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Measurement of Industrial Alcohol Concentration Capacitance Method and AIA-GA Nonlinear Correction

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Abstract

For the nonlinear output of capacitance sensor in the process of measuring industrial alcohol concentration and the lack of traditional genetic algorithms for nonlinear fitting, Propose an improved immune genetic algorithm. This approach combines the advantages of the artificial immune algorithm(AIA) and a genetic algorithm(GA) in the global search ability and convergence efficiency, introduce improved artificial immune mechanisms in genetic algorithms, to overcome its inherent precocity, low efficiency inadequate. Experimental results show that, compared with traditional methods, this method can effectively eliminate the influence of non-target parameter to sensor output, deal with the nonlinear problems efficiently .

Key words: CAPACITANCE METHOD, INDUSTRIAL ALCOHOL CONCENTRATION, GENETIC ALGORITHM, ARTIFICIAL IMMUNE ALGORITHM.

1. Introduction

Industrial alcohol is the basis of organic chemical raw materials and high-quality fuel, widely used in printing, electronics, hardware, spices, chemical synthesis, etc. Different areas of industrial alcohol concentration requirements vary, and accuracy requirements are high, detection of industrial alcohol concentration in general use of alcohol meter testing, the principle is in accordance with the solution density is detected, the method error is large, the accuracy is relatively limited. Because of the advantages of simple structure, high accuracy, fast response, and so on, the capacitance method has been widely used in the on-line detection of liquid [1].

As same as other sensors, capacitance method is also a serious problem with the nonlinear output[2]. Genetic Algorithm (abbreviated GA) as a traditional nonlinear global optimization method, the main feature is not dependent gradient information, especially for dealing with complex issues and problems in nonlinear. But it is easy to premature convergence to local optima, and the phenomenon of "premature"[3]. Artificial immune algorithm (AIA) is the function of the reference biological immune system, AIA based on the concentration of antibody breeding strategy can effectively maintain the diversity of the population. In this paper, we introduce the relevant steps of AIA into GA algorithm, and make corresponding

improvement, use local information to get involved in global optimization process, so as to overcome the degradation phenomenon in GA algorithm, and overcome the "premature" problem, which makes the non-linear correction process more accurate and efficient.

2. Measuring Principle of industrial alcohol concentration by capacitance method

The main components of industrial alcohol is ethanol, the relative dielectric constant is between 30 and 33, the dielectric constant of water is 81, it can be seen from the knowledge of physics, at different concentrations of alcohol mixed liquids with different mixing dielectric constant, the capacitive sensor the design is based on the second principle, that is, by measuring the capacitance value between the two plates, indirectly alcohol concentration. Plate capacitor structure shown in figure 1, r is the radius of the plate, d is the distance between the plates, a dielectric constant of the mixed liquid is assumed, then the capacitance value is corresponding to [4]:

$$C = (\epsilon\pi r^2/d)(1 + d/2r) \tag{1}$$

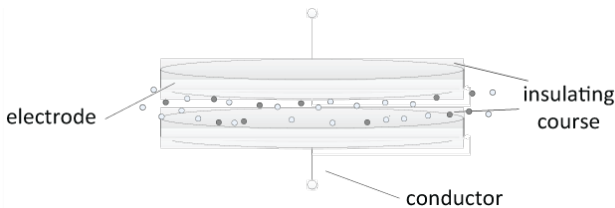


Figure 1. Structure of plate capacitor

If the volume fraction of the alcohol in the liquid is D , ϵ_c and ϵ_0 are the dielectric constant of the industrial alcohol and pure water, the dielectric constant ϵ [5] and the capacitance value of the plate are respectively:

$$\epsilon = D\epsilon_c + (1 - D)\epsilon_0 \tag{2}$$

$$C = \frac{\epsilon \cdot \pi r^2}{d} = \frac{\pi r^2}{d} (1 + d/2r) [D\epsilon_c + (1 - D)\epsilon_0] \tag{3}$$

Transformation of the above formula can be obtained, the final expression mixing industrial alcohol concentration of the liquid is:

$$D = \frac{2Cd - \epsilon_0\pi r(2r + d)}{\pi r(\epsilon_c - \epsilon_0)(2r + d)} \tag{4}$$

The analysis shows that, the volume concentration of industrial alcohol and the value of D in the theory of the value of the capacitance of the electrode is line-

ar. But because of the influence of many factors, these factors include, edge effects of plates, the structure of the plate manufacturing process, the contact resistance, down-lead parasitical capacitance, residual magnetic field after the molding of metallic materials, etc., constitute nonlinear factors [6]. The measurement output is often non-linear, we use the improved immune genetic algorithm that is AIA-GA algorithm output nonlinear correction, eliminating the effects of non-parametric factors on the measurement results, the original algorithm based on GA to improve the accuracy and efficiency optimization.

3. AIA-GA algorithm (containing a certain analysis)

In general, if x and y are respectively represented by the measured input and output, then for M multiple measured data (x_i, y) ($i=1,2,\dots,m$), can be used to describe the data of the N times the approximate function $y(x_i)$

$$y(x_i) = a_0 + a_1x_i + a_2x_i^2 + \dots + a_nx_i^n \tag{5}$$

$A = [a_0, a_2, \dots, a_n]$ is the $n + 1$ undetermined coefficient, the nonlinear correction aim is to obtain the best estimate of the value of A .

3.1 Genetic Algorithm (GA)

Genetic algorithm (GA) is a global search algorithm simulating natural selection and evolution process, search method for multiple individuals using the same process, at the same time the search range throughout the whole solution space. Traditional genetic algorithm with a display of its huge superiority at the same time, also exposed some limitations, such as traditional genetic algorithm in the near global optimal solution search speed slow, even into the local optimal solution [7], the traditional GA algorithm general steps are shown in figure 2 below:

3.2 AIA - GA algorithm

Unlike the GA algorithm, artificial immune algorithm (AIA) use the genetic mechanism of antibody diversity of the immune system and the cell selection mechanism, through of a body of confrontation and inhibition, finally find out and corresponding optimal antigen antibody, so as to achieve the aim of to solve the problem. AIA algorithm has fast convergence speed and good population diversity[8], introduction of AIA steps in the GA algorithm, and the corresponding improvement, involvement in global optimization with local information process, which can overcome

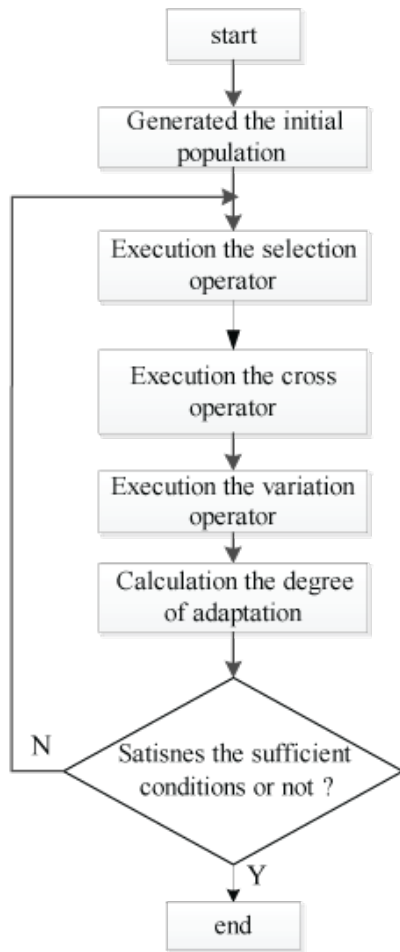


Figure 2. Genetic algorithm flowchart

the kind of crossover and mutation operation of GA algorithm degradation phenomenon, to overcome the premature problem. In this paper, we use the following two immune operations to optimize the genetic algorithm.

1. Based on the concentration of antibody selection

In general algorithm, the selection probability is proportional to the fitness of individual in the population. It is easy to make the individuals of the population of the population increase rapidly, which leads to the premature convergence of the algorithm. In order to overcome this shortcoming, this paper also considers the similarity of the antibodies in the encoding. In order to calculate the similarity and concentration of antibody, the antibody w, v , If there is the following relationship established:

$$d(w, v) < l \quad |ax_w - ax_v| < m \tag{6}$$

Called antibodies w and antibody, which is similar, namely antibodies ax_w and ax_v , fitness, l, m for more than 0 constant, set the number of antibodies v and antibody similar to the ratio of the total number of antibody v called concentration of antibody c_v .

The probability of selecting antibodies is:

$$p_v = \alpha \frac{av}{\sum_{v=1}^N av} + (1 - \alpha) \frac{1}{N} e^{-\frac{av}{\beta}} \tag{7}$$

Among them, were in $[0, 1]$ for the constant adjustment factor, it can be seen from the above equation, is probability of selection and fitness-related, but also related to the concentration, so to maintain the diversity of antibodies, but also ensure the convergence rate.

Where α and β are in $[0, 1]$ for the constant adjustment factor, it can be seen from the above equation, the degree of probability of selection and adaptation is not only related to fitness, but also with the concentration, so to maintain the diversity of antibodies, which can keep the diversity of the antibodies, and ensure the convergence rate of the algorithm.

2. immune operator based on hold best result

Genetic algorithm during each iteration, the operation should be carried out genetic selection, crossover and mutation, as well as strategies to maintain optimal solution, so that the next generation into the average fitness of the population of individuals than the previous generation is high. And the next generation will have to repeat the previous generation of the operation of these populations to adapt to the degree of adaptation, which is bound to make certain individuals in the presence of "degradation" phenomenon [9-10]. In this paper, a new operator, immune operator, is introduced into GA algorithm.

The immune operator includes three steps: vaccine extraction, vaccination and immune selection. Vaccine extraction is to extract M immune gene which have same relative position by a certain probability from the optimal antibody group. Then the M gene in the antibody group $c = [p_1, p_2 \dots p_n]$ was replaced by the immune gene which have the same position, that the process is vaccination. The immune selection is to test the vaccinated individuals, if the offspring's fitness is not as well as the parent that is caused by the adaptation of the offspring, it shows that the antibody in offspring is replaced by the parent offspring, if the child is better than the father, the parent will be replaced by offspring.

Immune annealing selection method is adopted, that when select individual from a previous generation introduce probability P_v , as shown below:

$$rp_v = \frac{\exp[av/T_k]}{\sum_{i=1}^m \exp[av/T_k]} \tag{8}$$

Where and av are v in $[0,1]$ for the constant adjustment factor, it can be seen from the above equation, the degree of probability of selection and adaptation is not only related to fitness, but also with the concentration, so to maintain the diversity of antibodies, which can keep the diversity of the antibodies, and ensure the convergence rate of the algorithm.

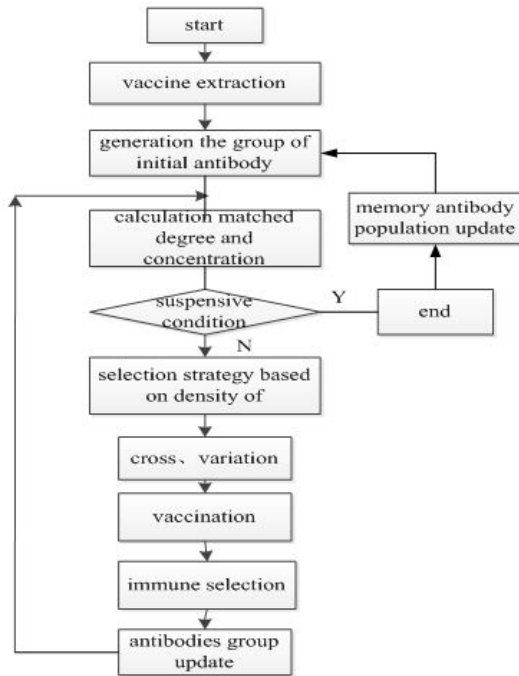


Figure 3. GA-AIA algorithm flowchart

4. Experimental verification

To verify the validity of the AIA-GA algorithm for the nonlinear correction of capacitive sensor output, an experiment on measuring the concentration of industrial alcohol by capacitance method is designed. Figure 4 is the industrial alcohol concentration measurement system block diagram which was carried out at room temperature and atmospheric pressure. Measurement circuit design based on the principle of NE555 multi harmonic oscillator, which through the MCU counting on the output square wave frequency to get the relationship between capacitance value and output frequency of the oscillator, so as to obtain the capacitance value of the capacitance measured by the square wave frequency.

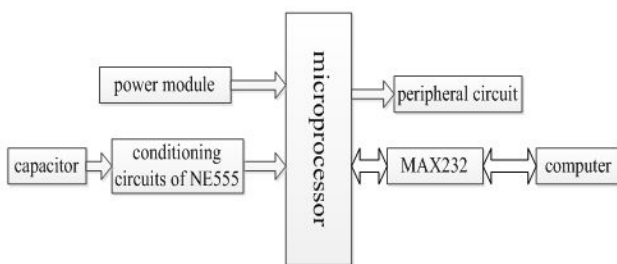


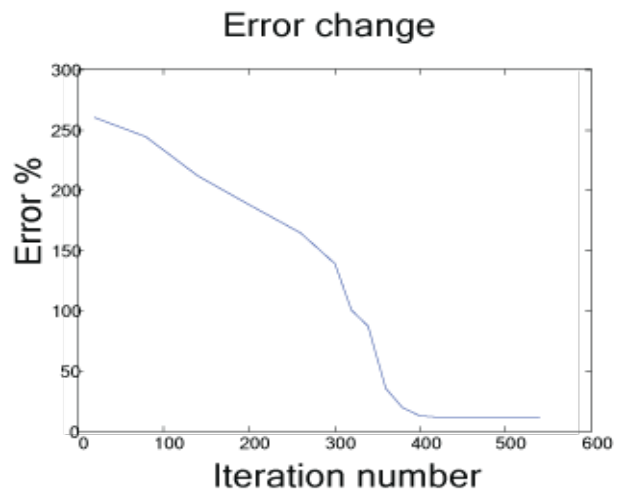
Figure 4. Block diagram of the measurement by capacitance method of industrial alcohol concentration

First, 15 groups alcohol and water mixtures which have different volume fractions were prepared for the experiment (concentration values which is equal interval in the range of 10%~39%), the mixture liquid volume on the standard of volume of liquid in the cylinder. The capacitor is placed in a mixture which have known the concentrations, at the same time, the frequency value f of the output of the system corresponding to the concentration value is recorded. Finally, the practical value data $d\%$ and corresponding frequency value f MHz of the 30 groups is obtained. As shown in table 1:

Table 1. 15 sets of raw data

d%	f MHz	d%	f MHz	d%	f MHz
10	5.601	20	9.101	30	11.501
12	6.173	22	9.523	32	11.953
14	6.813	24	10.273	34	12.273
16	7.237	26	10.712	36	12.502
18	8.392	28	11.272	38	13.212

On table data has obvious correlation, according to the prior knowledge of the least square method, the third order polynomial is chose to fit. First of all, the algorithm is trained by AIA algorithm and GA algorithm. After the actual simulation, the operating parameters of the algorithm are finally set as follows: sample number of groups is 100, crossover probability is 0.95, mutation probability is 0.02, When running to the 110 generation the error square tends to a constant value 11.9668, the algorithm ends, and save the time series values. At the same time, the traditional GA algorithm is used for the simulation. Simulation is shown in figure 5 and table 2: comparison of running results of GA and GA-AIA.



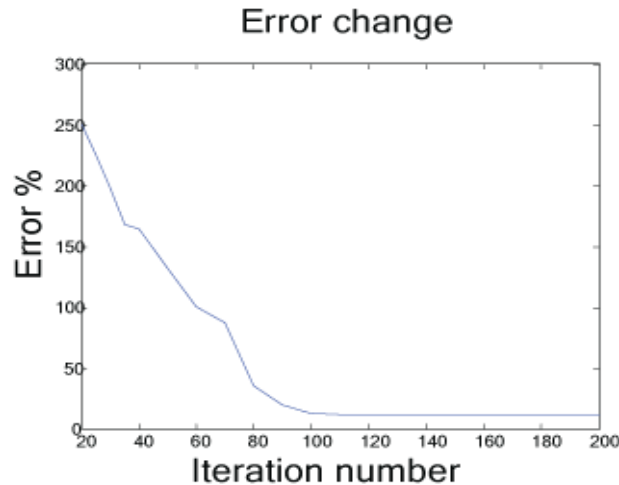


Figure 5. GA compared with AIA-GA algorithm iteration number

Table 2. Compared with GA GA-AIA operating results

Iteration number	Polynomial coefficients				Square error sum
	a_0	a_1	a_2	a_3	δ
GA:T=420	0.030	-0.627	7.147	-15.523	12.076
AIA-GA:T=110	0.034	-0.737	8.274	-19.137	5.872

Compared with the traditional GA algorithm, the convergence speed of the algorithm is fast and the stability is strong, and the GA algorithm is easy to fall into local minimum. Compared with the traditional GA-AIA algorithm. So, the GA-AIA algorithm is used to overcome the disadvantages of GA algorithm based on AIA optimization, play the advantages of GA algorithm.

From the results obtained by the above results, the fitting formula of the capacitance method for measuring industrial alcohol concentration is obtained. In order to compare the two algorithms in a more direct way, the fitting curves of the data given by the respective empirical formulas are made, as shown in figure 6, and the linear regression line is shown in figure 7.

$$d_G(f) = 0.030 - 0.627 * f + 7.147 * f^2 - 15.523 * f^3 \quad (9)$$

$$d_A(f) = 0.034 - 0.732 * f + 8.274 * f^2 - 19.137 * f^3 \quad (10)$$

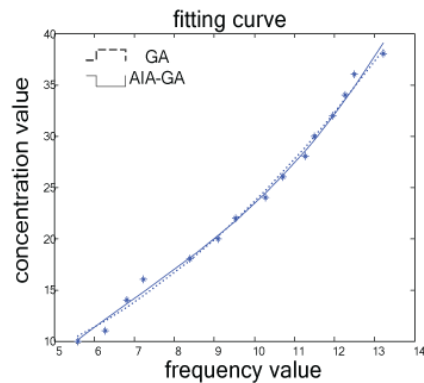


Figure 6. AIA-GA and GA curve fitting

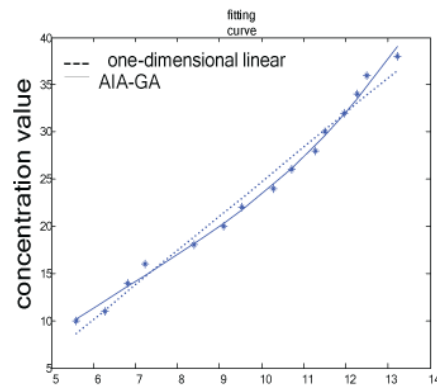


Figure 7. Simple linear regression and GA curve fitting

As can be seen from the figure 6, compared with the GA algorithm, the AIA - GA algorithm of fitting curve effect is better, from figure7 the results showed that a linear regression model with true value is different, which also proves that the nonlinear output of industrial alcohol concentration by the method of capacitance method.

In order to validate the model, using the same method in the same concentration range, 5 groups of industrial alcohol and water mixture were selected, and the predicted value of dl was obtained by using the mathematical model. The whole system was evaluated by comparing dl and ds.

Table 3. Five group theoretical value and the actual value and the relative error

Actual concentration ds	GA algorithm			AIA-GA algorithm		
	Measured dl	δ	T	Measured dl	δ	T
13.5	14.168	-0.668	420	13.568	-0.068	110
20.8	20.592	+0.208		20.612	+0.188	
25.3	25.754	-0.454		25.683	-0.383	
31.5	31.458	+0.042		31.534	-0.034	
35.5	36.653	-1.153		36.253	-0.753	

Table 3 shows that using GA algorithm drop algebra is 310, the average error is 0.505, the maximum error is 1.153, and the GA -AIA algorithm falling algebra is 80, AIA algorithm the average error is 0.2852, the maximum error is 0.753. The results show that the GA - AIA algorithm fitting results than the traditional GA algorithm effect is good, low error, and the convergence speed is fast.

5. Conclusions

Aiming at the problems of large measurement error and low accuracy in measurement of industrial alcohol concentration, a nonlinear correction technique based on improved GA-AIA is presented in this paper. This method combines the advantages of GA algorithm and AIA in convergence efficiency and global search ability, and introduces the concentration mechanism and immune operator in GA algorithm, which overcomes the shortcomings of its own existence, such as premature and low efficiency. The experimental results show that the nonlinear correction algorithm based on GA-AIA can make the nonlinear correction process of the capacitive sensor have the advantages of global optimization and accuracy, and can accelerate the convergence speed, and it has some application value in engineering.

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