Reliability Analysis of Automobile Frontal Collision based on Particle Swarm Optimization

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Abstract

In this paper, particle swarm optimization (PSO) is used to analyze the reliability of a vehicle frontal collision problem. The reliability index mathematical model is constructed by introducing interval uncertainty and parameter correlation. For constrained optimization problem, augmented Lagrangian multiplier method is used to transform it into unconstrained optimization problem, and particle swarm optimization algorithm is used to obtain the optimized solution. The results show that PSO can solve the problem of complex reliability mathematical model with certain nonlinear limit state equation, parameter uncertainty interval and parameter correlation, and has good calculation efficiency and convergence. The feasibility of the present algorithm is verified by numerical results.

Keywords

Particle Swarm Optimization; Correlation; Uncertainty Interval; Reliability Analysis; Augmented Lagrangian Multiplier Method.

1. Introduction

With the development of industry, automobile has become the main means of transportation. The increasing number of cars has also led to a large number of traffic accidents. In order to reduce traffic accidents and find traffic hidden dangers in advance, more and more scholars pay attention to the reliability analysis of vehicle collision. In reliability analysis, there are many uncertain factors, such as the properties of materials, splicing process and manufacturing accuracy. Traditional methods are difficult to solve these problems, so the research of intelligent algorithm is particularly important. In recent years, experts and scholars have conducted in-depth research on this issue [1-6]. Wang et al. combined BP neural network with particle swarm optimization algorithm, and put forward a new reliability evaluation method of landslide [7]. Liu et al. put forward a unit commitment model, which considers its economy and reliability, and used the most reliable index of system reliability to calculate. At the same time, the validity of the model is verified by using adaptive genetic algorithm [8]. Shen et al. put forward an improved artificial bee colony search algorithm to analyze the reliability of key parts of rolling stock and make a scientific plan for the maintenance cycle of rolling stock [9]. Xu et al. analyzed the non-probabilistic reliability optimization problem of interval model by using the improved moth flame algorithm for the more complex reliability double nesting problem, which provided a new research idea for the non probabilistic reliability optimization of engineering structure [10].

Through the research of the above scholars, this paper studies the vehicle frontal collision problem in reliability optimization. The mathematical model with uncertainty interval and parameter correlation is established, and particle swarm optimization algorithm is used for calculation. Through the analysis, we know that PSO can solve the reliability problem of nonlinear equation to some extent. In this paper, an example of automobile frontal collision is given to verify the effectiveness of the present method for reliability calculation with parameter correlation and uncertainty interval.

2. Introduction of particle swarm optimization algorithm and establishment of reliability index

2.1 Introduction of particle swarm optimization algorithm

Particle swarm optimization (PSO) is a global search intelligent algorithm inspired by artificial life intelligence (AI), which is proposed by Kennedy and Eberhart. The algorithm builds a mathematical model by simulating the migration and clustering behavior of birds. In this mathematical model, each bird is regarded as a particle and has its own flight experience. The individual's flight experience will be updated with the group's flight experience, and thus it changes the individual's flight route and approaches the best. The updating formula of particles is given as follows:

$$v^{t+1}(i,k) = \omega v^t(i,k) + c_1 rand[p^t_{best}(i,k) - x^t(i,k)] + c_2 rand[g^t_{best}(k) - x^t(i,k)] \quad (1)$$

$$x^{t+1}(i,k) = x^t(i,k) + v^t(i,k) \quad (2)$$

i represents the i -th particle; k represents the k -th coordinate component of the space point where the particle is located; superscript t represents the t -th iteration; ω represents the inertia weight, with the value range of $0.1 \sim 0.9$; c_1, c_2 represents the acceleration constant, with the value range of $1 \sim 2$; $rand$ represents the random function, with the value of $0 \sim 1$.

2.2 Parameter correlation and reliability index establishment

It is assumed that the limit state equation of the actual engineering structure is expressed as $Z = g(X_1, X_2, \cdots, X_n) = 0$, in which $X_1, X_2, \cdots, X_n$ is independent random variable with arbitrary distribution. $R - F$ (lakowitz fissley method) is used to normalize the equivalent of nonnormal variables, and the normal distribution variables such as mean σ'_{xi}, standard deviation μ'_{xi} and reliability index β are respectively derived as follows.

$$\sigma'_{xi} = \phi\{\Phi^{-1}[F_{xi}(xi^*)]\}/f_{xi}(X_i^*) \quad (3)$$

$$\mu'_{xi} = X_i^* - \Phi^{-1}[F_{xi}(xi^*)]/\sigma'_{xi} \quad (4)$$

$$\beta = \left(\sum[(X_i^* - \mu'_{xi})/\sigma'_{xi}]^2\right)^{1/2} \quad (5)$$

The initial design point is unknown. If the minimum reliability index value β is required, β should be regarded as a function of the point $P(X_1, X_2, \ldots, X_n)$ on the surface of the limit state equation. The design point P and the minimum reliability index β are derived. The mathematical model of reliability index is established as follows:

$$Min\beta^2 = \sum_{i=1}^{n}[(X_i^* - \mu'_{xi})/\sigma'_{xi}]^2 \quad s.t. Z = g(X_1^*, X_2^*, \ldots, X_n^*) = 0 \quad (6)$$

The correlation of parameteris very common in the actual engineering structure, and there is often obvious correlation between these structural parameters. Random variables X_i and X_j are used to describe the correlation degree, and the correlation coefficient $\rho_{X_iX_j}$ is[11]:

$$\rho_{X_iX_j} = \frac{E[(X_i - \mu_{X_i})(X_j - \mu_{X_j})]}{\sigma_{X_i}\sigma_{X_j}} = \frac{E(X_iX_j) - \mu_{X_i}\mu_{X_j}}{\sigma_{X_i}\sigma_{X_j}} \quad (7)$$

In the reliability analysis, the parameter correlation will have a great influence on the reliability index. If the function function can be expressed as the linear function of the normal random variable $x_1, \cdots, x_n$, that is:

$$Z = a_0 + a_1X_1 + \cdots + a_nX_n \quad (8)$$

Then the reliability index can be expressed as:

$$\beta = \frac{a_0 + a_1\mu_{X_1} + \cdots + a_n\mu_{X_n}}{\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i\sigma_{X_i}\rho_{X_iX_j}\sigma_{X_j}a_j}} \quad (9)$$

3. The reliability calculation of automobile frontal collision

According to the reliability analysis of the vehicle frontal collision example in [12], when the vehicle frontal collision, the vehicle head is impacted by the force, which is the main deformation area of the vehicle. Through the analysis of the thickness d_1 of the front anti-collision beam, the thickness d_2 of the inner plate of the energy absorption plate, the thickness d_3 of the outer plate of the energy absorption plate, the thickness d_4 of the inner plate of the front longitudinal beam, the thickness d_5 of the outer plate of the front longitudinal beam, and the elastic modulus P of the front anti-collision beam as the design variables, the energy absorbed E by the energy absorption box is taken as the safety index, and the minimum reliability index mathematical model is established. The finite element model of 100% frontal impactis shown in Fig.1, the design variable parameters are shown in Table 1, and their corresponding distribution is shown in Table 1. The limit stateequation is given as follows:

$$g = E(d_1, d_2, d_3, d_4, d_5, P) \tag{10}$$

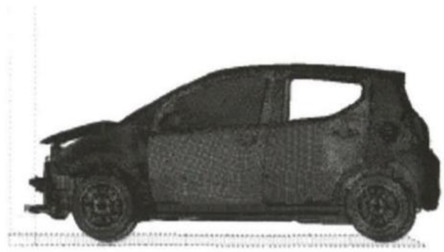

Fig. 1 The finite element model of 100% frontal impact

Table 1. The computaional results of two methods

Variable	Mean value	Standard deviation
d_1	0.7	0.07
d_2	1.6	0.12
d_3	1.6	0.12
d_4	1.5	0.1
d_5	1.6	0.12
P	210	20

Using particle swarm optimization algorithm to calculate the reliability index value of the example in this paper, the calculation results are shown in Table 2, and the iterative process is shown in Fig.2.

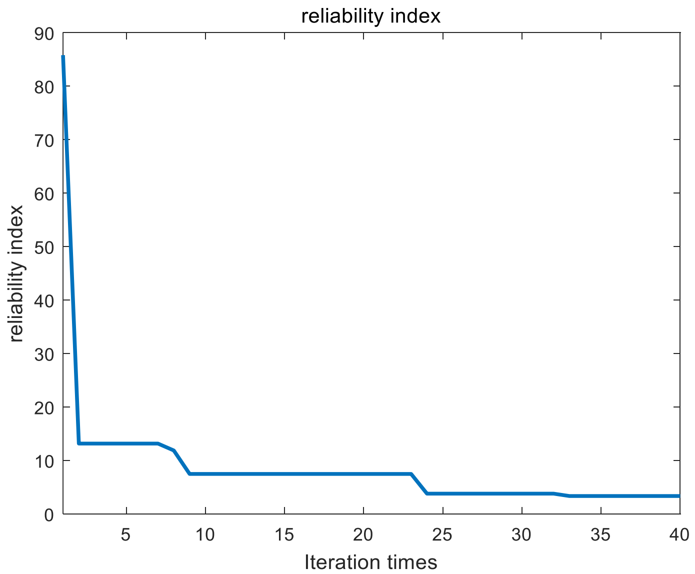

Fig. 2 Iterative process of differential evolution algorithm

Table 2. The computational results

Reliability index	Failure probability	Iteration times
3.2562	5.6457e-04	33

It can be seen from Fig. 2 that through particle swarm optimization algorithm, the stable reliability index value β = 3.2562 and the failure probability P_f = 5.6457e-04 are obtained in 33 steps, and the stable value is obtained by particle swarm optimization algorithm with fewer iterations, which proves the feasibility of the present algorithm for reliability index calculation. In the actual engineering structure, the parameters often have certain uncertainty. Considering the different uncertainty of vehicle structure parameters, the reliability index value is calculated,and the results are shown in Table 3, and the curve of reliability index and uncertainty of related parameters is shown in Fig. 3.

Table 3. Change table of reliability index with uncertainty of relevant parameters

Uncertainty of parameters/%	β Change range	β Uncertainty
5	[3.1456,3.3369]	5.87
10	[3.0349,3.4468]	12.65
15	[2.9621,3.5611]	18.39
20	[2.8438,3.6521]	24.82

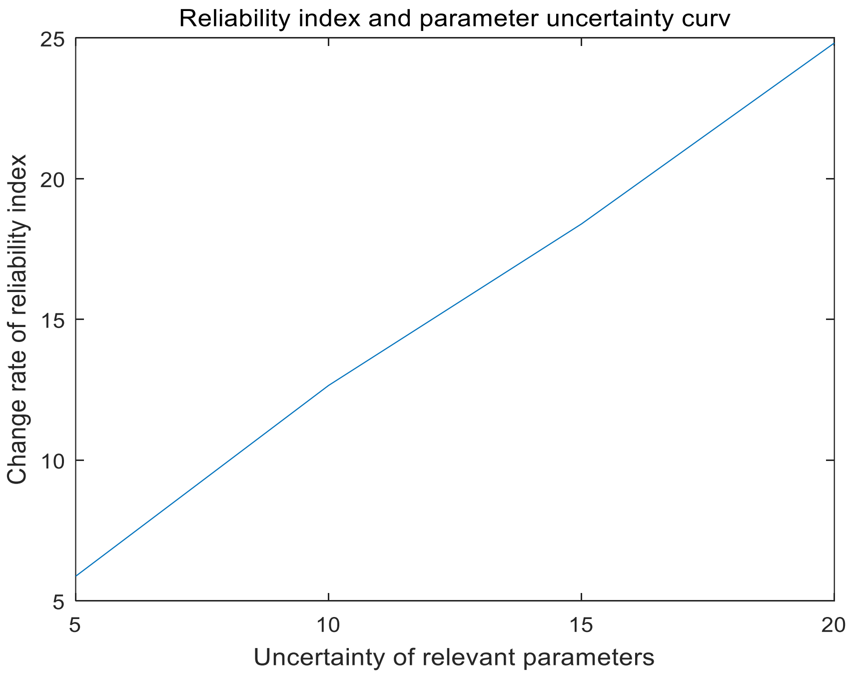

Fig. 3 Reliability index and uncertainty curve of related parameters

It can be seen from Fig. 3 that after the uncertainty interval is added, the result of reliability index changes, and there is a positive correlation. The reliability index increases with the increase of the uncertainty interval.

In practical engineering, the structuralparametersare often not independenteach other, but there will be a certain correlation. In this paper, it is considered that there is a correlation between the thickness d_2 of the inner plate of the energy absorption plate and the thickness d_3 of the outer plate of the energy absorption plate. The correlation coefficient $\rho_{d_2 d_3}$= 0.8 is set to analyze the effect of the parameter correlation on the reliability index. The comparison between consideringthe parameter correlation and withoutconsidering the parameter correlation is shown in the Fig.4.

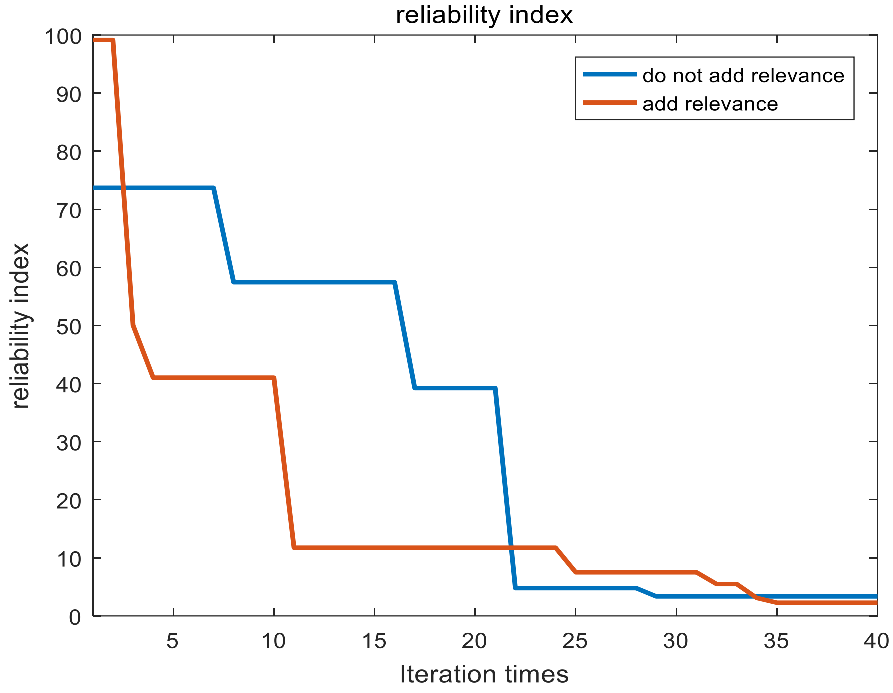

Fig. 4 Contrast chart with and without correlation

The reliability index β =2.2737 after the parameter correlation is added, which has a great change compared with the no correlation β = 3.2562, and the change rate of reliability index is 30.2%. In both cases, the PSO algorithm obtains the stable reliability index in a few iterations, which verifies the feasibility of the PSO algorithm for calculating the reliability index under this condition. The addition of parameter correlation will have a significant impact on the calculation of reliability index. In engineering structure, it is very important and necessary to consider the correlation of parameters.

4. Conclusion

In this paper, the particle swarm optimization algorithm is used to solve the reliability analysis problem of vehicle frontal collision. The reliability index value is obtained, and the uncertainty interval of parameters and the correlation of parameters are considered respectively. After the parameter correlation is added, the reliability index value is reduced by 30.2%, resulting in a large fluctuation, which shows the importance of considering the parameter correlation in the actual structure. The Particle swarm optimization (PSO) algorithm can solve the problem of complex reliability mathematical model with certain nonlinear limit state equation, parameter uncertainty interval and parameter correlation. In the practical engineering structure, the particle swarm optimization algorithm has a certain guiding significance for the reliability calculation of the structure.

Acknowledgments

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References

[1] S.Y. Zhuo, W.Y. Tang, H.B. Yan, Analysis of the influence of optimization algorithm on ship reliability, Ship Science and Technology 11 (2019) 32-36.(In Chinese)

[2] L.J. Wang, Y.X.Xie, Z.J. Wu, Y.X. Du, K.D. He, A new fast convergent iteration regularization method, Engineering with Computers 35 (2019) 127–138.

[3] L.J.Wang, L. Xu,Y.X.Xie, Y.X. Du, X. Han, A new hybrid conjugate gradient method for dynamic force reconstruction, Advances in Mechanical Engineering 11 (1) (2019) 1–21.

[4] L.J. Wang, J.W. Liu, Y.X.Xie, Y.T. Gu, A new regularization method for the dynamic load identification of stochastic structures, Computers and Mathematics with Applications 76 (2018) 741–759.

[5] L.J. Wang, Y.X.Xie, Q.C. Deng, The dynamic behaviors of a new impulsive predator prey model with impulsive control at different fixed moments, Kybernetika54 (2018) 522-541.

[6] S.H. Wang, Research on software reliability model based on improved harmony search algorithm, The Journal of Shandong Agriculture and Engineering University 6 (2019) 15-16.(In Chinese)

[7] B.L. Wang, F.L. Meng, C. Zeng, J. Guo, X. Liu, Reliability evaluation method of landslide based on PSO-BP neural network of natural selection strategy, Journal of China & Foreign Highway 3 (2019) 1-9.(In Chinese)

[8] X.C. Liu, Y.L. Zhu, R. Deng, Y.J. Zhai, Unit commitment model and algorithm considering system economy and reliability, Smart Power 7 (2019) 8-14.(In Chinese)

[9] G.Q. Shen, D.Q. He, W.J. Tan, J. Miao, Reliability research on key parts of locomotive and vehicle based on improved artificial bee colony algorithm, China Mechanical Engineering 3 (2018) 279-285.(In Chinese)

[10] G.N. Xu, S.Y. Huang, Z.Y. Tang, T. Xu, Interval non probabilistic reliability optimization design based on improved moth flame algorithm, Machine Design & Research 4 (2018) 37-40.(In Chinese)

[11] J.T. Yao, Z.P. Dong, Correlation of random variables and structural reliability,Journal of Xi'an University of Architecture & Technology(Natural Science Edition) 2 (2000) 114-118.(In Chinese)

[12] Q. Wang, Z.L. Liang, Reliability optimization design of vehicle frontal impact with mixed uncertainty of probability interval,Automotive Engineering 5 (2019) 545-549.(In Chinese)