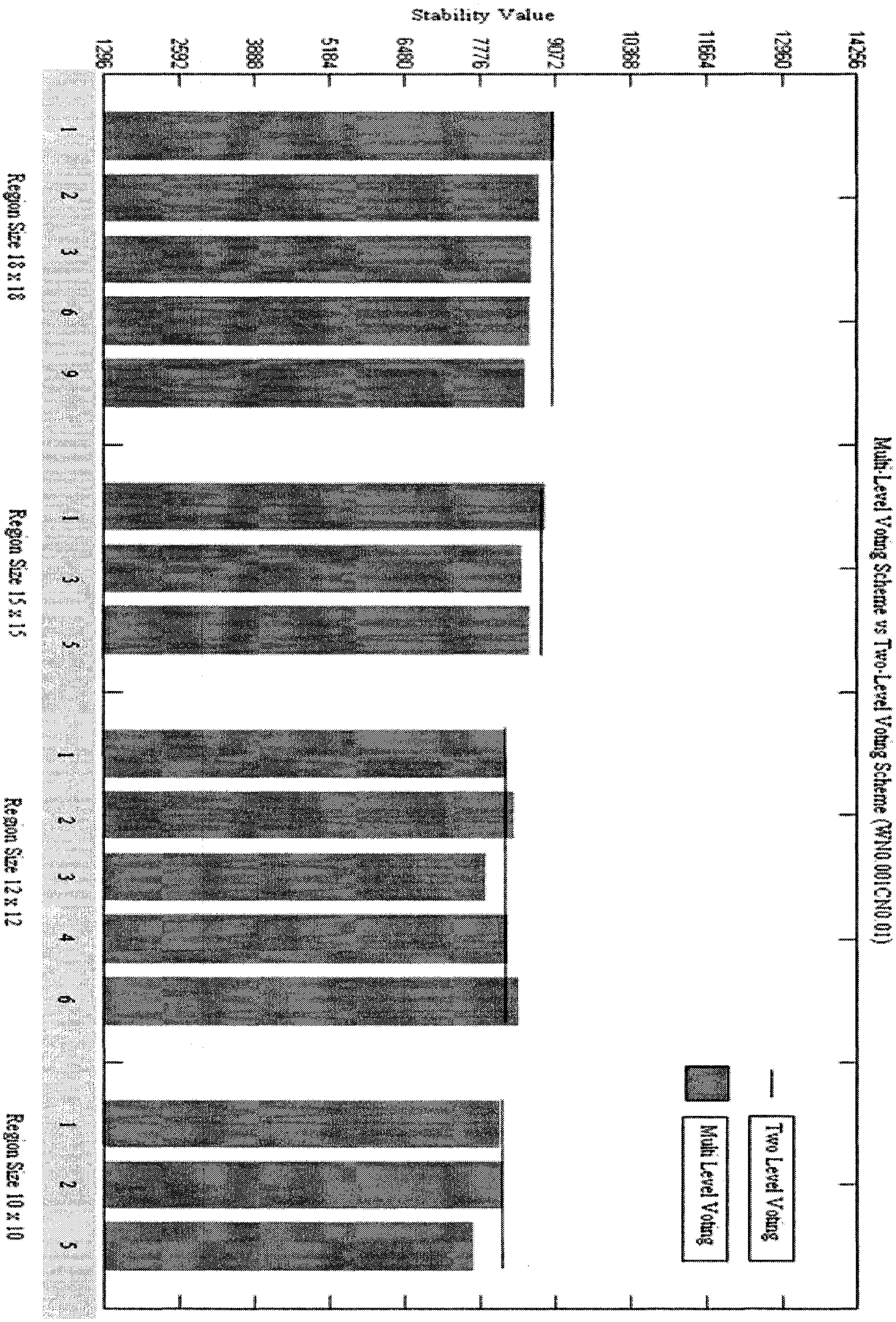
- When region (the first-level window) size is 18 x 18, we divide each region further into sub-regions of size 2 x 2, 3 x 3, 6 x 6, 9 x 9
- When region (the first level window) size is 15 x 15, we divide each region further into sub-regions of size 3 x 3, 5 x 5
- When region (the first level window) size is 12 x 12, we divide each region further into sub-regions of size 2 x 2, 3 x 3, 4 x 4, 6 x 6
- When region (the first level window) size is 10 x 10, we divide each region further into sub-regions of sizes 2 x 2, 5 x 5

Table 4.16 Multi-level voting scheme vs. two-level voting scheme (WN0.001CN0.01)

Length of Region Size	**Length of Sub-Region**	**Stability of Value**
18	1	9062.03
18	2	8805.10
18	3	8659.41
18	6	8642.05
18	9	8570.27
15	1	8909.48
15	3	8505.96
15	5	8653.96
12	1	8231.80
12	2	8377.11

12	3	7888.18
12	4	8276.18
12	6	8465.26
10	1	8138.84
10	2	8152.67
10	5	7673.28

Figure 4.15 Multi-level voting scheme vs. two-level voting scheme (WN0.001CN0.01)


Multi-Level Voting Scheme vs Two-Level Voting Scheme (WN0.001CN0.01)
Stability Value
1296
2592
3888
5184
6480
7776
9072
10368
11664
12960
14256
Two Level Voting
Multi Level Voting
1
2
3
6
9
Region Size 18 x 18
1
3
5
Region Size 15 x 15
1
2
3
4
6
Region Size 12 x 12
1
2
5
Region Size 10 x 10

Discussion:

When white noise is 0.001 and concentrated noise size is less than 0.01 of the nation size, the multi-level voting scheme is generally comparable to, but not as good as, the two-level voting scheme when the window size is between 18 and 10.

4.6 Comparison and Summary of Test Results

In this section, we compare the two-level regional voting scheme with the best results from multi-level voting scheme when region (the firs- level window) sizes are varied (see original data from 4.3.2 – 4.3.13)

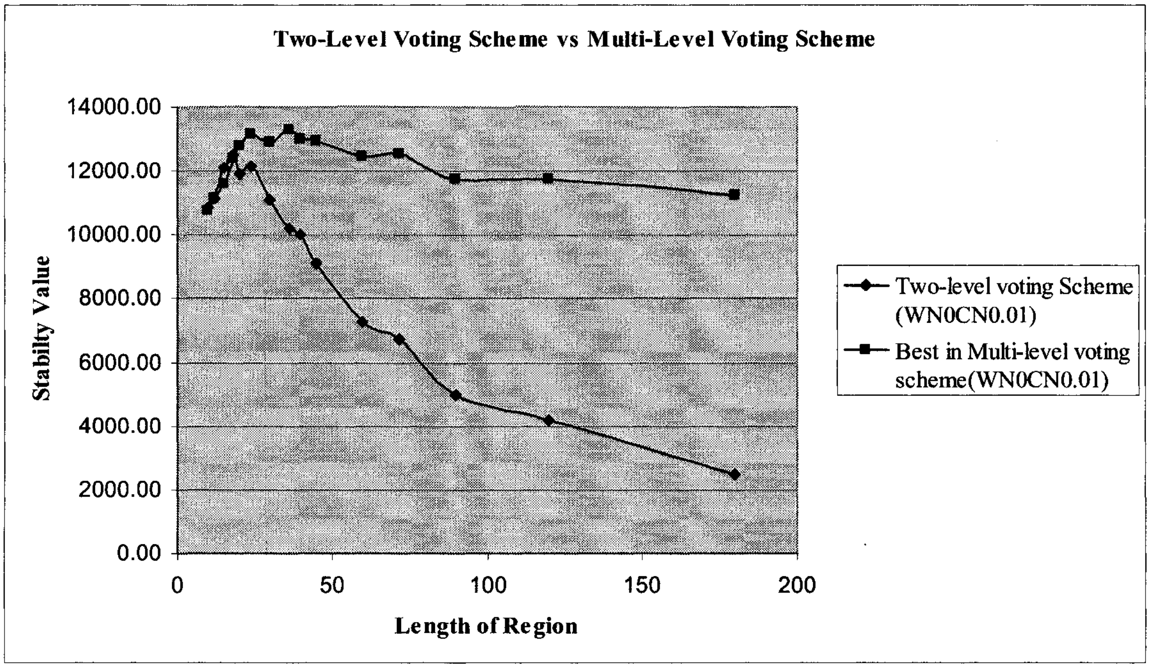
The result table is as following when noise mode is WN0CN0.01:

Table 4.17 Two-level voting vs. multi-level voting scheme (WN0CN0.01)

Length of Region	**Two-level voting Scheme (WN0CN0.01)**	**Best in Multi-level voting scheme(WN0CN0.01)**
10	10853.92	10755.04
12	11153.15	11178.41
15	12114.72	11622.00
18	12483.85	12387.98
20	11916.06	12800.29
24	12158.00	13151.55
30	11112.69	12897.22
36	10198.35	13294.85
40	10010.12	13016.93
45	9120.47	12943.09
60	7286.01	12444.81
72	6742.03	12542.22
90	5000.05	11781.42
120	4194.54	11740.14
180	2488.03	11269.21

The chart is as following:

Figure 4.16 Two-level voting vs. multi-level voting scheme (WN0CN0.01)



The result table is as following when noise mode is WN0.001CN0.01:

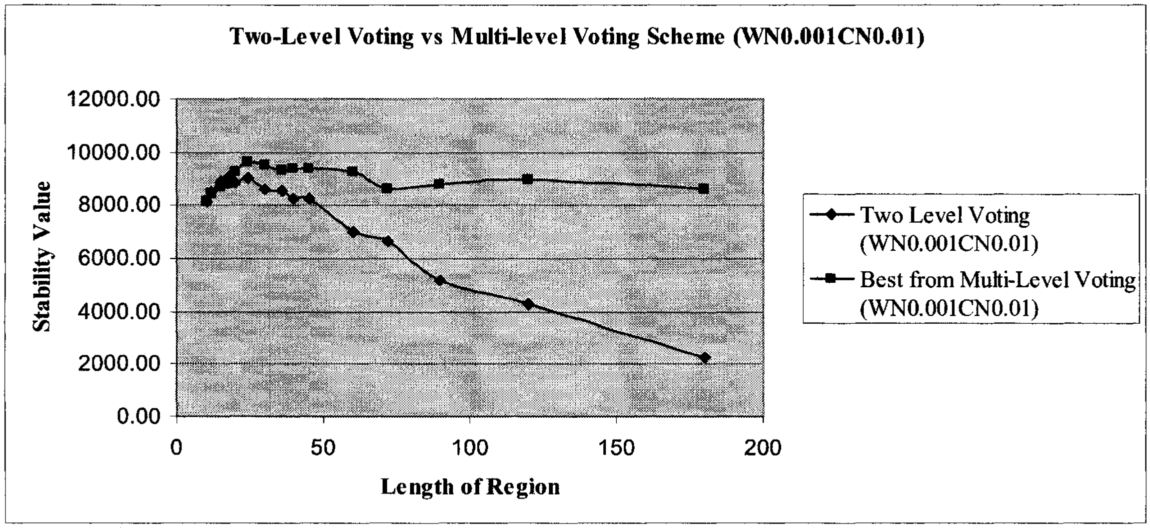
Table 4.18 Two-level voting vs. multi-level voting scheme (WN0.001CN0.01)

Length of Region	**Two Level Voting (WN0.001CN0.01)**	**Best from Multi-Level Voting (WN0.001CN0.01)**
10	8138.84	8152.67
12	8469.58	8465.26
15	8909.48	8653.96
18	9062.03	8805.10
20	8855.02	9256.90
24	9037.10	9599.23
30	8631.94	9516.80
36	8549.72	9305.80
40	8272.52	9385.15

45	8267.64	9404.97
60	6993.81	9246.60
72	6648.99	8599.17
90	5154.24	8780.05
120	4301.79	8946.79
180	2251.66	8598.93

The corresponding chart is as following:

Figure 4.17 Two-level voting vs. multi-level voting scheme (WN0.001CN0.01)



4.7 Conclusions

From the above test results and analysis, we can form the following conclusions:

1. Using multi-level region voting mode, we verify the previous study about the stability nature of the two-level regional voting scheme.

2. The stability nature of the multi-level voting scheme to concentrated noise is comparable with the stability nature of two-level regional voting scheme. If the region size is less than 20, we can see the stability nature of the two-level regional voting scheme is better than that of

the multi-level regional voting scheme. Under this region length range, the two-level regional voting scheme gets the highest mark.

3. The multi-level voting scheme's stability nature to white noise is not as good as its stability nature to concentrated noise. We observe the same characteristics in the two-level voting scheme.

4. When the region (the first-level window) size is constant, we find the stability value distribution corresponding to sub-region size is similar to that of the two-level regional voting scheme: the stability value hits maximum when sub-region size is around 18. If the sub-window size is larger or smaller than this sub-region size, we can see the stability characteristics decline.

5. Considering the face image size of our face recognition system is 60 x 60 pixels, we may conclude that system performance when applying the multi-level regional voting scheme may be just comparable with or not as good as system performance when applying the two-level regional voting scheme.

CHAPTER 5 RESULTS OF FACE RECOGNITION SYSTEM

We implement the face recognition system by applying the two-level regional voting scheme and the multi-level regional voting scheme. In this system, one subset of FERET image database is used as the benchmark to evaluate the performance of the multi-level voting scheme by comparison with the two-level voting scheme. Each probe image is matched against those in the gallery, and the vote generated by first-level voting can be used as a measure of system performance.

Like other regional voting schemes, the multi-level voting scheme is also sensitive to image shift. We apply the shifting process in the system in order to enhance system performance. By comparing results with or without shifting process, we are able to illustrate that the shifting process is one of the factors important to system performance.

Following are our test results and summary. For each test set, we list its test setting, result table, chart, and some discussion. Here the size of each probe and gallery image is 60 x 60 pixels. By applying the multi-level voting scheme, we divide the one image into first-level windows (corresponding to regions in the multi-level voting scheme model), then divide the first-level windows into second-level windows (corresponding to sub-regions in the multi-level voting scheme model). We define "Hit" as the number of probes which have one and only one matched image in the gallery, "Fail" as the number of mismatches, "Tie" as the number of probes which have multiple matches. We adjust the tie by the method mentioned in chapter three and calculate the "Real Hit". System performance is defined as Matching Percentage = Real Hit / Total Number of Probe.

5.1 System Performance with National Voting Scheme

For comparison with the two-level regional voting scheme and multi-level regional voting scheme, we apply the national voting scheme first to the face recognition system. The size of the probe and gallery images is 60 x 60 pixels. For shifting purposes, we use window size 58 x 58 and apply one-step shifting or no shifting. The matching percentage is 76.40% when there is no shifting applied and 76.90% when there is one-step shifting (Table 5.1).

Table 5.1 System performance with national voting scheme

	Number Of Probe	**Hit**	**Tie**	**Fail**	**Real Hit**	**Matching Percentage**
No Shifting	1195	913	0	282	913	76.40
One Step Shifting	1195	919	0	276	919	76.90

5.2 System Performance with Two-Level Voting Scheme

We use the two-level regional voting scheme in the face recognition system. By using the two-level regional voting scheme, we are going to test this system and validate the previous stability study results on the two-level regional voting scheme.

Test setting: we apply the two-level voting scheme in the face recognition system. The size of the probe and gallery images is 60 x 60 pixels. Images are divided into windows. During the tests, we varied the size of windows with one step shifting, or no shifting.

Table 5.2 Matching percentage by applying the two-level regional voting scheme (no shifting)

Length of Window	**2**	**3**	**4**	**5**	**6**
Hit	663	764	813	831	870
Tie	81	77	80	78	74
Fail	451	354	302	286	251
Real Hit	694.461	793.677	842.872	859.793	894.891
Matching Percentage	58.11	66.42	70.53	71.95	74.89
Length of Window	**10**	**12**	**15**	**20**	**30**
Hit	887	900	898	906	841
Tie	99	117	105	132	186
Fail	209	178	192	157	168
Real Hit	920.848	937.467	930.292	934.5	892.75
Matching Percentage	77.06	78.45	77.85	78.2	74.71

Table 5.3 Matching percentage by applying two-level regional voting scheme (One step shifting)

Length of Window	**2**	**3**	**4**	**5**	**6**
Hit	576	836	943	987	1007
Tie	84	77	50	58	57
Fail	535	282	202	150	131
Real Hit	609.38	866.231	962.407	1007.12	1027.29
Matching Percentage	50.99	72.49	80.54	84.28	85.97
Length of Window	**10**	**12**	**15**	**20**	**30**
Hit	1030	1028	999	984	880

Tie	53	55	69	88	175
Fail	112	112	127	123	140
Real Hit	1048.19	1047.86	1023.17	1002	929
Matching Percentage	**87.72**	**87.69**	85.62	83.85	77.74

To see system performance, we compare the results by no shifting and one-step shifting in the following chart:

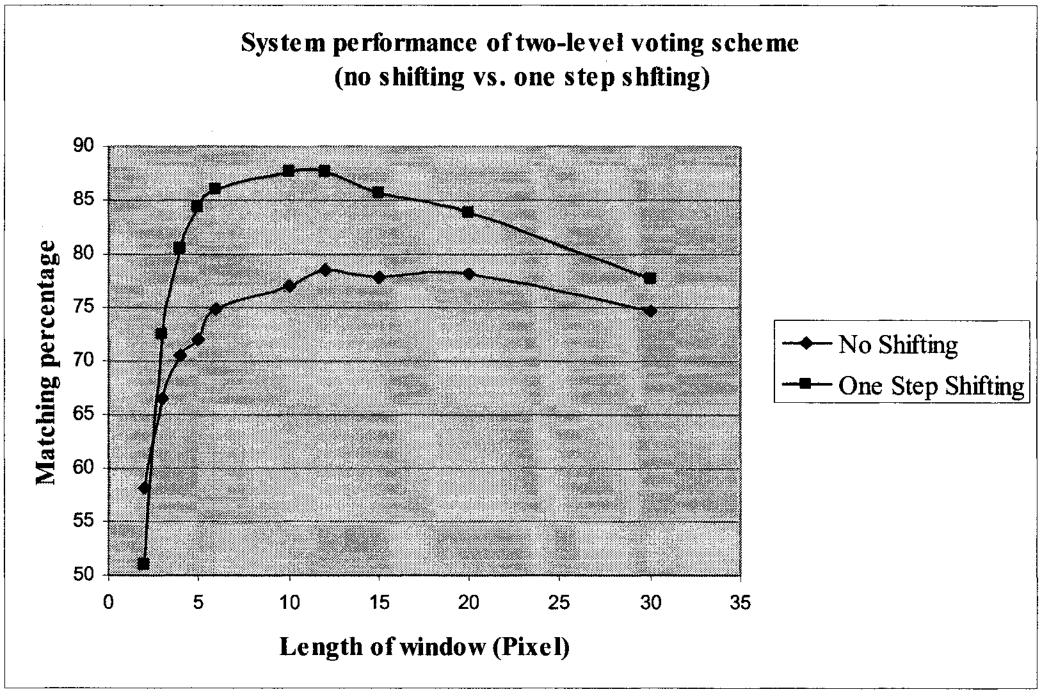


Figure 5.1 System performance of two-level voting scheme (no shifting vs. one step shifting)

Discussion:

When the two-level voting scheme is applied to the face recognition system, the matching percentage curves validate previous analysis of regional voting schema: the stability margin always increases as the size of the region decreases down to a certain value of region size, beyond which the stability value starts to decrease [6]. From the charts above, we can see that system performance reaches a peak when the length of the window is between 10 and 15 pixels.

Shifting process plays an important role for matching percentage. When we apply shifting, system performance is better than without shifting.

System achieves 87.72% matching percentage using the two-level voting scheme when the window size is 10 x 10 pixels and shift step is 1.

5.3 System Performance with Multi-level Voting Scheme

In the following test sets, we apply the multi-level voting scheme to the face recognition system. For each test set, we set the first-level window number as a constant, for example: 4, 9, 16, 25, 36, 100, and 225. The corresponding length of each window is 30 pixels, 20 pixels, 15 pixels, 12 pixels, 10 pixels, 6 pixels and 4 pixels. Then we divide the first-level window into second-level windows with different sizes. For example, we divide the whole image into 2 x 2 = 4 first-level windows. The size of the first-level window is 30 x 30 pixels. Then we divide them into the second-level windows at different sizes: 2 x 2, 3 x 3, etc. Also we apply no shifting or one-step shifting.

Note that we can consider the two-level voting scheme a special case of the multi-level voting scheme. For example, we divide the whole image into 4 first-level windows and divide the first-level windows into 900 second-level windows. This is the same as applying the two-level voting scheme in order to divide the image into windows with size 30 x 30. So based on this, we can compare the system performance of the two-level regional voting scheme and the multi-level regional voting scheme.

5.3.1 Test setting: The number of the first level windows is 4

The number of first-level windows is 4. Then we divide the first-level windows by the second-level windows with varied sizes: 6 x 6, 10 x 10, 15 x 15 and 30 x 30. Also we apply one-step shifting or no shifting.

Table 5.4 System performance with multi-level voting scheme (number of the first level windows = 4)

Length of the second level window	**6**	**10**	**15**	**30**
Matching Percentage (No shifting)	62.61	68.68	72.50	74.71
Matching Percentage (one step shifting)	77.52	81.57	80.07	77.74

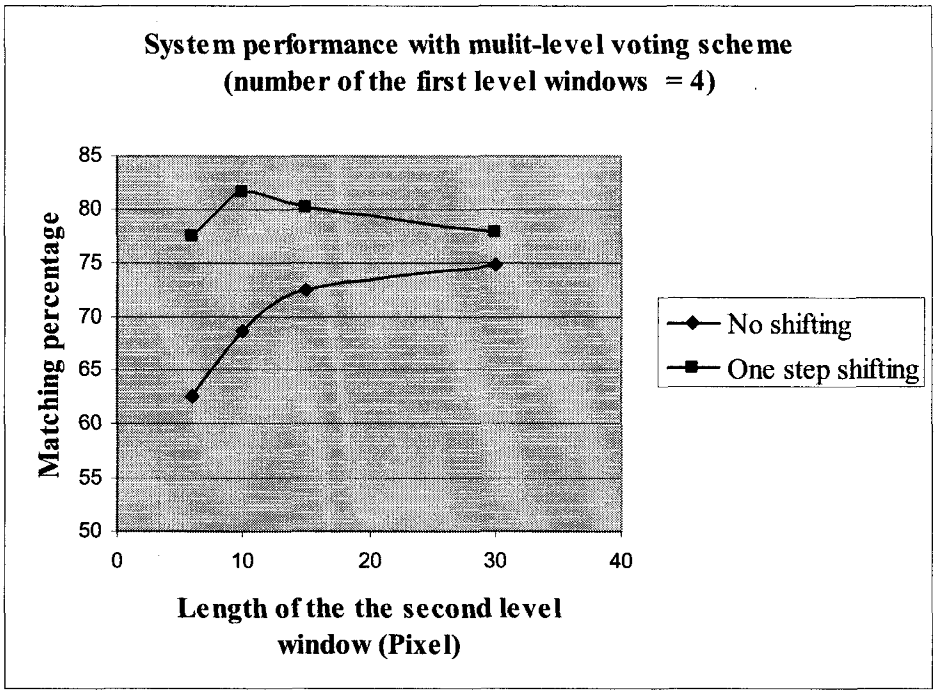


Figure 5.2 System performance with multi-level voting scheme (number of the first level windows = 4)

Discussion: When the number of the first-level windows is 4, system performance with the multi-level voting scheme is better than with two-level voting scheme. When the second-level window size is 10 with one-step shifting, the matching percentage is 81.57. But matching percentages with the two-level voting scheme are below 80 percent with or without shift. Also, from the chart it is obvious that system performance with shifting is better than without shifting.

5.3.2 Test setting: The number of the first-level windows is 9.

The number of the first-level windows is 9. Then we divide the first-level window by the second-level windows with varied sizes: 2 x 2, 4 x 4, 5 x 5, 10 x 10, and 20 x 20. Also we apply two options for shift steps: one-step shifting or no shifting.

Table 5.5 System performance with multi-level voting scheme (number of the first level windows = 9)

Length of the second level window	2	4	5	10	20
Matching Percentage (No shifting)	42.17	56.71	60.86	71.40	78.20
Matching Percentage (one step shifting)	34.47	71.06	76.45	83.74	83.85

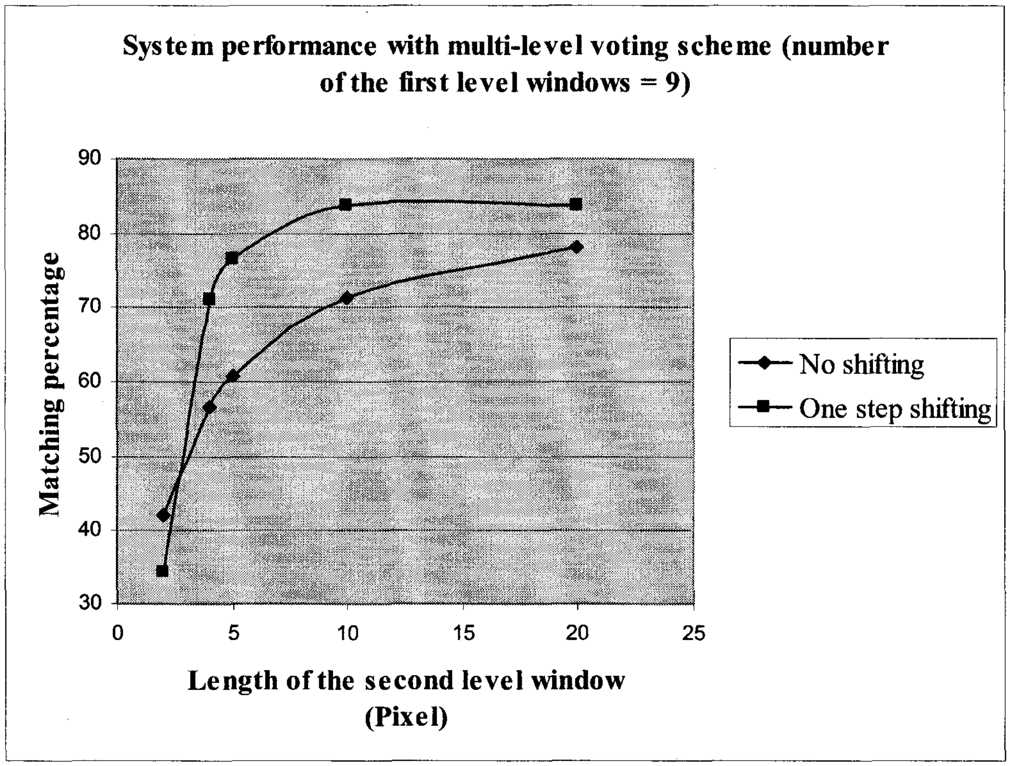


Figure 5.3 System performance with the multi-level voting scheme (number of the first level windows = 9)

Discussion:

When the number of the first-level windows is 9, the second-level window size is 10 x 10 and shift step is 1, the matching percentage (83.74%) of the multi-level voting scheme is very close to matching percentage of the two-level voting scheme (83.85%) with one-step shifting.

5.3.3 Test setting: The number of the first level windows is 16

The number of the first-level windows is 16. Then we divide first-level windows by the second-level windows with varied sizes: 3 x 3, 5 x 5, and 15 x 15. Also we apply two options for shift steps: one-step shifting or no shifting.

Table 5.6 System performance with the multi-level voting scheme (number of the first level windows = 9)

Length of the second level window	3	5	15
Matching Percentage (no shifting)	53.79	66.23	77.85
Matching Percentage (one step shifting)	62.20	80.39	85.62

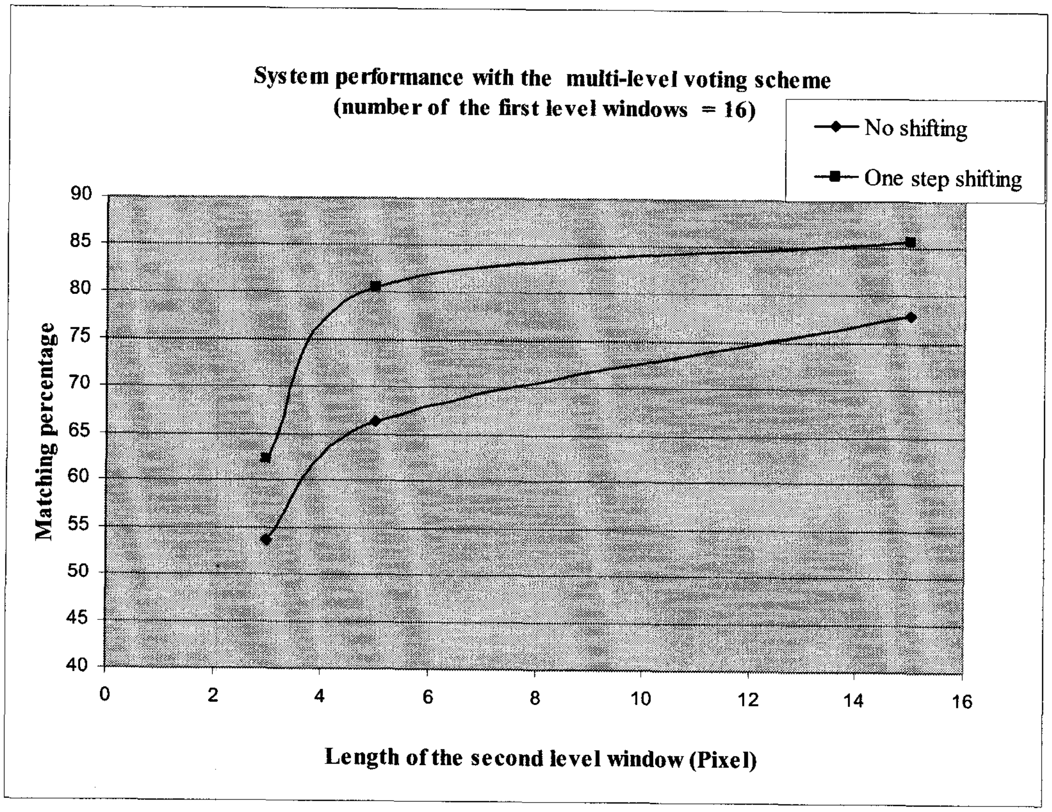


Figure 5.4 System performance with the multi-level voting scheme (number of the first level windows = 16)

Discussion:

In the multi-level voting scheme, when there are 16 first-level windows and the second window size is 3 x 3 or 5 x 5, the matching percentage is worse than the two-level voting scheme which has a window size of 15 x 15 pixels.

5.3.4 Test Setting: The number of the first level windows is 25

The number of the first-level windows is 25. Then we divide the first-level window by the second-level windows with varied sizes: 3 x 3, 4 x 4, and 12 x 12. Also we apply two options for shift steps: one-step shifting or no shifting.

Table 5.7 System performance with the multi-level voting scheme (number of the first level window = 25)

Length of the second level window	**3**	**4**	**12**
No shifting	58.18	65.83	78.44
One step shifting	64.25	76.23	87.69

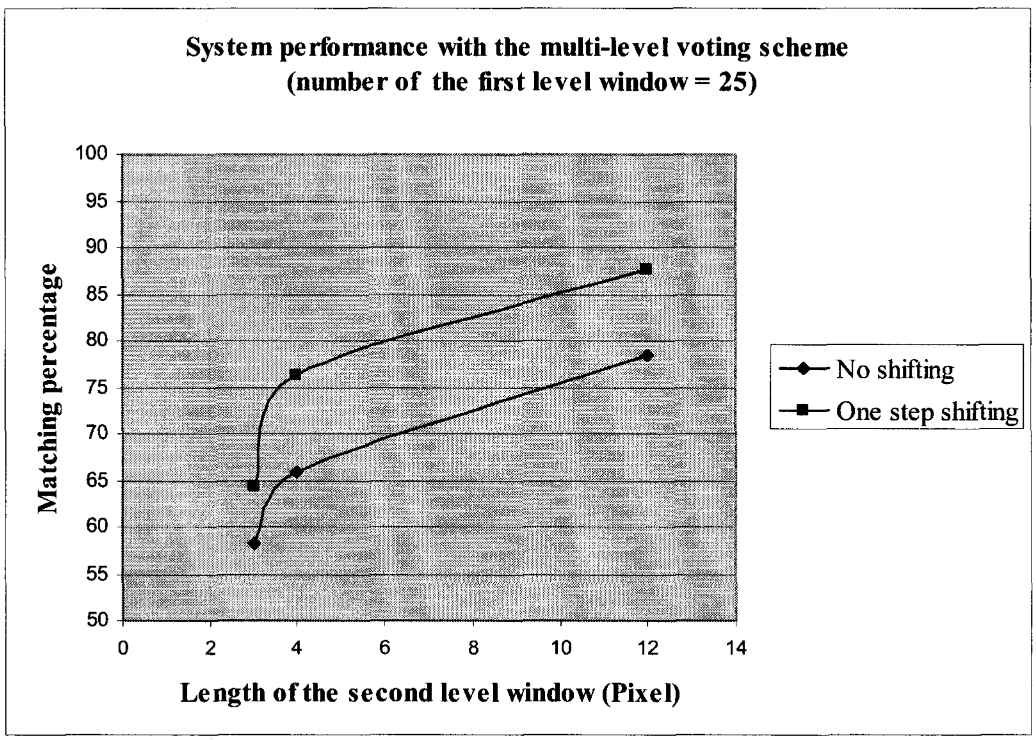


Figure 5.5 System performance with the multi-level voting scheme (number of the first level windows = 25)

Discussion:

With the multi-level voting scheme, when the number of first-level windows is 25 and the second-level window size is 3 x 3 or 4 x 4, the matching percentage is worse than the two-level voting scheme which has a window size of 12 x 12 pixels.

5.3.5 Test setting: The number of the first level windows is 36

The number of the first-level windows is 36. Then we divide the first-level windows by the second-level windows with varied sizes: 2 x 2, 5 x 5, and 10 x 10. Also we apply two options for shift steps: one-step shifting or no shifting.

Table 5.8 System performance with the multi-level voting scheme (number of the first level windows = 36)

Length of the second level window	**2**	**5**	**10**
No shifting	45.12	69.03	77.06
One step shifting	37.53	83.15	87.72

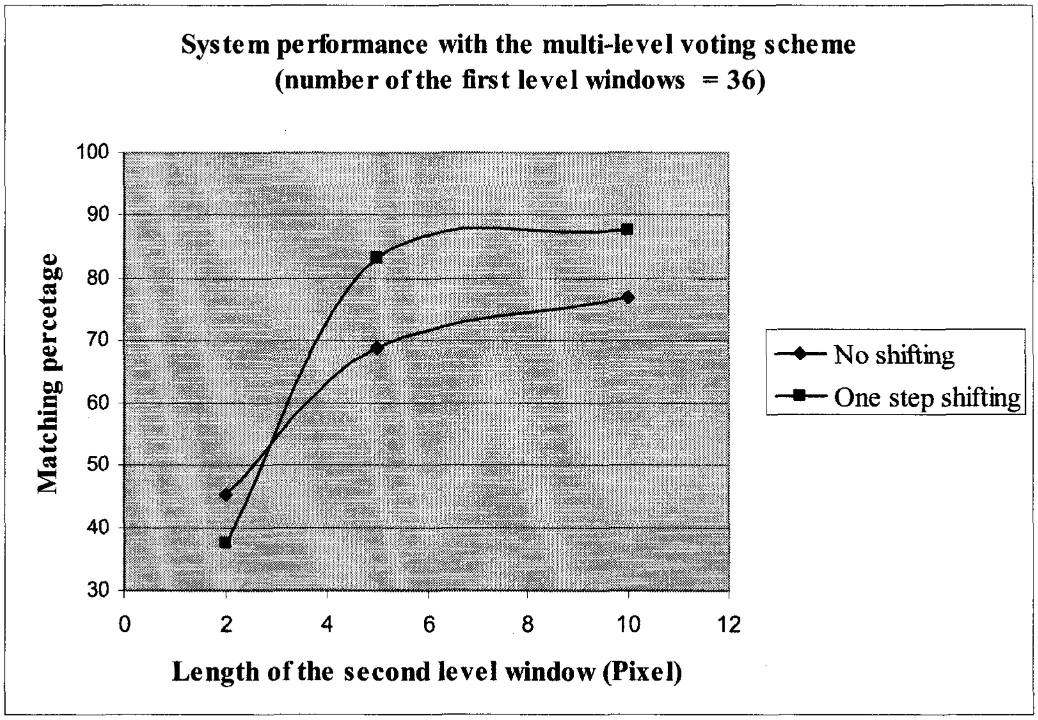


Figure 5.6 System performance with the multi-level voting scheme (number of the first-level windows = 36)

Discussion:

With the multi-level voting scheme, when the number of first level windows is 36 and the length of the second level window is 2 or 5, system performance is worse than with the two-level voting scheme in which the window size is 10 x 10 pixels.

5.3.6 Test setting: The number of the first level window is 100

The number of the first-level windows is 100. Then we divide the first-level windows by the second-level windows with varied sizes: 2 x 2, 3 x 3, and 6 x 6. Also we apply two options for shift steps: one-step shifting or no shifting.

Table 5.9 System performance with the multi-level voting scheme (the number of the first level windows = 100)

Length of the second level window	**2**	**3**	**6**
Matching Percentage (no shifting)	53.59	64.87	74.89
Matching Percentage (one step shifting)	48.45	71.80	85.97

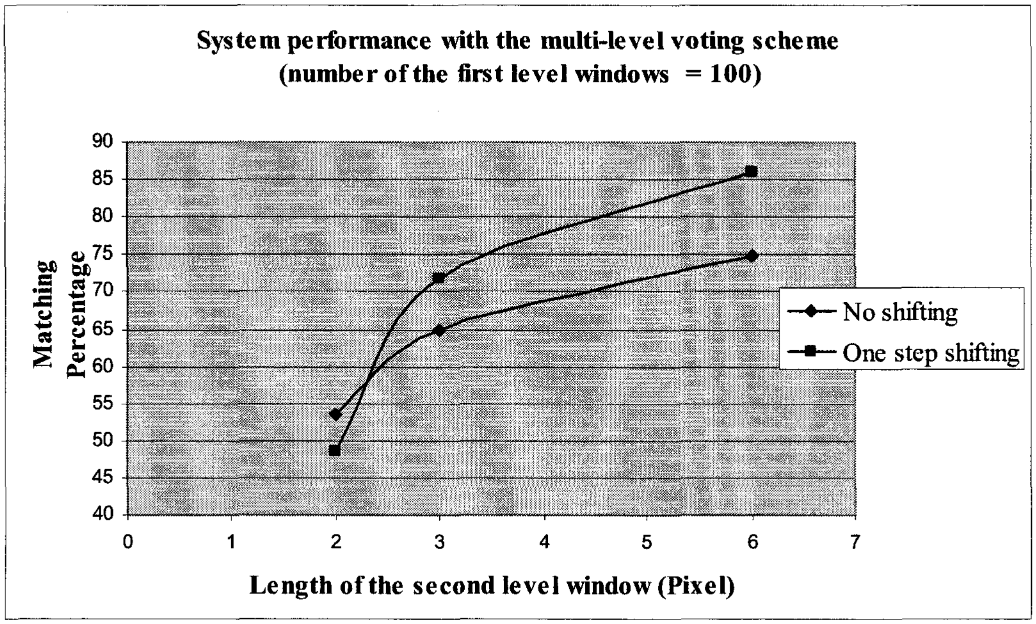


Figure 5.7 System performance with the multi-level voting scheme (number of the first level windows = 100)

Discussion:

With the multi-level voting scheme, when the number of the first-level windows is 100 and the second level window size is 2 x 2 or 3 x 3, system performance is worse than with two-level voting scheme in which window size is 6 x 6 pixels.

5.3.7 Test setting: The number of the first-level windows is 225

The number of the first-level windows is 225. Then we divide the first-level window into the second-level windows with varied sizes: 2 x 2, and 4 x 4. Also we apply two options for shift steps: one-step shifting or no shifting.

Table 5.10 System performance with the multi-level voting scheme (number of the first level windows = 225)

Length of the second level window	2	4
No shifting	56.57	70.53
One step shifting	50.98	80.54

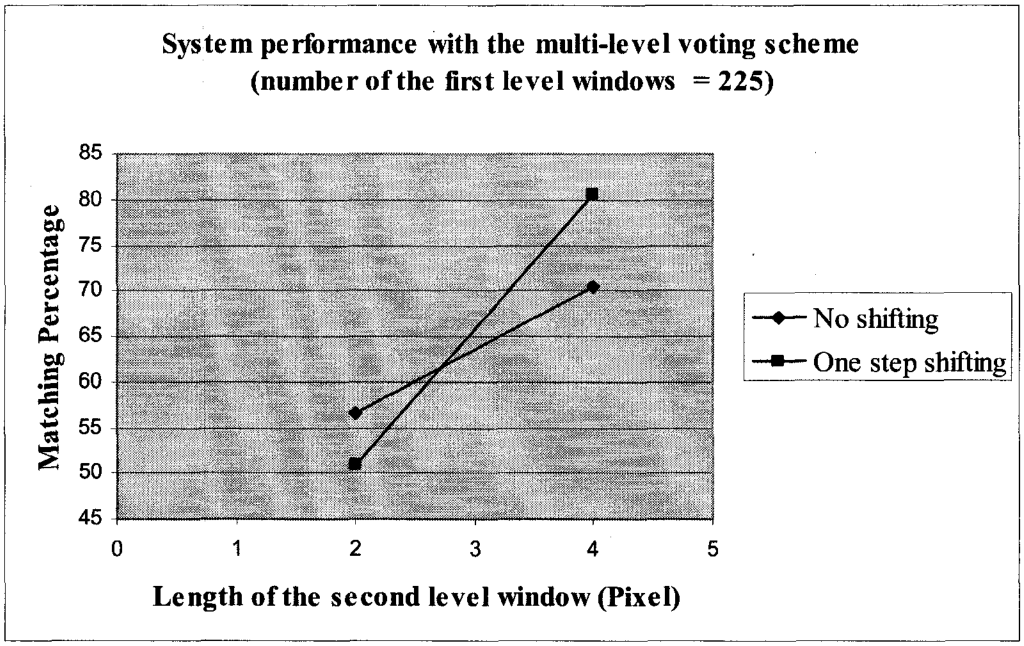


Figure 5.8 System performance with the multi-level voting scheme (number of the first level windows = 225)

Discussion:

With the multi-level voting scheme, when the number of the first-level windows is 225 and the second-level window size is 2 x 2, the matching percentage is worse than when the two-level voting scheme has a window size of 4 x 4 pixels.

5.4 Comparison study for the multi-level voting scheme and the two-level voting scheme

From the test results 5.1 ~ 5.3, we observe that the two-level regional voting scheme and multi-level regional voting scheme are better than national voting scheme according to best matching percentage. Also in general system performance is better when we apply one-step shifting than when there is no shifting. In this section, we compare the best system performance of the multi-level voting scheme with the two-level voting scheme when the one-step shifting is applied.

Table 5.11 System performance comparison between multi-level voting scheme and two-level voting scheme (one-step shifting)

Length of the first level window	4	6	10	12	15	20	30
Two-level voting scheme	80.54	85.97	87.72	87.69	85.62	83.85	77.74
Multi-level voting scheme	50.98	71.80	83.15	76.23	80.39	83.74	81.57

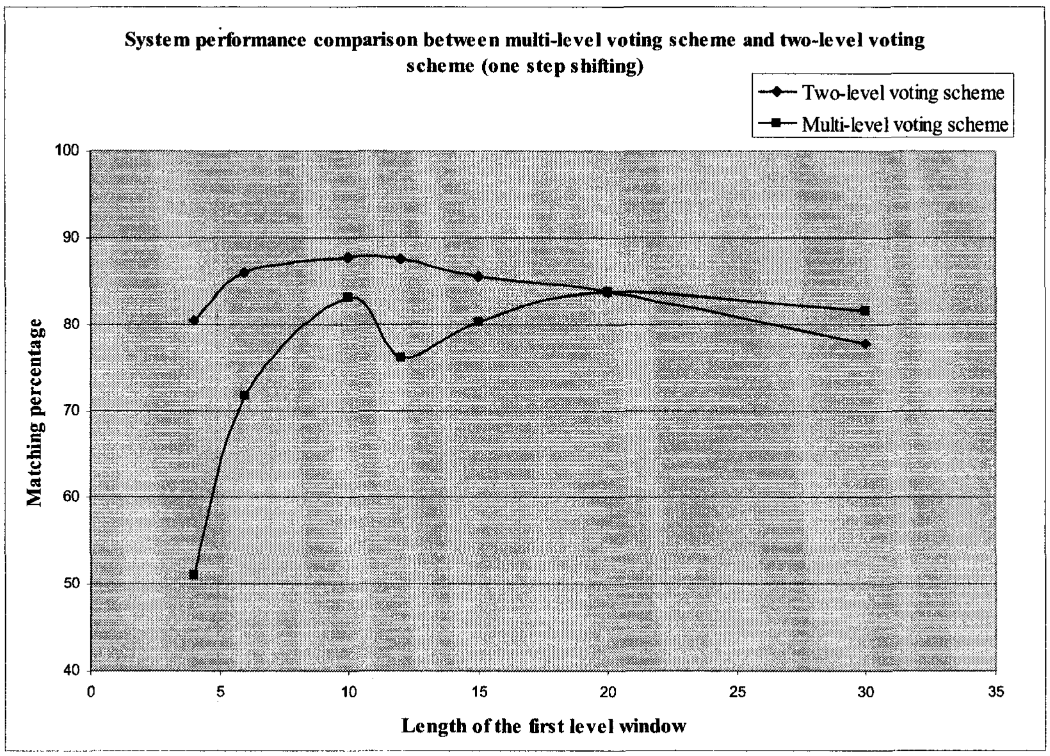


Figure 5.9 System performance comparison between multi-level voting scheme and two-level voting scheme (one-step shifting)

Discussion:

When the first-level window is relatively big (for example, in test set 5.3.1, the window size is 30 x 30 pixels), if we divide the first-level window into the second windows, system performance of the multi-level voting scheme is better than the performance of the two-level voting scheme.

In most cases, system performance with the multi-level voting scheme is worse than or closes to the system performance with the two-level voting scheme.

5.5 Summary of Face Recognition System Test Results

By extensive tests using the multi-level voting scheme and two-level voting scheme on the face recognition system, we are able to obtain a deep understanding of the characteristics of the multi-level voting scheme and the two-level voting scheme. We have the following conclusions:

The multi-level voting scheme does not achieve the highest system performance in the face recognition system. By applying the two-level voting scheme, the system achieves 87.72% matching percentage when the window size is 10 x 10 pixels and shift step is 1.

We observe that system performance using the two-level voting scheme is not good when the first level window size is relative large (30 x 30 pixels in our tests). But if we divide the first-level window into the second level windows, system performance can be improved.

Shifting process is one important factor for this face recognition system. Considering a small window or the second-level window in the application of the two-level regional voting scheme and multi-level regional voting scheme, we believe that how shift process and number of shift steps are chosen affects the face recognition system's performance and is worth further study.

By applying the two-level regional voting scheme, test results validate previous analysis of regional voting schemes: the stability margin always increases as the size of region decreases down to a certain value of region size, beyond which the stability value starts to decrease [6]. By applying the multi-level regional voting scheme, test results confirm our observation in chapter 4: overall system performance with the multi-level regional voting scheme may be just comparable with or not as good as system performance with the two-level regional voting scheme. If the region size is less than 20, we can see the stability nature of the two-level regional voting scheme is better than the stability nature of the multi-level regional voting scheme. Under this range of region length, the two-level regional voting scheme gets the highest marks.

CHAPTER 6 SUMMARY

The reason we choose the face recognition problem is that there are still many open questions that need to be solved. Based on previous study that concludes the local voting scheme is more stable than the national voting scheme, we introduce the multi-level regional voting scheme. By setting up an experimental model and extensive tests, we observe its stability characteristics. Also, we apply two-level regional voting scheme and multi-level regional voting scheme in the face recognition problem and confirm the experimental results.

With Monte Carlo analysis, we find that the multi-level regional voting system has a stability nature which is comparable to the two-level regional voting scheme in some degrees. The stability value of multi-level systems maintains a relatively high level no matter the size of region. But in the two-level voting scheme, the stability margin always increases as the size of a region decreases down to a certain value of region size, beyond which the stability value starts to decrease. Both regional voting schemes, the two-level regional voting scheme and the multi-level regional voting scheme, are better than the national voting scheme regarding their stability value to the concentrated noise.

Based on the observations on the stability value of multi-level regional voting scheme and two-level regional voting scheme, we apply the multi-level regional voting scheme and the two-level regional voting scheme into the face recognition system. For the multi-level regional voting scheme, we are able to obtain comparable results to the two-level voting scheme in some degrees; however, the two-level regional voting scheme achieves better performance than the multi-level regional voting scheme. In our face recognition system, using FERET database Facial Expression (fafb) evaluation task, we achieve 87.72 matching percentage using the two-level voting scheme when the sub-window size is 10 x 10 pixels and shift step is 1.

In our experiments of FERET database fafb task, we use the JPG face images of FERET data disc, of which the resolutions are 256 x 384 pixels[1]. After the normalization and cropping stage, each gallery and probe image is represented by 60 x 60 floating numbers. The analysis of the stability value of multi-level regional voting schemes indicates that, the multi-level regional voting scheme should have more choices in region and sub-region sizes, and thus may reach better performances, if the cropped standard image faces are of significantly higher resolutions.

There are several high resolution facial image databases available. The color FERET database contains 11338 facial images with 512 by 768 pixels resolutions. FRVT/FRGC (BEE) (Biometric Experimentation Environment for the Face Recognition Vendor Tests and Face Recognition Grand Challenge) data consists of 50,000 recordings, divided into training and validation partitions. In FRVT/FRGC, the resolution of still images is 2272 by 1704 pixels [24]. We can expect that, significantly higher resolution faces can be obtained by normalizing and cropping these images. If we introduce the multi-level regional voting scheme into these benchmark databases and compare with the two-level regional voting scheme, we may see more interesting results.

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[1] The resolution jpg files in the disc are not as high as that of the ppm files.

In conclusion, we explore the stabilities of two types of the regional voting schemes and reach some conclusions about their characteristics. By applying two types of the regional voting schemes in the face recognition problem we compare the system performance for human face recognition. Also we observe that shift process is one of the important factors for matching percentage. We believe that this research will facilitate understanding about the regional voting scheme and help future studies on face recognition problems.

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