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Multi-class classification method of support vector machine based on error correction coding

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Abstract—In the space radiation environment, there will be many errors in the multi-classification results of support vector machine which caused by single event flipping, the ability of correcting classification errors through error correction coding is studied in this paper, results of simulation confirm that error correction coding can increase the accuracy, which is beneficial for anti-single event flip.

Keywords- support vector machine; multi-classification; error correction coding; single event flip; Hamming distances

I. INTRODUCTION

Support vector machines[1] have broad application prospects[2], but in aerospace applications, the severe radiation environment in space poses a huge challenge to data processing performance. Due to the existence of cosmic rays, single event flipping will cause errors in data processing results, which will cause serious harm for the reliability of the system[3]. In recent years, many anti-single event inversion work in the space radiation environment has achieved fruitful results. Various software and hardware measures have appeared one after another, such as device shielding, three-mode redundancy[4], scrubbing[5] and readback [6].

From the perspective of multi-class classification based on error correction coding, this paper studies the measures of support vector machines to deal with the single event flip for enhancing the reliability of support vector machines in the radiation environment.

II. BACKGROUND

The multi-class classification method based on Error-Correcting Codes (ECC) is a method to transform multi-class classification problems into multiple two-class classification problems. For the problem of Q class data classification, the classification is transformed into S-two-class classification by carrying out a binary encoding of length S for each class. Since the classifier on each code point only needs to do two types of classification, SVM can be used.

III. METHODOLOGY

A. ECC-SVM principle

See Table I, which shows the basic principles of a 4-category, 7-bit coded ECC-SVM. ECC-SVM needs to construct a code matrix composed of {0, 1}, which is assumed to be $M_{Q \times S}$, in multi-class classification, the row Q corresponds to the number of sample categories, and the column S corresponds to the number of classifiers that will be trained. While $M_{qs} = 1 (M_{qs} = 0)$, this sample was used as a positive example (negative example) to train the sth classifier f_s which is relative to the qth class. The work of ECC-SVM is divided into two steps: training and classification. In the training process, train the classifier $f(x) = (f_1(x), \dots, f_s(x))$ according to the principles above. In the process of classification, for a new sample X, calculate the distance between the output vector of the classifier $f(X)$ and each category vector, so that the class with the smallest distance is the class that X belongs to, namely:

$$K = \operatorname{argmin}_{q \in [1 \dots Q]} (d(M_q, f(X))) \quad (1)$$

In the (1), K is the category which X belongs to, and d is the distance function, generally using Hamming Distance.

$$d(M_q, f(x)) = \sum_{s=1}^S \frac{|2m_{qs} - \operatorname{sgn}(f_s) - 1|}{2} \quad (2)$$

TABLE I ECC-SVM WITH 4 CATEGORIES AND 7-BIT ENCODING

Category	ECC						
	f_1	f_2	f_3	f_4	f_5	f_6	f_7
1	0	0	0	0	0	0	0
2	1	1	1	1	0	0	0
3	1	1	0	0	1	1	0
4	1	0	1	0	1	0	1

For ECC-SVM, when the coded rows are the same, the corresponding category of the row cannot be recognized.. When the coded columns are the same, they correspond to the same classifier, and deleting one of them has no effect on the output result. For two coded complementary columns, the output results of corresponding classifiers of

them are also complementary, essentially they are the same column. Columns with all "0" or all "1" are meaningless, and the classifier cannot be trained. Therefore, effective ECC coding must meet four conditions: (1) the rows of the coding matrix are not correlated, (2) the columns of the coding matrix are different and not complementary, (3) there are no columns with all "0" or all "1", and (4) For Q class classification, the code length S must be satisfied $\log_2 Q < S \leq 2^{Q-1} - 1$.

According to the coding theory, for an error correction code with a minimum Hamming distance of d , errors of $\lfloor (d-1)/2 \rfloor$ bit can be corrected. Therefore, for an output code with error correction capability, the minimum Hamming distance between code words should be greater than or equal to 3.

B. ECC-SVM coding method and performance

Dietterich gave four ECC coding methods which are commonly used [7], including detailed coding method, column selection method, hill climbing method and BCH coding method. In addition, Cramer and Singer proposed the concept of continuous codes [8], and Utschick proposed the maximum expectation coding algorithm [9], which is to optimize ECC by constructing a maximum objective optimization function.

In terms of coding performance evaluation, Francesco [10] believes that the performance of ECC is related to many factors, including: similarity of code words, performance of classifiers, complexity of actual problems, choice of classifiers, and correlation of code columns and so on.

IV. EXPERIMENTS AND RESULTS

The multi-classification method based on error correction coding has been proposed for a long time. However, due to the complexity of the coding method, the selection of codewords and the optimization of performance, the degree of attention and the widespread use of it are very small. However, the study in this article found that the increased redundancy characteristics from its encoding can not only realize the error correction of ordinary multi-classification, but it is also extremely beneficial to correct the errors caused by the single event flip effect in aerospace applications. The complexity of realization and the cost of device resources are much smaller than the three-mode redundancy technology which commonly is used in aerospace applications.

In order to verify the performance of the ECC-SVM for multi-classification in errors correcting that be caused by single event flipping, Letter Image Recognition Data in the UCI machine learning database are simulated in this paper. Data of A, B, C, D and E are taken for multi-classification, each of them be taken different 100 sets of data for training and testing. In order to judge the error correction effect of error correction code groups which with different Hamming distances for the single event effect, three codes are taken in this article for simulating which are shown in the following table II.

Matlab's fixed-point toolbox is used in this article to realize fixed-point simulation and the injection of single-bit of single-event flips. The injection of single event flip is assumed in such an idealized situation, we only consider the

injection for operation result of kernel function of the support vector machine, the probability of single event flip is taken in the order of $10^{-9}/KB \cdot s$ in the simulation, and only one-time injection is considered in time. The kernel function used in the simulation is Gaussian kernel, because of its good locality, it is more widely used in practical applications than polynomial kernel. The fixed-point number in the simulation are taken 64 bits, the decimal part are 32 bits, the integer part are 31 bits, and the highest bit is the sign bit. In the injection of single event flips, only one flip is considered at a time, and multiple flips are not considered at the same time. The injection probability of the single event flip can be controlled, and which value and which bit of the result of the kernel matrix being injected is controlled by a random number. Three different Hamming distance codes with three different injection probabilities of 0.000000009, 0.000000005, and 0.000000001 in single event flipping are simulated in this paper. Each simulation is performed 200 times, and the graphs are plotted as from Fig. 1 to Fig. 9. The average value of judgment accuracy for the 200 times' simulation is calculated as Table III.

TABLE II CODE GROUP SELECTION IN ECC-SVM MULTI-CLASS SIMULATION

Code Group	Code1	Code2	Code3
Code word	0000000000	0111111111	0111111111
	0000000111	1000111111	0000000011
	0001111000	1111000011	0000111100
	0110011001	1011001100	1011001100
	1010101010	0101010101	1101010101
Minimum Hamming distance between codes	3	4	5

V. RESULTS AND DISCUSSION

It can be seen from Table III that in the absence of single event inversion injection, the accuracy of the result of ECC-SVM is the largest, and in the case of single event inversion injection, the accuracy is increasing with the increase of the Hamming code distance, which confirms the multi-classification performance and the multi-class error correction performance of ECC-SVM. From Fig. 1 to Fig. 9, it can be clearly observed that in the same code group, as the probability of single event flipping injection decreases, the accuracy of the ECC-SVM result is steadily increasing. In the case of different code groups with the same single event flip injection rate, the correct rate of the judgment for the code group with a large Hamming distance is greater than that with a small Hamming distance. The data in Table 3 also confirms this conclusion, indicating that ECC-SVM has the ability to correct the single event flip error. From the data in Table 3, a phenomenon is observed, in the case of a large single event flip injection rate, as the Hamming distance of the code group increases, the accuracy rate of the judgment result also has a tendency to increase, and which is much larger than that in the case of no single event inversion injection, which shows that the code of large Hamming distance has superior error correction performance for large single event inversion injection rate.

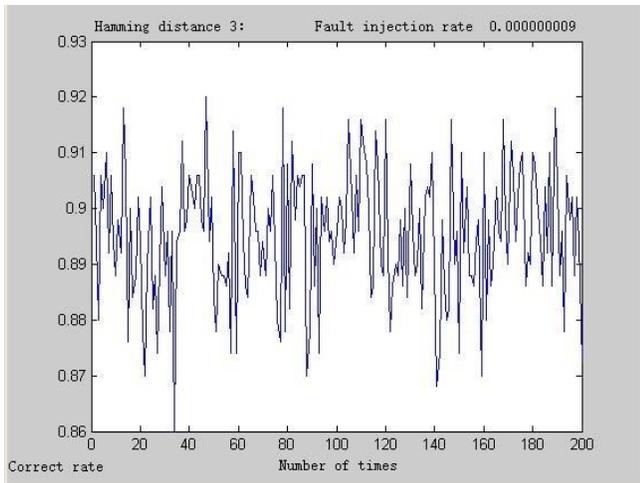


Figure 1. Hamming distance 3, injection rate 0.00000009

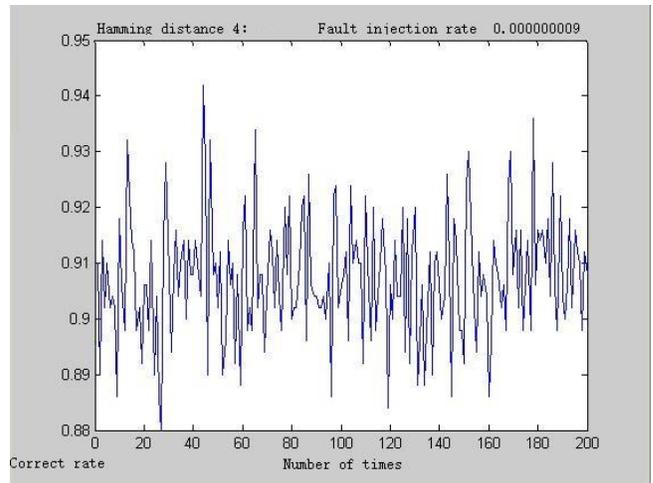


Figure 4. Hamming distance 4, injection rate 0.00000009

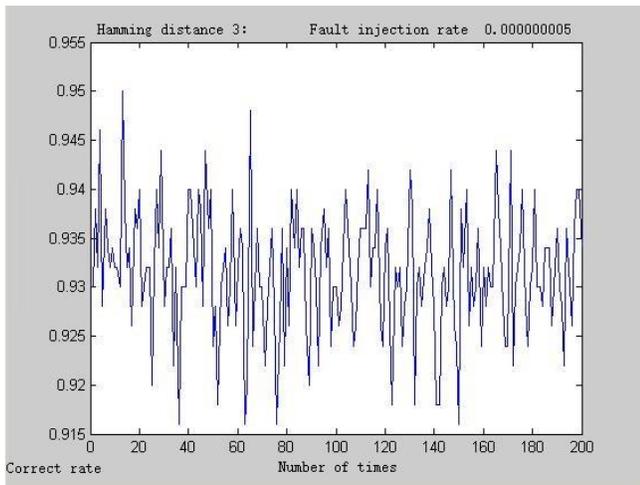


Figure 2. Hamming distance 3, injection rate 0.00000005

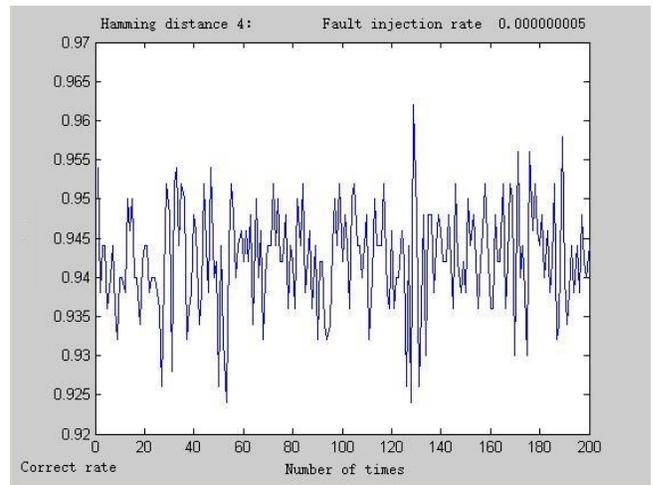


Figure 5. Hamming distance 4, injection rate 0.00000005

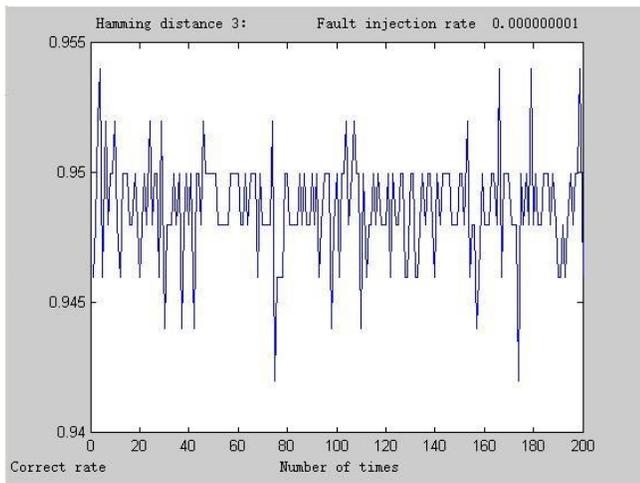


Figure 3. Hamming distance 3, injection rate 0.00000001

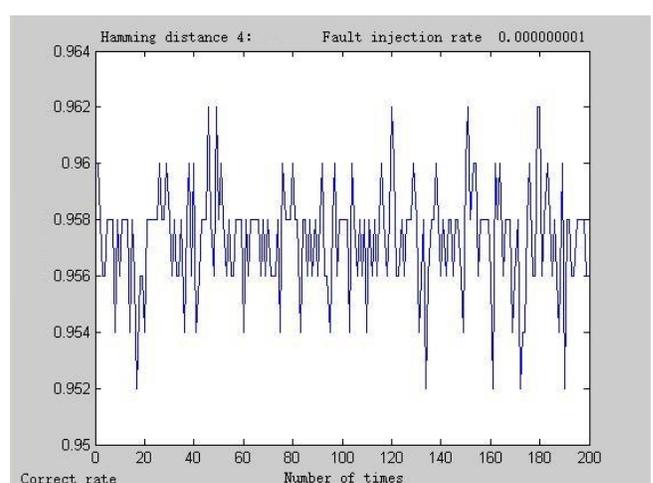


Figure 6. Hamming distance 4, injection rate 0.00000001

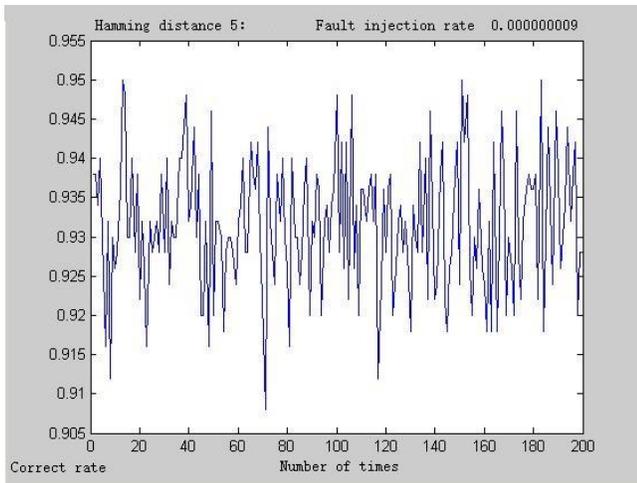


Figure.7. Hamming distance 5, injection rate 0.000000009

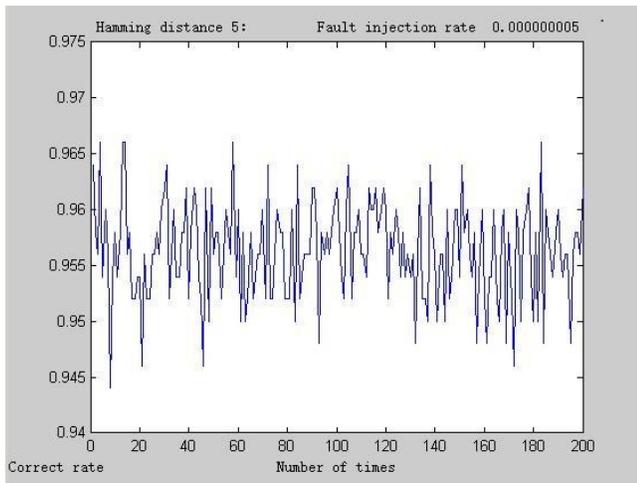


Figure. 8. Hamming distance 5, injection rate 0.000000005

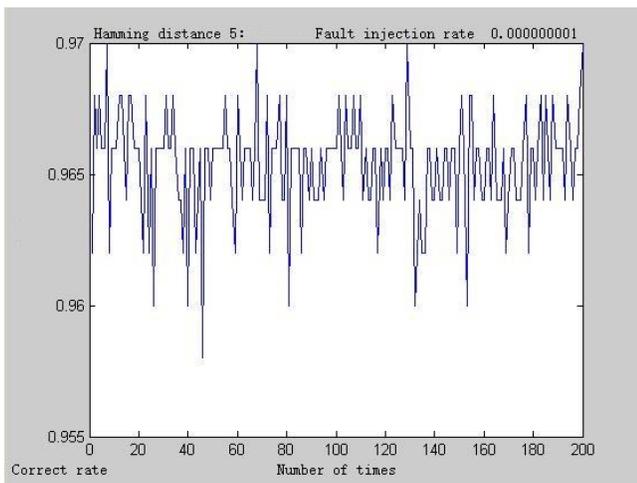


Figure. 9. Hamming distance 5, injection rate 0.000000001

TABLE III SIMULATION RESULTS OF 200 AVERAGE CORRECT RATES UNDER DIFFERENT SINGLE EVENT INVERSION INJECTION RATES

Single Event Flip Injection Rate	Code 1 Result Correct Rate	Code 2 Result Correct Rate	Code 3 Result Correct Rate
9×10^{-9}	0.8952	0.9074	0.9316
5×10^{-9}	0.9315	0.9424	0.9563
1×10^{-9}	0.9487	0.9573	0.9654
0	0.95	0.958	0.966

VI. CONCLUSION

The anti-single event flipping effect of support vector machines in the application of multi-classification with error correction coding is studied in this paper. The results of simulation experiments prove that the ECC-SVM multi-classification method has a good error correction effect for the single event flipping effect. The data processing performance of the support vector machine can be improved in a radiation environment.

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Competing interests statement: The authors declare that they have no competing financial interests.

author contribution: Li Junfei designed experiments , carried out experiments and wrote the manuscript;Zhao Longhai analyzed experimental results.

Figures

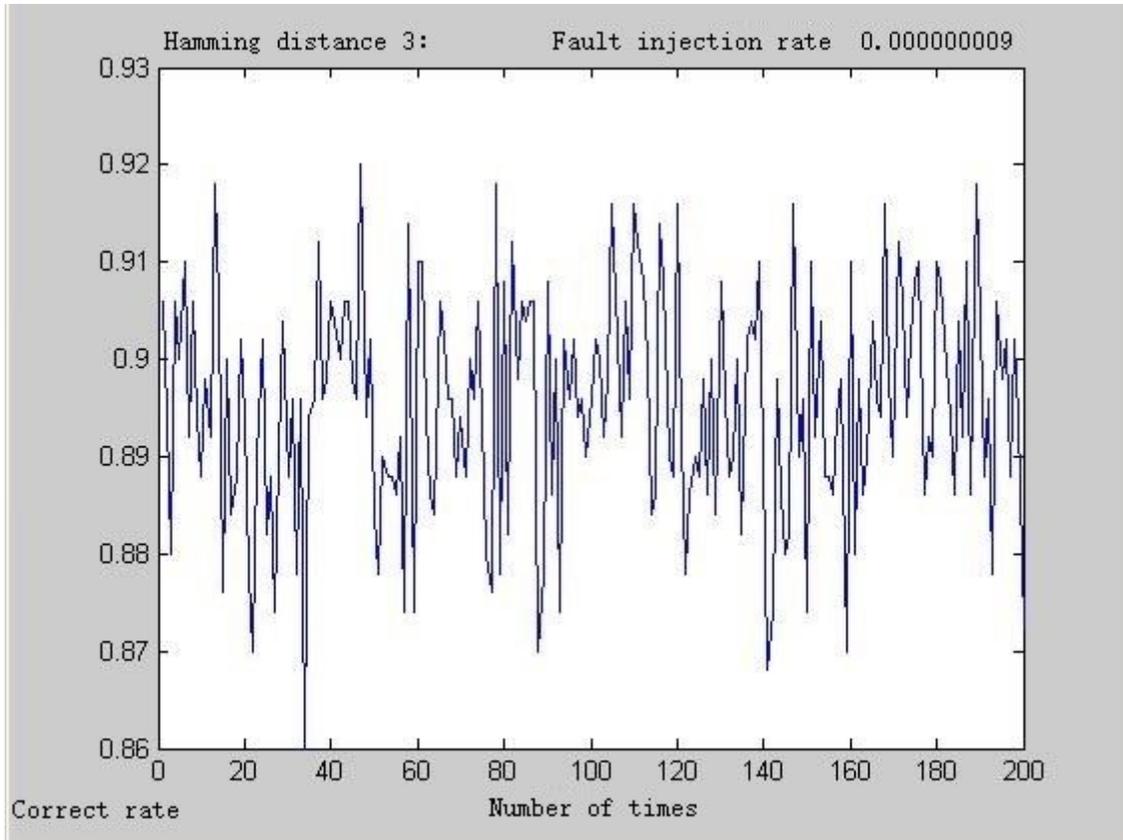


Figure 1

Hamming distance 3 injection rate 0.000000009

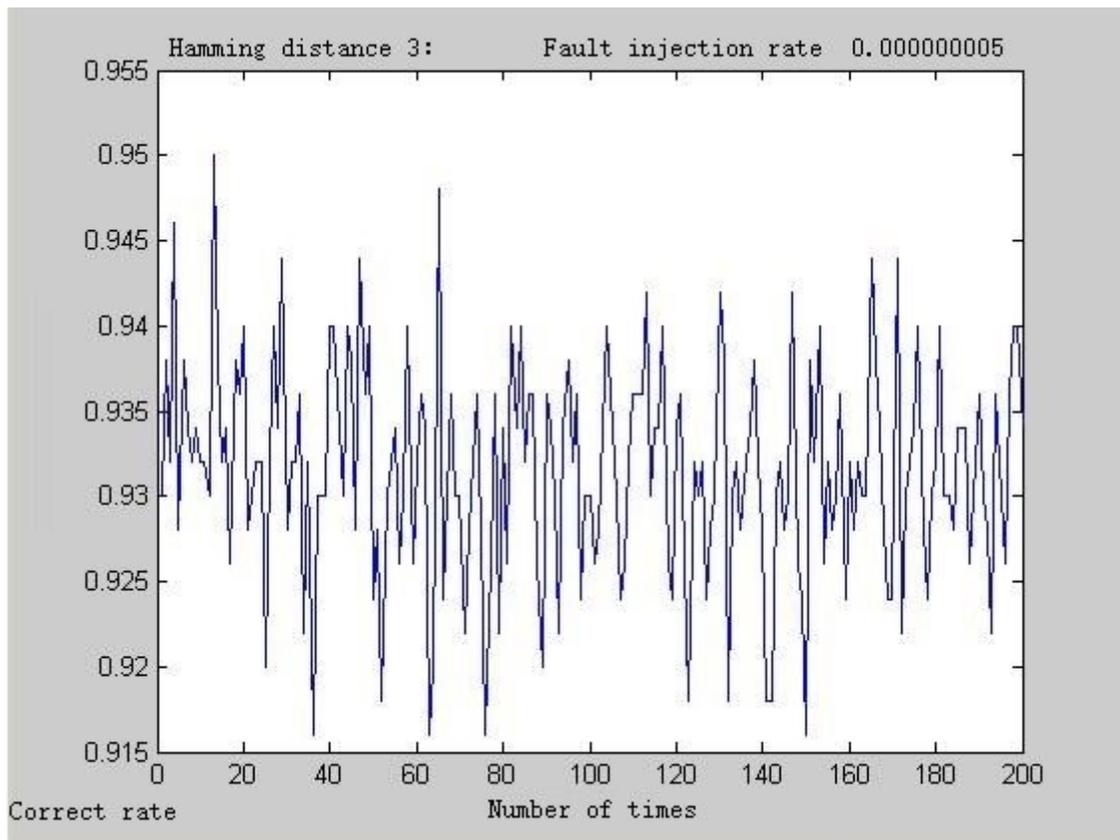


Figure 2

Hamming distance 3 injection rate 0.000000005

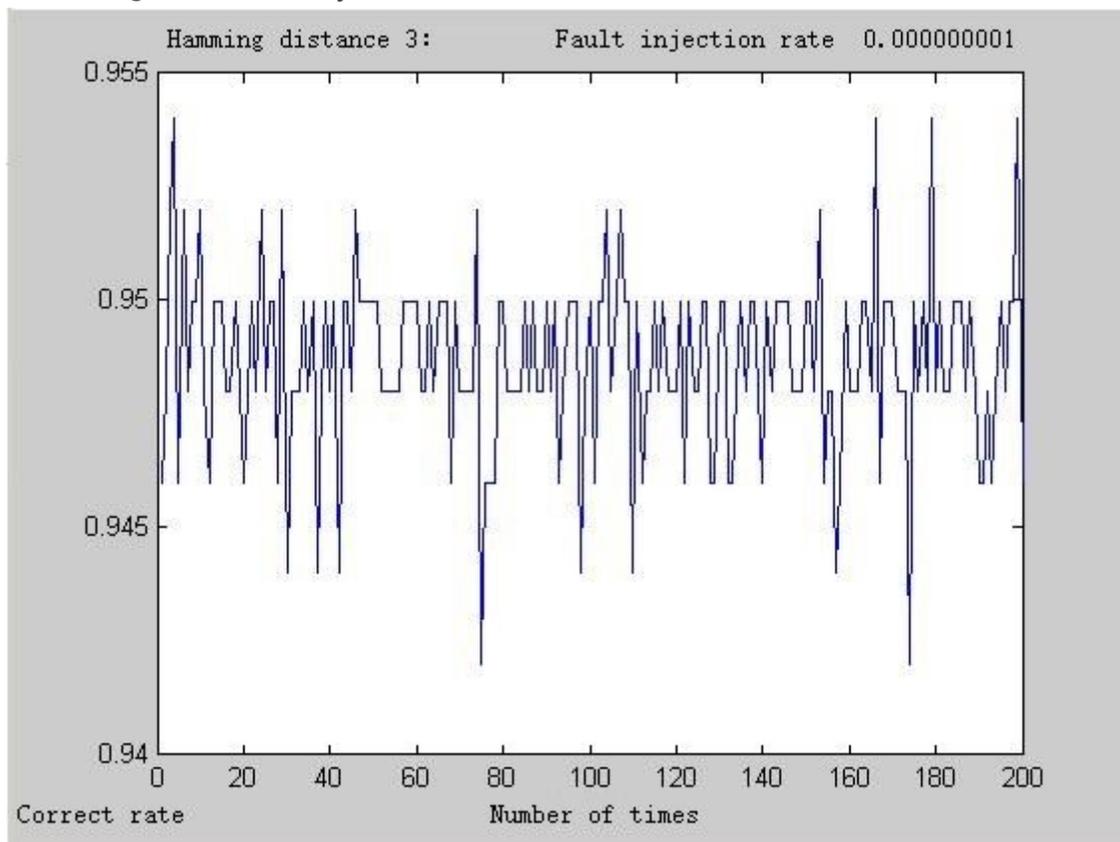


Figure 3

Hamming distance 3 injection rate 0.00000001

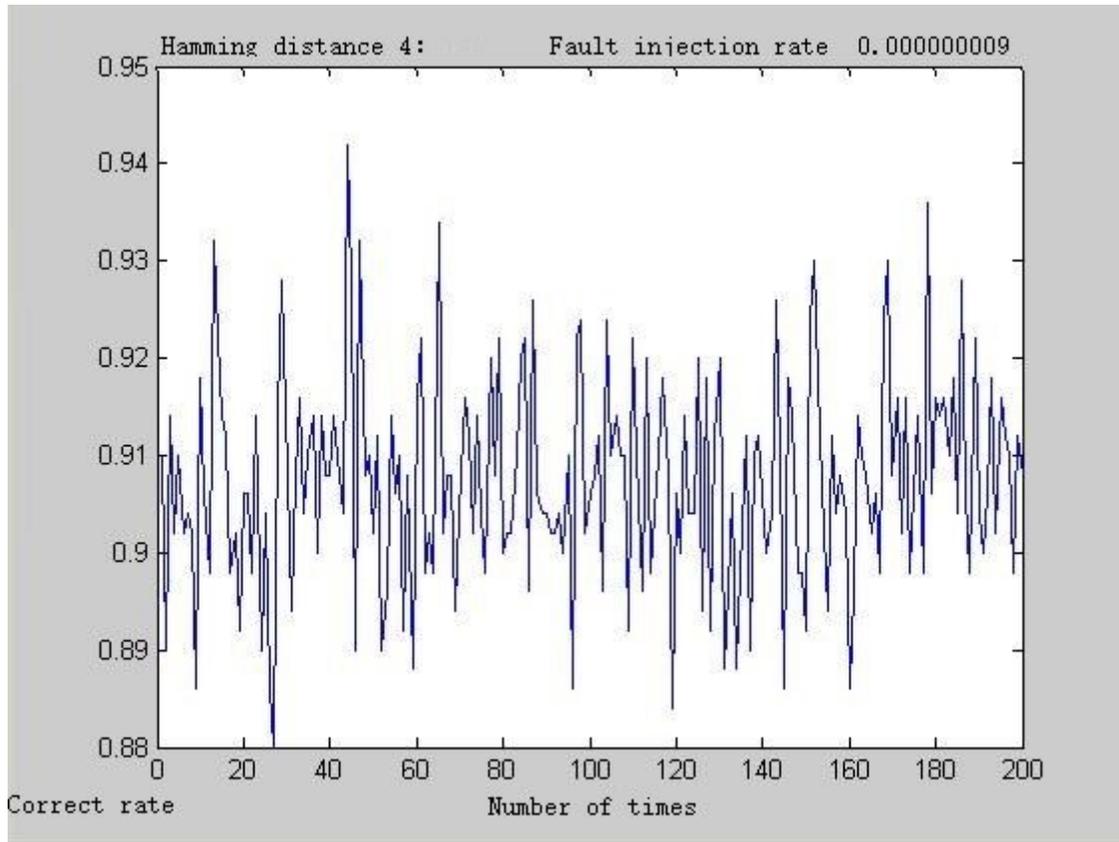


Figure 4

Hamming distance 4 injection rate 0.00000009

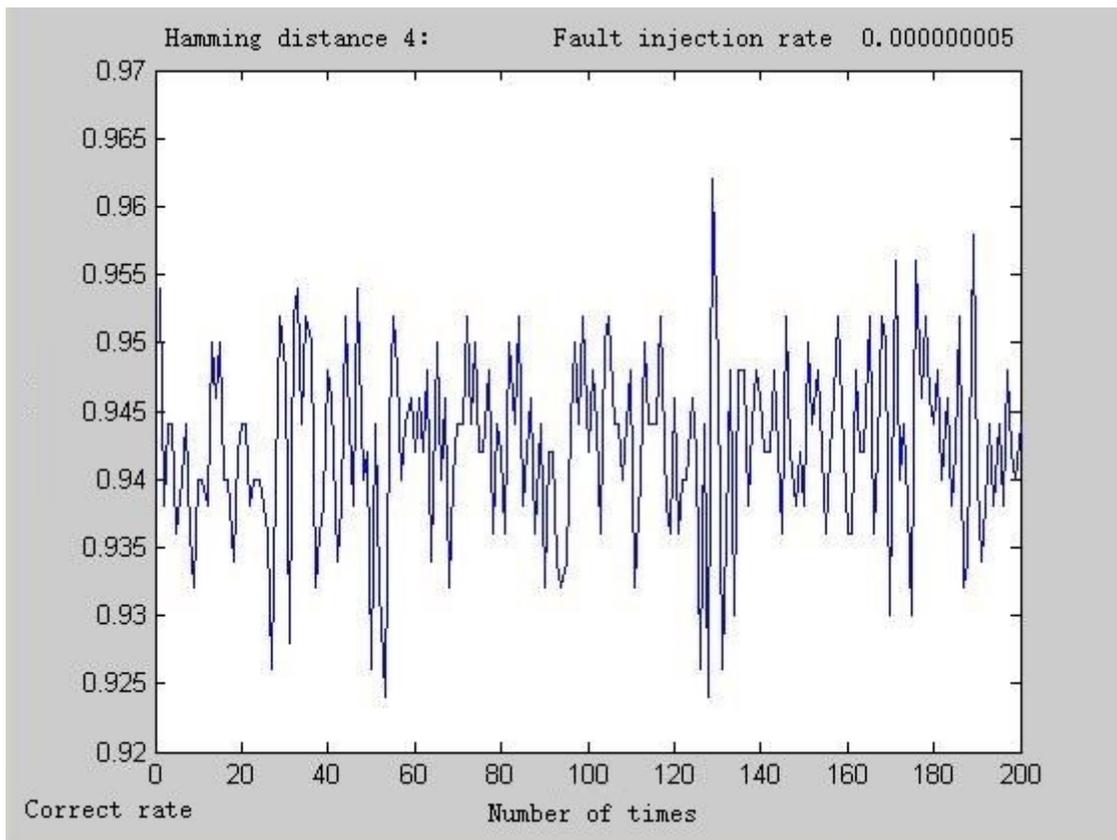


Figure 5

Hamming distance 4 injection rate 0.000000005

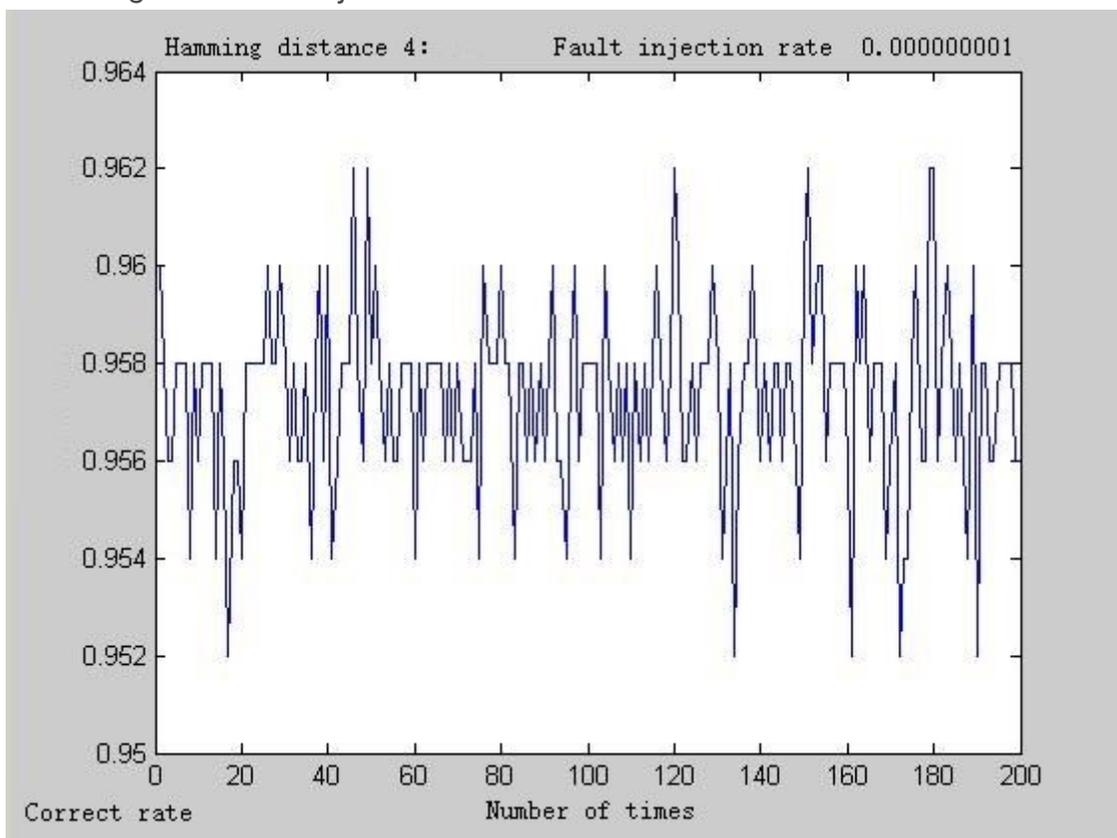


Figure 6

Hamming distance 4 injection rate 0.000000001

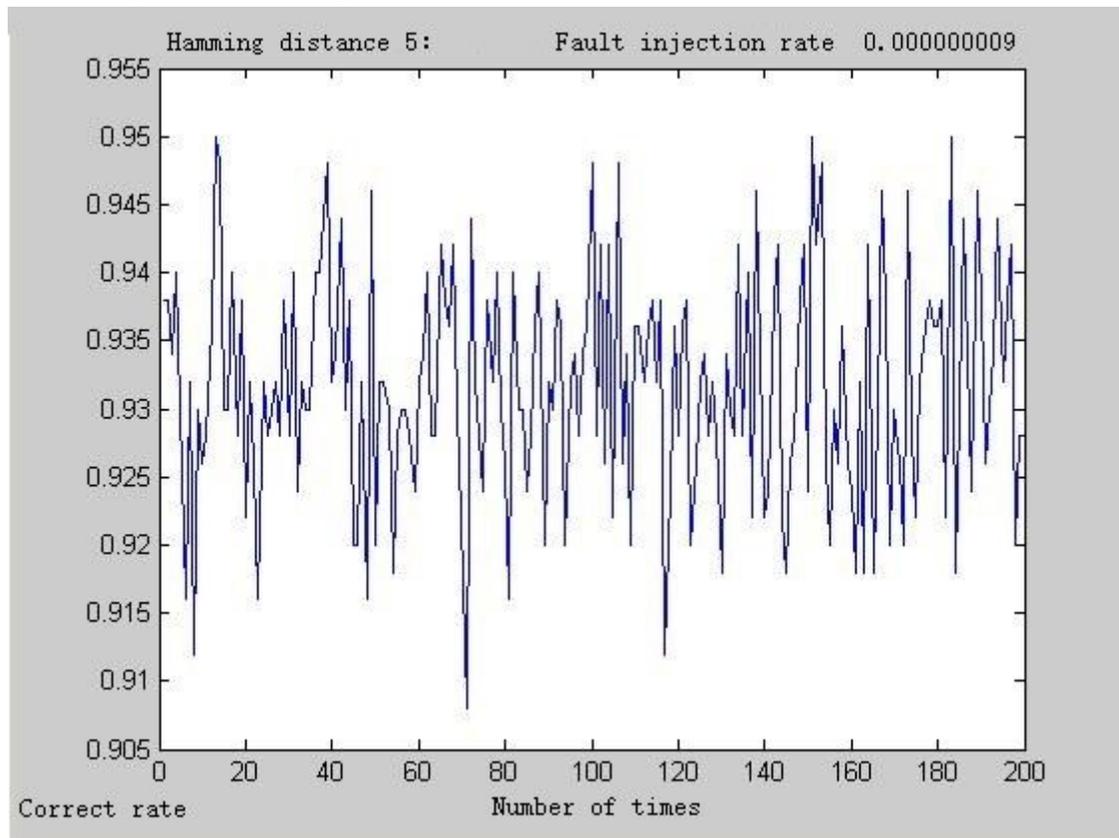


Figure 7

Hamming distance 5 injection rate 0.000000009

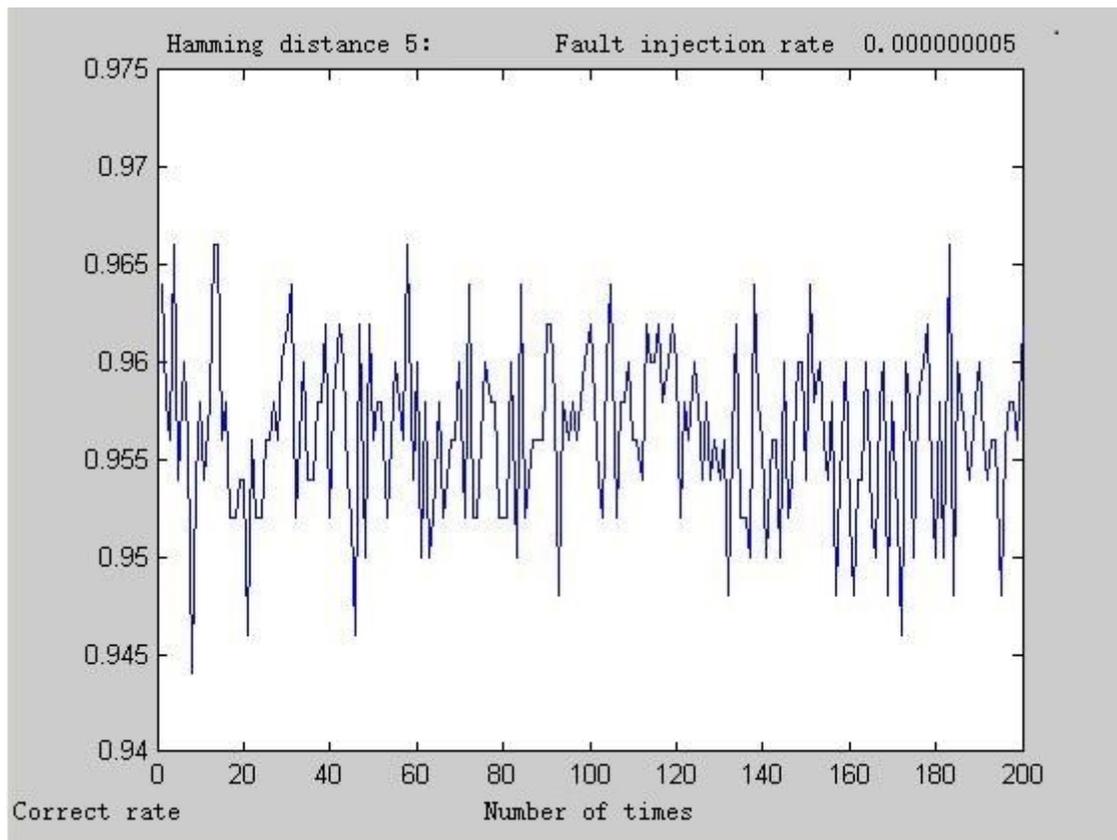


Figure 8

Hamming distance 5 injection rate 0.000000005

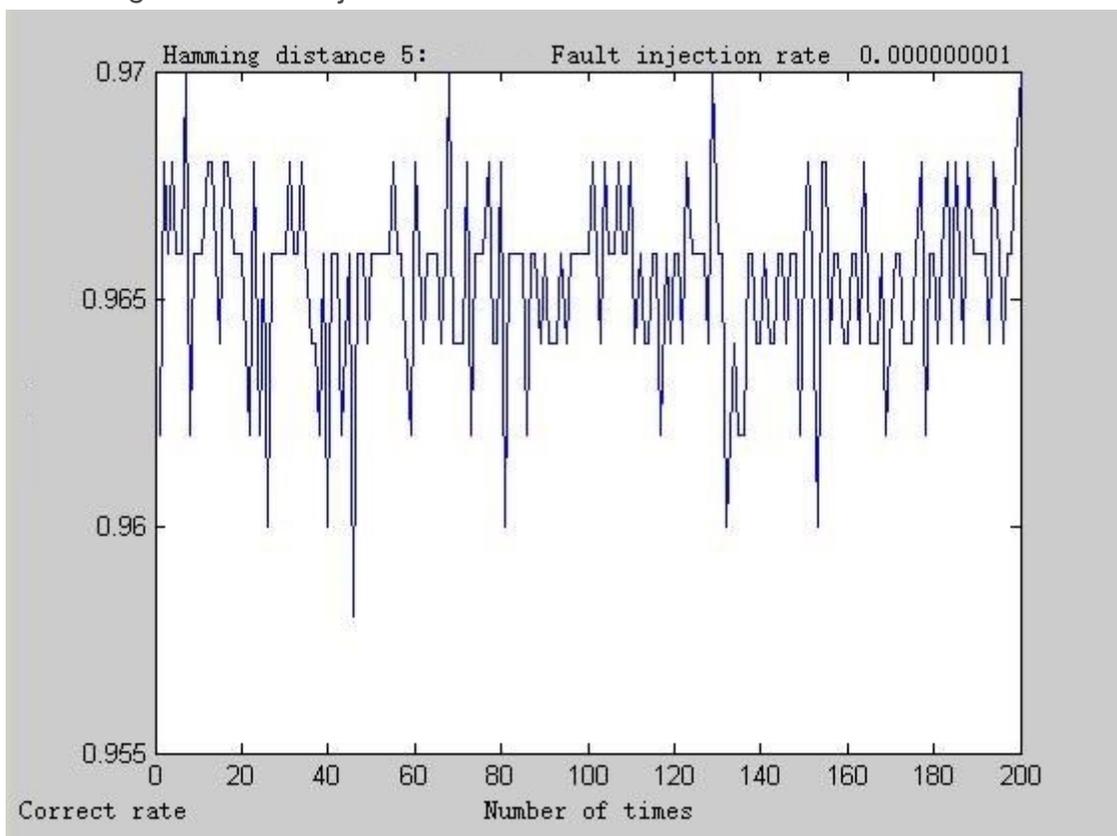


Figure 9

Hamming distance 5 injection rate 0.00000001