Orthogonal Optimization Algorithm in Application to Circuit Design

Swarm Intelligence Algorithm Based on the Analysis of Variance Ratio

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***Abstract*—This paper put forward a novel intelligent algorithm of orthogonal design for circuit parameters. The intelligent orthogonal optimization differs from conventional orthogonal design. According to variance and variance ratio analysis of the orthogonal design, the next searching direction and range of each variable are determined, which is able to be circulating in the optimization of searching. The intelligent orthogonal optimization is performed until error value of the variance ratio for each variable is zero, namely the calculation is terminated when the variance ratio of each variable is approximately equal, which is the optimal solution. Correspondingly, the variable range of the orthogonal array in preceding step is the tolerance of the optimal solution. The characteristic of this method is no need for special tolerance design. The tolerance of optimal solution is obtained when the parameter design is completed. In contrast with general orthogonal design method and other optimization methods of Genetic algorithm (GA)， particle swarm optimization （PSO）, and so on, the intelligent orthogonal optimization has the advantage of less calculation time, higher speed, no exiting of prematurity of local circulation and slow convergence of global search. A circuit of the regulated power supply serves as optimization design paradigm in this paper. The calculation process and result show that this method is simple and practical, and also it will have a useful application prospect in the field of circuit design.**

Keywords- swarm intelligence; orthogonal design; variance ratio; Circuit Design

I. INTRODUCTION

In the design and production of the integration circuit and separation circuit, the designers always hope that the circuit with high performance and high production yield is designed. The performance of a specific circuit is multifaceted, such as static characteristics, transient characteristics， alternating current characteristics and so on. Designers seek for possible optimal properties of the circuit to meet the design index. Circuit parameters optimization is one of research directions.

Three Stage Design Team of Chinese Association for Applied Statistics published Three Stage Design for Incomputable project[1] in 1985. In this book Three Stage Design based on orthogonal array is applied to the optimization design of circuit parameters. The three stage design is known as the Taguchi method.

Yu Daoheng[2](1987) presented the method of optimal design by means of orthogonal array for parameters of electronic circuit. Zhang jiancheng and Yu Daoheng[3](1990) established a new mathematical model for circuit tolerance design, which is based orthogonal array.

Fathi Yahya[4](1991) proposed an algorithmic strategy for solving the parameter design problem. An illustrative numerical example, discussing the design of a Wheatstone bridge, is presented, which is the same example used by Taguchi to illustrate the orthogonal array method.

Okura T., Kanai M., Ogata S., Takei T. and Takakusagi H.[5](1995) described an evaluation technique for solder paste printability using a solder paste inspection system and optimization of printing parameters. They presented a printability evaluation adopted procedure based on the quality engineering (TAGUCHI method).

Tagawa Kiyoharu, Masuoka Mikiyasu and Tsukamoto Masahiko[6](2005) presented a robust optimum design approach to tackle the structural design of surface acoustic wave (SAW) filters. For deciding an optimal structure of SAW filters based on the computer simulation, the equivalent circuit model of IDT, which includes several uncertain parameters, has to be utilized. In order to cope well with the designing imperfections caused by the inevitable dispersion of these uncertain parameters the Taguchi method is employed.

Li Guomei and Mai Yunfei[7](2011) studied the design of voltage stabilizing circuit, which is based on orthogonal experiment.

Fahsyar Puteri Nor Aznie and Soin, Norhayati[8](2012) outlined the Taguchi optimization methodology, which is applied to optimize the significant parameters in designing the radiofrequency identification (RFID) tag rectifier. The design parameters evaluated are size of transistor (W/L), number of stage (N), and capacitor (C) which realized could gain the circuit performance.

Cai Jinding, Ma Xikui and Huang Dongquan[9](2000) presented a genetic algorithm method for computing parameters of experimental circuits, which can be used to compute parameters of lower voltage experimental circuits accurately.

Han li, Hu Yi and Yao Lianfu[10](2003) improved a combining genetic algorithm with simplex method in optimum assignment for circuit component tolerance.

Chen Yu and Zheng Lixin[11](2010) used adaptive genetic algorithm to track genetic parameters of evolutional process and adjust corresponding strategy based on typical filter circuit structure.

Fu Zhong yun and Cai Jin ding[12](2006) proposed particle swarm optimization algorithm to compute parameters of lower voltage experimental circuits .

To solve the problems of nonlinear distortion and safety caused by high heat when power transistors work in normal state, Fang Zhenguo，Chen Debao and Yang Yijun[13](2012) proposed the particle swarm optimization algorithm to optimize the parameters of the circuit based on the global convergence.

Genetic Algorithm (GA) and particle swarm optimization （PSO）are currently very popular intelligent optimization algorithm. They have some defects more or less such as long searching time, much calculation amount, being prone to trap in premature local loop, slow speed of global convergence and so on. To improve the speed of global convergence and the accuracy of the optimization of searching, The worldwide researchers introduced lots of modified algorithm and admixture algorithm.

Because the characteristic of the orthogonal array is homogeneous dispersion and regular comparable, the orthogonal design is provided with the capability of rapid global searching. Generally speaking, the actual optimal solution cannot be found out by traditional orthogonal optimization. To overcome this shortcoming, we proposed a new orthogonal optimization algorithm[14,15]. The new algorithm not only breaks the limitation of only once searching in the orthogonal optimization, but also finds out the method of confirmation for further searching direction and searching scale of orthogonal optimization which is based on the variance analysis and variance ratio analysis of orthogonal design.

II. PRINCIPLE AND ALGORITHM[16]

As we know, although the orthogonal design has been widely used, but has obvious defects. This method is only suitable to obtain the optimal solution of the current finite parameters, which is usually not the optimal solution for the engineering purposes. Both variance analysis of orthogonal design and F test indicate the significance of variables, and they generally are used to choose the optimal composition from the variable parameters which is already known. If new analysis of variance ratio is developed in the variance analysis of orthogonal design, the useful information in the variance analysis will be utilized completely. Meanwhile, the variance ratio analysis also will give the searching direction and searching scale for the additional orthogonal optimization. Until the variance ratio of every variable reaches to zero or equal, the orthogonal intelligent optimization does not continue. According to the analysis result of the variance ratio, new orthogonal array will be composed by the selected variable parameters of final orthogonal array. Circulating optimization search and sequential circulation, the optimal solution does not be found until the error term of every variable in the variance analysis is zero which is to say the variance ratio of different variables is equal wholly to each other.

The algorithm has the following steps:

A. Selection of orthogonal array

The orthogonal array $L_a(b^c)$ is an important tool for this intelligent algorithm, where b is the level number of the variable in the problem, a is the line number of orthogonal array, as well as c is the column number of orthogonal array. Suitable orthogonal array $L_a(b^c)$ should be selected by the variable dimension n. The principle to be obeyed is the variable dimension n of the resolved problem is less than the column number c of orthogonal array. Generally, $L_{25}(5^6)$, $L_{50}(5^{11})$, $L_{49}(7^8)$, $L_{81}(9^{10})$, $L_{121}(11^{12})$ and $L_{169}(13^{14})$ are selected to be used. When $n \leqslant 5$, the orthogonal array $L_{25}(5^6)$ is usually selected because this array with level number five is prone to judge the direction of optimization searching. For the function problem with high or super-high dimension, hyper-saturation random orthogonal array should be selected (the detail principle and steps will be represented in addition).

B. Disposal of intelligent constraint

Most of the optimization problems are constrained problems. However, intelligent optimization algorithms are basically aiming at the unconstrained optimization problems and the corresponding random optimization algorithm is presented. Therefore, the constrained optimization problems should be combined with constraint handling techniques. According to the characteristics of orthogonal optimization method, the permanent penalty function method with laminate penalty factor can be adopted to solve the problem. That is to say, the more the breach values of constraint, the more the penalty factor. It can be also solved by dominating selection techniques of multi-objective.

C. Swarm encode method

In order to be suitable for various practical problems, various admixture variables such as continuous variable, discrete variable, integer variable and real variable and so on are adopted to encode, so the code transfer is not necessary any more. The selection principle of this encode type is that the original configuration and property of the variable in practical problems should not be changed, in order to be used suitably and to improve the resolved efficiency.

D. Individual homogeneous initialization

According to the definition domain interval of the individual variable x, the individual initial value with number of b should be randomly selected all of the variables. For initial searching can be done in a larger range, all variables should be homogeneously divided into the individual initial value with number of b.

E. Swarm homogeneous initialization

In order to form the orthogonal initialized swarm $\mathbf{X}_{0b}$ which is the homogeneous distribution group with the number of a, all of the individual variables are arrayed in subsequence based on the arrangement typical of the orthogonal array $L_a(b^c)$.

F. Search of initialized swarm[J]

Every initialized swarm group should be calculated against the objection function and the constraint conditions respectively, while the analytical calculation based on the variance analysis method of orthogonal design should be done and the analysis of variance ratio should be added. The traditional analysis method of variance is the F test. Mr. Taguchi put forward the concept of the variance ratio, and proposed that the variance ratio can be used for quantitative analysis of the significance test. Instead of the F test, we use the variance ratio of factors to analyze variance.

Because the result of variance ratio analysis includes the conclusion resulted from the test of significance of F test, the F test in variance analysis of orthogonal design is not necessary any more. After the variance analysis, the optimal group of individual swarm $\mathbf{X}^*=(x_1^*,x_2^*,\cdots,x_b^*)$ should be found out based on the consequence of the variance analysis.

G. Orthogonal intelligent optimization

When not all of the variance ratio of every variable reach to 0, the orthogonal intelligent optimization will be necessary. With the centre of the variable x in the current optimal group and the range of the variance ratio of every variable, a new orthogonal array will be formed while the value is selected as table Ⅱ. Proceed with calculation of optimization searching, variance calculation, variance ratio analysis and sequential circulation, the optimal solution does not be found until the error term of every variable in the variance analysis is 0 or sub equal.

III. ENGINEERING APPLICATION

In order to compare, take an example of the regulated power supply which is optimized by Liu Sui-shui [17] (1992) .

The 5v operating voltage is commonly used by computer digital circuits. Its accuracy is 5±1%. According to the design requirements, the series linear regulator circuit is used. Its schematic diagram is as shown in Fig 1.

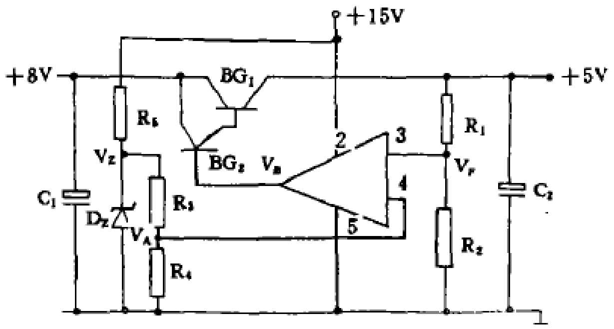

Figure 1. Schematic diagram of series linear regulator circuit

Technical requirements:
Output voltage =5±0.05 v
Output current=1 A

The value of output voltage can be computed from

$$V=(1+\frac{R_1}{R_2})(\frac{R_4}{R_3+R_4})V_E-\frac{R_1+R_2}{AR_2}V_{BE} \qquad (1)$$

where

V_E= regulated value of voltage regulator tube =6.02v
V_{BE}= base and emitter voltage of compound triode=0.7v
A= magnification of operational amplifier
R_1,R_2,R_3,R_4= value of resistance

The accuracy of output voltage can be estimated from

$$\min f(\mathbf{x})=|V-5|$$
$$\mathbf{x}=(x_1,x_2,x_3,x_4,x_5)^T=(R_1,R_2,R_3,R_4,A)^T \qquad (2)$$

Table Ⅰ presents a range of parameter values. The value of resistance is discrete variable. The resistance value is chosen from E24 series of the International Engineering Consortium (IEC).

TABLE I. RANGE OF PARAMETERS VALUES

Parameters	Range of values	Precision class
R_1	30~130 Ω	±5%
R_2	680~1500 Ω	±5%
R_3	680~1500 Ω	±5%
R_4	2700~3900 Ω	±5%
A	2000~10000	±50%

We use the orthogonal array $L_{25}(5^6)$ to solve the problem. The solving process is in Table Ⅱ and Table Ⅲ. Stop calculating when the accuracy of engineering problems is met. The accuracy is computed by maximum deviation of variable tolerance in Table Ⅲ.

The optimal result is: $x_1=R_1=36\pm1.8$, $x_2=R_2=680\pm34$, $x_3=R_3=1100\pm11$, $x_4=R_4=3600\pm36$, $x_5=A=2500\pm1250$, $f(\mathbf{x})$=0.000055614v, accuracy = 0.77%.

The result in [17] is: $x_1=R_1=51\pm2.5$, $x_2=R_2=1000\pm50$, $x_3=R_3=1000\pm10$, $x_4=R_4=3300\pm33$, $x_5=A=10000\pm5000$, $f(\mathbf{x})$=0.000731v, accuracy = 0.77%.

IV. CONCLUSION

A new intelligent algorithm of orthogonal design for circuit parameters is proposed, which differs from general orthogonal design. This algorithm uses the characteristic of orthogonal design, which is easy to find the optimal variable composition of the current optimal value and to find the variable interval which includes the optimal solution in one arrayed calculation. The calculation steps may be as follows:

a) For a problem to be optimized, chooses orthogonal array and initial design parameters.

b) The preliminary design parameters are firstly calculated by an orthogonal array.

c) The searching direction and searching scale of contemporary parameters are secondly determined by the variance ratio, and so the orthogonal array for further optimization is formed intelligently.

d) The intelligent orthogonal optimization is performed until error value of each variable is zero, namely the calculation is terminated when the variance ratio of each variable is equal, which is the optimal solution.

e) Correspondingly, the variable range of the orthogonal array in preceding step is the tolerance of the optimal solution.

Compared with conventional orthogonal design and other optimization algorithm, this method has more merit, such as the less searching time, less amount of calculation and slow convergence of global search and no exiting of prematurity of local circulation. Therefore, the orthogonal optimization algorithm will make a better application use in the field of circuit design.

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TABLE II. THE ORTHOGONAL ARRAY $L_A(B^C)$ AND THE INDIVIDUAL VALUE OF SELECTED VARIABLES X_{1I}, X_{2I}, X_{3I}, X_{4I}, X_{5I} IN A SEQUENCE

Seq.	$L_a(b^c)$	b	x_{1i}, i=1,2,⋯,b	x_{2i}, i=1,2,⋯,b	x_{3i}, i=1,2,⋯,b	x_{4i}, i=1,2,⋯,b	x_{5i}, i=1,2,⋯,b
1	$L_{25}(5^6)$	5	30, 51, 82, 100, 130	680, 910, 1100, 1300, 1500	680, 910, 1100, 1300, 1500	2700. 3000, 3300, 3600, 3900	2000, 4000, 6000, 8000, 10000
2	$L_{25}(5^6)$	5	30, 33, 36, 43, 51	680, 750, 820, 910, 1000	910, 1000, 1100, 1200, 1300	2700, 3000, 3200, 3300, 3600	2000, 2500, 3000, 3500, 4000
3	$L_{25}(5^6)$	5	34.2, 35.64, 36, 36.36, 37.8	646, 673.2, 680, 686.8, 714	1045, 1089, 1100, 1011, 1155	3420, 3564, 3600, 3636, 3780	1250, 1875, 2500, 3750, 5000
4	$L_{25}(5^6)$	5	34.2, 35.64, 36, 36.36, 37.8	646, 673.2, 680, 686.8, 714	1045, 1089, 1100, 1011, 1155	3564, 3582, 3600, 3618, 3636	1250, 1875, 2500, 3750, 5000
5	$L_{25}(5^6)$	5	34.2, 35.64, 36, 36.36, 37.8	646, 673.2, 680, 686.8, 714	1089, 1095, 1100, 1105, 1011	3564, 3582, 3600, 3618, 3636	1250, 1875, 2500, 3750, 5000

TABLE III. THE OPTIMAL VALUE OF $F(X_1, X_2, X_3, X_4, X_5)$, THE CORRESPONDING OPTIMAL VARIABLE X_1, X_2, X_3, X_4, X_5,AND THE VARIANCE RATIO P

Seq.	$f(x_1, x_2, x_3, x_4, x_5)$	accuracy	x_1	x_2	x_3	x_4	x_5	ρ_{x1}	ρ_{x2}	ρ_{x3}	ρ_{x4}	ρ_{x5}	ρ_e
1	0.1040	20.67%	36	820	1100	3000	4000	—	—	022182	0.09159	0.17169	0.51489
2	0.0000556	13.27%	36	680	1100	3600	2500	—	0.04159	0.43095	0.22631	—	0.30116
3	0.0000556	2.59%	36	680	1100	3600	2500	0.14587	0.07245	0.09523	0.20590	0.14794	0.33259
4	0.0000556	1.72%	36	680	1100	3600	2500	—	—	0.73638	0.04625	0.06419	0.15317
5	0.0000556	0.77%	36	680	1100	3600	2500	—	—	0.16703	0.17862	0.50148	0.15286