Adaptive Genetic Algorithm for Sensor Coarse Signal Processing

Xuan Huang
Cognitive Science Department, Xiamen University, Xiamen, Fujian, China, 361005
Fujian Key Laboratory of the Brain-like Intelligent Systems (Xiamen University), Xiamen, Fujian, China, 361005
Economic Management Department, Zhangzhou Institute of technology, Zhangzhou, Fujian, China, 363000

Wenhua Zeng
School of software, Xiamen University, Xiamen, Fujian, China, 361005

***Abstract*—As with the development of computer technology and informatization, network technique, sensor technique and communication technology become three necessary components of information industry. As the core technique of sensor application, signal processing mainly determines the sensor performances. For this reason, study on signal processing mode is very important to sensors and the application of sensor network. In this paper, we introduce a new sensor coarse signal processing mode based on adaptive genetic algorithm. This algorithm selects crossover, mutation probability adaptively and compensates multiple operators commutatively to optimize the search process, so that we can obtain the global optimum solution. Based on the proposed algorithm, using auto-correlative characteristic parameter extraction method, it achieves smaller test error in sensor coarse signal processing mode of processing interference signal. We evaluate the proposed approach on a set of data. The experimental results show that, the proposed approach is able to improve the performance in different experimental setting.**

***Index Terms*—Genetic Algorithms; Sensor; Signal Processing**

I. Introduction

With the development of computer technology and improvement of informationization degree, network technique, the sensor technique and communication technology constitute three pillars of information industry. In information system, sensor plays an increasingly important role. How to obtain information, especially obtainexact and reliable information has been the important issue of electronic information scientific research [1]. That is, obtaining information from the outside world only with the help of human organs is far from being able to meet people's demand. Therefore, whether it's in science, production or scientific research fields, sensors have been the essential tool and important channel. Since the sensor is located at interface for the object of study, it can provide processing and determination of systems with more accurate raw data. At present, sensor technology has been widely used in survey of resource, ocean exploration, science and technology, industrial manufacture, national defense construction and is playing an increasingly important role [2, 3].

However, as the core of sensor application, the condition of signal processing determines the sensor's performances to a large extent. Therefore, investigating signal processing mode for sensor has an important significance to sensor and the application of sensor network. In recent years, with the rapid development of artificial intelligence technique, it provides the study on coarse signal processing mode with new thoughts for people. What's more, algorithms, such as artificial neural network, support vector machine (SVM), Bayesian decision theory and particle swarm optimization algorithm [4], have been applied to the study on coarse signal processing mode by more and more scholars. However, because artificial neural network is based on empirical risk minimization principle, shortcomings, such as over-fitting, slow learning rate, easily appeared in the study on coarse signal processing mode. At the same time, recognition performance of SVM can be greatly influenced by parameters, in other words, suitable parameter selection will prompt SVM to show great superior. However, image pattern recognition will be faced with great difficulty when parameter selection is not suitable, such as recognition time becomes longer, recognition accuracy rate becomes lower and so on [5].

Moreover, how to select parameters of SVM has been a key issue in real application of recent years. Also, it's difficult to meet the assumption of naive Bayes classification method when processing large-scale classification problems and select the required evaluation function [6-7]. In addition, the complexity of learning training is very high. Crossover and mutation probability for simple genetic algorithm are typically determined according to rule of thumb, therefore it has a great influence on convergence and global optimum. On the basis of actual biological evolution theory, these probabilities shall change with the occurring of evolution to improve adaptive process of species. On account of which one study on coarse signal processing mode for sensor based on adaptive genetic algorithm (AGA) is presented in this paper [8]. This algorithm is able to adaptively select crossover and mutation probability and

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commutatively compensate multiple operators to optimize the search process, so that global optimum can be obtained [9].

TABLE I. BASIC STEPS FOR GENETIC ALGORITHM

Operation / Steps	Content
1.Individual coding	Datasets are encoded into binary string.
2.Generating swarm	N swarms are randomly generated, and their biological evolutions are simulated, so that excellent swarms can be obtained.
3.Design for fitness function	Calculate function of each swarm with fitness function to provide swarm evolution with basis.
4.Individual selection	Select m pairs of individuals from swarms as parents to raise up seed according to certain probability.
5.Individual crossover	Randomly select a pair of individuals and one integer n, at which gene of parents shall be exchanged with each other.
6.Individual difference	Select several individuals from the swarm according to certain probability and reserve one bit of the selected individual to simulate the accidental gene mutation in biological evolution and make a new evaluation, selection, crossover and mutation to new generated individuals, so on ad infinitum. And the iteration process will converge and the algorithm will be over when fitness reaches a certain critical value.

AGS was presented by Adaptation in Natural and Artificial Systems published by John Holland in 1975 and the major concept was from Darwinian evolution. Moreover, AGS has been widely used in optimization control of engineering or science, business prediction and finance, such as investment portfolio, trading strategy, futures option, financial crisis forecasting and so on, while economists mainly forecast time series and exchange market with genetic algorithm [10-11]. To overcome the limitations of the previous approaches, we in this paper proposed an adaptive genetic algorithm based approach which shows attractive abilities in processing coarse signal.

On account of the shortcomings of above method, namely, the finite adaptive capacity to data, coarse signal processing algorithm for sensor based on adaptive genetic algorithm is introduced [13]. In this paper, sinusoidal signal produced by processor is used to simulate ac electricity signal and current signal is processed with correlation analysis method. So that the interference of weak signal with same frequency and signal with low correlation to experimental results. Make a feature extraction of the processed ac electricity signal based on adaptive genetic algorithm thought, which can be used as the input. Then study coarse signal processing mode for sensor with three signal processing methods, such as traditionally defined feature parameters, LS feature parameters and correlation analysis feature parameters [12].

First, in this method, data and their features are preprocessed, objective function is created according to coarse signal processing problems for sensor, and then it is optimized with adaptive genetic algorithm. Due to the strong optimizing capacity and capacity avoiding local optimum of adaptive genetic algorithm, the obtained results can achieve or be much closed to global optimum solution.

Experimental results show that (1) the test error of LS method is obviously smaller than that of traditional feature method when processing signal, while test error of analysis method based on correlation is obviously smaller than that of LS method. In other words, the correlation analysis method has the smallest relative test error and may get the optimum effect when processing signal, which can be met whether it's under the condition of 5%, 7% or 9%. (2) Test precision of the three methods improves with the increase of N, see from the Table, test precision of N at 70 is higher than that of N at 10, no matter for any condition of interference amplitude. (3) Test precision decreases with the increase of interference amplitude. Seen from the Table, test precision sharply decreases with the increase of interference amplitude. It is worth noting that, the advantage of the proposed approach is that adaptive genetic algorithm is able to find the global optimum solution, which could significantly improve the performance.

II. PROPOSED SCHEME

To overcome the limitations of previous approaches, as mentioned in Section 1, we in this Section will present our adaptive genetic algorithm based approach. First, in the proposed approach, we simulate a set of signal using the processor. Second, the coarse signal is preprocessed and the feature is extracted. Third, the objective function is constructed based on the coarse signal processing problem. Forth, the constructed objective problem is optimized using the adaptive genetic algorithm. Benefit from the strong optimization ability of genetic algorithm, i.e., avoiding local optimum, the solution achieves the much better performance, in compression with related previous approaches. Further, the frame diagram of the presented method is shown as below and the more specific process will be described in Section 3 in order. In this Section, modeling of problems and description of adaptive genetic algorithm are the key points. We first describe the problem of this paper, and then present the adaptive genetic algorithm with its details.

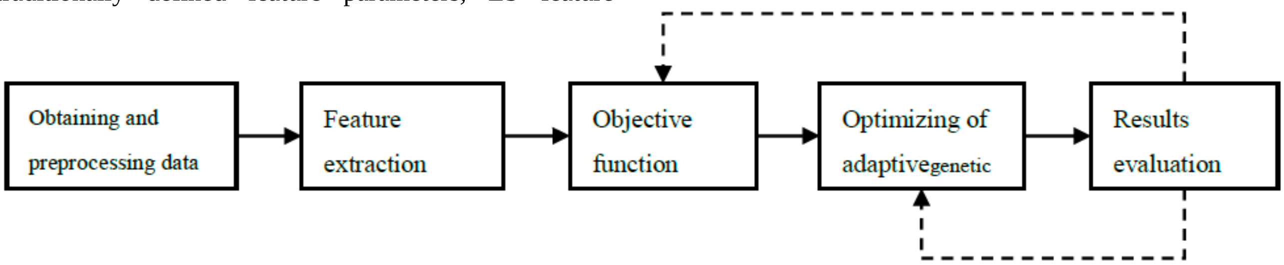

Figure 1. Frame diagram for coarse signal processing algorithm for sensor presented in this paper

A. Problem Description and Modeling

As a tool of optimization solving, SMA can be treated as akind of effective searching procedure, including the searching of a set of optimized parameters or models. Meanwhile, GA can simulate the process of species evolution with three basic operation mechanisms, such as selection, crossover and mutation. With evolution of the three processes, parent generates new offspring, and the better swarm of each generation has high probability to be partly or completely passed on to the next generation. GA is akind of optimization algorithm based on probability rule and the concept of survival of the fittest between living beings in natural world. Simulate chromosomes of various living beings with a set of special bit string and calculate the fitness to environment according to chromosomes. Chromosomes between generations can be randomly evolved into offspring with better fitness. The higher the fitness of chromosomes is, the more chances to pass gene on to offspring are, and the alternative action of evolution will be continued until termination conditions are fulfilled. Calculating steps are shown as Table 1 and Figure 2. The algorithm flow is shown as below.

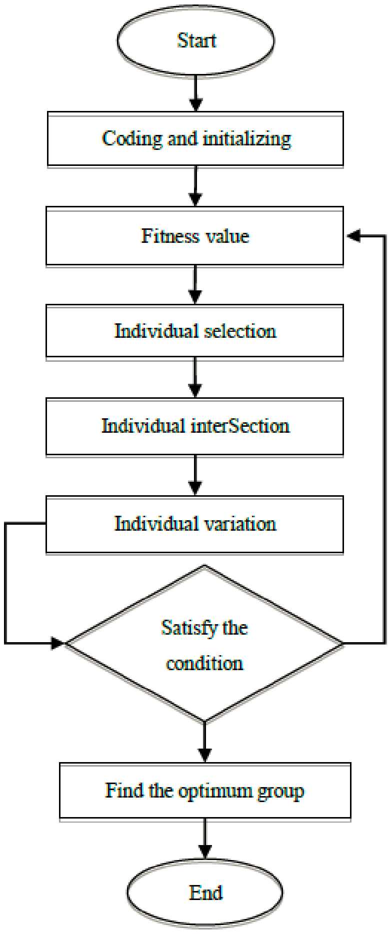

Figure 2. Flow chart for genetic algorithm

B. Adaptive Genetic Algorithm

Although AGS has many advantages, it also has lots of shortcomings under some conditions. Some findings show that cases, such as precocity and local convergence are easily appeared in the application process of GA, which is also the biggest flaw of AGS [14, 15]. The reasons leading to above cases are in links, such as individual coding, selection, crossover, mutation, mutation operator and probability determination of crossover and mutation. What's more, the performances of GA are greatly influenced by probabilities of crossover and mutation. In AGS, the probabilities of crossover and mutation are typically determined by empirical estimation method, which greatly influences the convergence and global optimum. However, according to actual biology evolutionary theory, these probabilities shall be changed with the occurrence of evolution to improve species' adaptive process. In this case, adaptive genetic algorithm is presented in this paper, this algorithm may adaptively select crossover and mutation probability and commutatively compensate multiple operators to optimize the search process, so that global optimum can be obtained [16, 17].

C. Selection for Fitness Function

Each individual is usually selected based on fitness value and individuals with larger fitness value are selected, then global optimum can be kept, but premature convergence easily appears. For this reason, individual diversity shall be kept during selection process to the greatest extent. In this paper, proportional selection method is used, so that probability of individuals with larger fitness value being selected is higher. And fitness function can be typically adjusted as below:

$$f'(x_i) = |f(x_i) - \bar{f}| \tag{1}$$

In equation (1), $f(x_i)$ is the fitness value corresponding with x_i, $\bar{f}$ is the average of fitness value for n species.

$$\bar{f} = \frac{\sum_{i=1}^{n} f_i}{n} \tag{2}$$

Such adjustment can increase the original fitness value. Therefore, its probability of being selected will be obviously increased. Probability of being selected for individuals in the middle is lower, therefore diversity of species can be kept at the beginning of evolution to avoid problems, such as local convergence and mode cheating, prematurely appear. Consequently, to make sure the probability of being selected for individuals with low selection probability before evolution so as to keep diversity of swarm, fitness function can be adjusted as following in this paper [5]:

$$f'(x_i)\begin{cases} |f(x_i) - \bar{f}|\ t < 0.6T \\ \tan\left(\frac{1}{T} \times \frac{\pi}{4}\right) \times f(x_i) + f_{max}\ t < 0.6T \end{cases} \tag{3}$$

III. Experimental Verification

Coarse signal processing algorithm for sensor based on adaptive genetic algorithm previously presented will be verified through experiments in this Section. In this paper, ac electricity signal is used for simulation when conducting an experiment and experimental flow is shown as below:

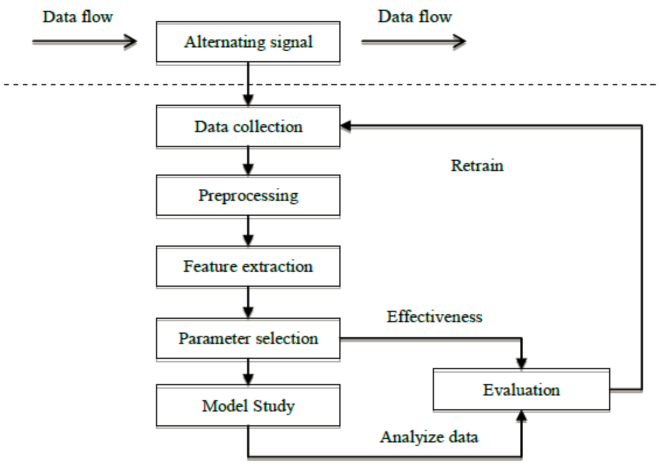

Figure 3. Flow diagram of experiment

TABLE II. DATA COLLECTED IN EXPERIMENT

Sampling sites \ Signal parameters	U_1	ε_{U_1}	θ_1	ε_{θ_1}
1	246.71	12.16	0.45	14.39
	245.80	11.75	0.44	14.93
2	235.98	7.43	0.47	11.54
	239.76	8.94	0.53	12.69
3	243.19	11.23	0.43	14.63
	244.96	11.39	0.46	14.98
4	235.49	5.01	0.47	12.06
	231.69	4.98	0.43	11.92

A.Signal Collection

In this paper, sinusoidal signal produced by processor is used to simulate ac electricity signal.

$$U(n) = 220\sqrt{2}\left(314.16 m_{Sample\_period} \times n + \frac{\pi}{6}\right) \quad (4)$$

Seen from the above equation, effective value for signal is 220V, frequency is 50Hz, initial phase is 30 degree, where m_{Sample_period} is the sample period. The collected coarse signal is shown in Table 2.

B. Signal Processing

In this paper, correlation analysis method is used to process the produced current signal. In correlation analysis, assume that the collected coarse signal for sensor is shown as equation (5) and (6).

$$y(t) = \sin(2\pi f t) \quad (5)$$

$$r_u(t) = \sum_{i=1}^{k} U_i \sin(2\pi f_i t + \theta_{ui}) \quad (6)$$

where $k > 1$, θ_{ui}, f_i and U_i are respectively initial phase, frequency and effective value for voltage of the ith frequency component $r_{ui}(t)$. Meanwhile, $R_{\hat{u}y}(\tau)$ can be used to express mutual relation of $y(t)$ and $\hat{u}(t)$, as shown equation (7).

$$R_{\hat{u}y}(\tau) = \lim_{T\to\infty}\int_{-\frac{T}{2}}^{\frac{T}{2}} \hat{u}(t)y(t+\tau)dt \frac{U_m}{\sqrt{2}}\cos(2\pi f\tau - \theta_{u0})$$

$$+ \lim_{T\to\infty}\int_{-\frac{T}{2}}^{\frac{T}{2}} \sum_{i=1}^{k} U_i \sin(2\pi f_i t + \theta_{ui}) \sin\big(2\pi f(t+\tau)\big)\, dt$$

$$= \frac{U_m}{\sqrt{2}}\cos(2\pi f\tau - \theta_{u0}) + \begin{cases} \sum_{i=1}^{k} \frac{U_i}{2}\cos(2\pi f\tau - \theta_{ui}), f_i = f \\ 0 \; f_i \neq f \end{cases} \quad (7)$$

Because there is very weak signal in the collected signal, especially for signal with same frequency, such weak signal is ignored with equation (8) when processing in this paper, so that the effect of weak signal on experimental results can be eliminated.

$$R_{\hat{u}y}(\tau) = \frac{U_m}{\sqrt{2}}\cos(2\pi f\tau - \theta_{u0}) \quad (8)$$

T_c is sampling period and $y(i) = y(iT)$. During the process of eliminating weak signal, when N is very large, there will be:

$$R_{\hat{u}y}(0) \approx \frac{1}{N}\sum_{i=0}^{N-1} \hat{u}(t)y(i) \quad (9)$$

Combining equation (9) and (9) can give the final processing results for weak signal:

$$\left.\begin{aligned} \tan\theta_{i0} &\approx (\hat{\imath}(0)N)/\left(2\sum_{i=0}^{N-1}\hat{\imath}(i)y(i)\right) \\ I &\approx \sqrt{\frac{2}{N^2}\left(\sum_{i=0}^{N-1}\hat{\imath}(i)y(i)\right)^2 + \frac{\hat{\imath}^2(0)}{2}} \end{aligned}\right\} \quad (10)$$

The collected signal is passed through the above processing process, which can effectively eliminate interference of weak signal with same frequency and signal with low correlation on experimental results [6].

C. Signal Feature Extraction

In this paper, feature extraction of coarse signal to be processed is conducted based on the thought of adaptive genetic algorithm, and the general flow is shown as Table 3 [16]:

TABLE III. FEATURE EXTRACTION PROCESS

Steps \ Content	Content
1Initial setup	Set the swarms, which is ac electricity signal preprocessed, that is to say, set the probabilities of selection, crossover and mutation, swarm scale and evolving algebra for these signals according to the thought of genetic algorithm.
2Generate random individuals	A swarm of presents is randomly generated from processed signals and each individual is one character subset, each gene of individual is one character.
3Calculate fitness value for individuals	For each individual signal is one character subset, decoding operation shall be conducted according to decoding steps, so that the adjusted fitness can be calculated according to equation (3).
4Determine breed probability	Determine the probability of each offspring according to the fitness obtained from step 3 and the selected selection operator.
5Generate new individuals	Randomly select new round of parent according to the obtained probabilities of crossover and mutation to generate new individual, so that the new next generation will be formed.
6Obtain the optimum character subset	Repeat step (3) to (5) until conditions of convergence are met to terminate iteration.

TABLE IV. RELATIVE TEST ERRORS WHEN INTERFERE AMPLITUDE IS 5% OF $\mathbf{U_v}$AND$\mathbf{I_m}$ RESPECTIVELY

N	R_{c1}	R_{p1}	R_{Q1}	R_{S1}	R_{c2}	R_{p2}	R_{Q2}	R_{S2}	R_{c3}	R_{p3}	R_{Q3}	R_{S3}
10	-0.23	-11.61	-39.74	-12.89	-0.05	-3.21	-4.96	-3.31	-0.02	-2.58	-3.70	-2.79
20	-0.09	-4.29	-7.69	-5.09	-0.06	-1.98	-2.36	-1.98	-0.03	-1.29	-1.49	-1.32
70	0.01	-0.87	-0.81	-0.84	-0.02	-0.39	-0.29	-0.37	-0.01	0.12	0.29	0.14

TABLE V. RELATIVE TEST ERRORS WHEN INTERFERE AMPLITUDE IS 7% OF $\mathbf{U_v}$AND$\mathbf{I_m}$ RESPECTIVELY

N	R_{c1}	R_{p1}	R_{Q1}	R_{S1}	R_{c2}	R_{p2}	R_{Q2}	R_{S2}	R_{c3}	R_{p3}	R_{Q3}	R_{S3}
10	-0.40	-17.58	-95.29	-30.12	-0.23	-6.43	-12.63	-6.20	-0.05	-5.21	-7.59	-5.26
20	-0.14	-5.29	-13.65	-6.02	-0.05	-3.59	-5.62	-3.79	-0.04	-2.56	-3.19	-2.98
70	0.03	-1.52	-1.03	-1.56	-0.03	-0.79	-0.69	-0.77	-0.03	0.19	0.59	0.36

IV. EXPERIMENTAL RESULTS AND ANALYSIS

In this paper, sinusoidal signal produced by processor is used to simulate ac electricity signal, the collected signal is processed with correlation analysis method to effectively eliminate interference of weak signal with same frequency and signal with low correlation on experimental results, see Section 3.2 for details. Feature extraction shall be conducted after processing signal, so that signal can be the mode easily recognized by computers, signal feature extraction flow is shown as Table 3 in Section 3.3.

In this paper, traditional feature parameter extraction method, LS feature parameter extraction method and correlation analysis feature parameter extraction method are respectively used to conduct experiments when voltage and interference amplitude I_m for current are respectively 5%, 7% and 9% of voltage(U_v)and current signal amplitude. Each experiment is repeated for 20 times and the relative test error is treated as evaluative criteria during experimental process, and test error is 0.45%, voltage, current and frequency are respectively 220V, 10A and 50Hz, pure signal $\theta_{i0} = 15^0$, $\theta_{v0}=25^0$, and N is respectively 10,20 and 70 in each experiment. Also, relative test error of $\cos\varphi$, P, Q and S are respectively R_{ci}, R_{pi}, R_{Qi}, R_{Si}. The experimental results are reported in Table 4, 5 and 6, which are respectively test results of traditional feature parameter extraction method, LS feature parameter extraction method and correlation analysis feature parameter extraction method.

Table 4 is the experimental results for traditional feature parameter extraction method; LS feature parameter extraction method and correlation analysis feature parameter extraction method. Experimental method is described as Section 3.2, traditional feature parameter extraction method, LS feature parameter extraction method and correlation analysis feature parameter extraction methods are respectively used to conduct experiments. What's more, the goal of the experiment is to compare the three feature extraction methods. Experimental parameters are that interference amplitude is 5%, N is 10, 20 and 70. Experimental results are expressed with relative test error. Seen from Table 4, (1) when N=10, test errors of LS method are respectively -0.05, -3.21, -4.96 and -3.31, which is obviously lower than -0.23, -11.61,-39.74 and -12.89 obtained with traditional feature extraction method. (2) however, test errors of correlation analysis method are respectively -0.02, -2.58, -3.70 and -2.79, which is obviously lower than that of LS method. Therefore, the optimum effect and the smallest relative test error can be obtained when processing signal with correlation analysis method. Reasons for the above results are: in the traditional feature parameter extraction method, LS feature parameter extraction method and correlation analysis feature parameter extraction method, the traditional feature parameter extraction method ignores the estimation of initial sampling sites and has the largest operand, while correlation analysis method has the smallest operand. LS method can reduce the negative influence brought by interference to the largest extent through minimizing error sum of errors for sample mode and signal sample. Compared with the above two methods, correlation analysis method has stronger capacity in processing interference signal, so it has higher test precision.

TABLE VI. RELATIVE TEST ERRORS WHEN INTERFERE AMPLITUDE IS 9% OF U_V AND I_M RESPECTIVELY

N	R_{c1}	R_{p1}	R_{Q1}	R_{S1}	R_{c2}	R_{p2}	R_{Q2}	R_{S2}	R_{c3}	R_{p3}	R_{Q3}	R_{S3}
10	-0.69	-23.56	-179.23	-45.69	-0.23	-10.69	-30.12	-16.56	-0.06	-8.96	-14.65	-10.26
20	-0.30	-7.98	-21.45	-8.59	-0.10	-6.25	-13.69	-7.21	-0.06	-5.26	-7.46	-5.26
70	0.10	-2.36	-3.98	-2.94	-0.06	0.98	1.95	0.94	-0.04	0.19	0.65	0.36

Table 5 is the experimental results for traditional feature parameter extraction method; LS feature parameter extraction method and correlation analysis feature parameter extraction method. Experimental method is shown as Section 3.2, traditional feature parameter extraction method, LS feature parameter extraction method and correlation analysis feature parameter extraction methods areused to conduct experiments respectively. What's more, the goal of the experiment is to compare the three feature extraction methods. Experimental parameters are that interference amplitude is 7%, N is 10, 20 and 70 respectively. Experimental results are expressed with relative test error. Seen from Table 5, the test precisions of the three methods increase along with the increasing of N. Take correlation analysis method for example, when N=70, test errors are -0.03, 0.19, 0.59 and 0.36, when N=10, test errors are -0.05, -0.05, -7.59, -5.26. That is, test precision of N=70 is higher than that of N=10. The possible reasons leading to above results are three fold: (1) the anti-interference increases with the increase of N. (2) Among traditional feature parameter extraction method, LS feature parameter extraction method and correlation analysis feature parameter extraction method, traditional feature parameter extraction method ignores the estimation of initial sampling sites. (3) LS method can reduce the negative influence brought by interference to the largest extent through minimizing error sum of errors for sample mode and signal sample. Compared with the above two methods, correlation analysis method has stronger capacity to process interference signal, so it has higher test precision. In addition, it is worth noting that traditional feature extraction method has the largest operand, while correlation analysis method has the smallest operand.

Table 6 is the experimental results for traditional feature parameter extraction method; LS feature parameter extraction method and correlation analysis feature parameter extraction method. Experimental method is shown as Section 3.2, traditional feature parameter extraction method, LS feature parameter extraction method and correlation analysis feature parameter extraction methods are respectively used to conduct experiments. What's more, the goal of the experiment is to compare the three feature extraction methods. Experimental parameters are that interference amplitude is 9%, N is 10, 20 and 70. Experimental results are expressed with relative test error. Take LS feature extraction method for example, Seen from Table 6, when interference amplitudes are 5%, 7% and 9%, the corresponding test errors are respectively -0.05, -0.04, 0.03, namely, test error decreases with the increase of interference amplitude. Result of 9% is the same with that of 5% and 7%. The possible reasons leading to above results are (1) the anti-interference increases with the increase of N. (2) Among traditional feature parameter extraction method, the LS feature parameter extraction method and correlation analysis feature parameter extraction method, traditional feature parameter extraction method ignores the estimation of initial sampling sites. (3) LS method can reduce the negative influence brought by interference to the largest extent through minimizing error sum of errors for sample mode and signal sample. Compared with the above two methods, correlation analysis method has stronger capacity to process interference signal, so it has higher test precision. (4) Adaptive genetic algorithm may fully use correlation analysis method to extract feature signal.

V. CONCLUSION

For AGS, empirical estimation method is typically used to determine probabilities of crossover and mutation, which can greatly influence convergence and global optimum. But according to actual biology evolutionary theory, these probabilities shall be changed with conducting of evolution to improve species' adaptive process. In view of this, study on coarse signal processing mode for sensor based on adaptive genetic algorithm is presented in this paper. And this algorithm can adaptively select crossover and mutation probability and commutatively compensate multiple operators to optimize the search process, so that global optimum can be obtained. The analysis of experimental results shows that (1) measuring error for LS method is significantly lower than that of traditional feature extraction method when processing signal, and measuring error for correlation analysis method is obviously lower than that of LS method. In other words, the optimum results can be obtained when processing signal with correlation analysis method, which has the smallest relative error and can fulfill the above conclusions whether it's 5%, 7% or 9%. (2) The test precisions for the three methods increase with the increase of N, that is to say, no matter the interference amplitude is, the test precision of N=70 is higher than that of N=10. (3) The adjusted fitness function is presented in this paper to calculate fitness values of individuals, with the difference of fitness function, fitness values of individuals are different, so probability of individual being selected will be greatly influenced and determination of fitness function is still the next striving direction.

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