Simulation Study on the Prediction of Dangerous Conditions for Occupant in a Running Vehicle Equipped with Airbag

Weigang ZHANG[1] Ding CHEN[2]

[1]State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, China, zhangwg@hnu.edu.cn

[2]Hunan University, Changsha, China, 13787116236@163.com

Abstract: Generally, when a vehicle is equipped with an airbag, crash tests are conducted to check the performance of the airbag on certain defined conditions. Even if the performance of the airbag is perfect during the test, it may hurt vehicle occupant in reality traffic due to changed boundary conditions, such as the out-of-position occupant. This paper has built a simulation model for occupant and restraint system including an airbag by using MADYMO software, and conducted the crash simulation for a combination of different boundary conditions: different size dummies, different sitting positions, and different crash speed. According to the results of the MADYMO simulations, a metamodel was constructed and validated, through which all the dangerous conditions for vehicle occupant could be predicted by using NSGA-II genetic optimization algorithm. The results of this research will be useful in further intelligent airbag system development.

Keywords: Simulation Study, Prediction of Dangerous Conditions, Vehicle Occupant, Airbag, Metamodel

1. Introduction

Airbag is an important safety system for vehicle occupants when crash accident happens, and its protection effects have been widely approved[1,2]. However, airbag can also be a potential dangerous object for occupants. Recently, occupant injury caused by airbag has happened frequently. For example, in a rear end collision accident which was not serious, a 10 years old child who sat in the front side seat was injured by the expanding airbag[3]. That is to say, airbag is not absolutely safe. Then, it is necessary to know when the airbag is safe and when it is not[4-6].

From laboratory tests and computer simulation[7], it has been found that airbag's protection effect is affected by boundary conditions, such as vehicle crash speed, occupant size and sitting position, etc, that is to say, for a vehicle with very good crash test results, when it runs on road, it may not be safe for out-of-position occupant[5]. Thus for a vehicle equipped with airbag, it is necessary to investigate the safe and unsafe conditions.

This paper established a vehicle's crash simulation model by using MADYMO software. In order to investigate the safe condition and unsafe condition, a series of simulations were conducted, based on which the metamodel was constructed and validated. By using NSGA-II genetic optimization algorithm[8], Pareto solutions were obtained, which means that safe conditions and unsafe conditions were successfully predicted, which is useful for further intelligent restraint system development.

2. Methods

2.1 Establishing and Validating of Simulation Model

A car is taken as an investigation model. A MADYMO simulation model has established including the occupant compartment, restraint system and dummy. The restraint system includes seatbelt and airbag, and the dummy has three kinds of Hybrid III 50 percent male, 95 percent male, and 5 percent female[9]. The established model is shown as Figure 1.

This project is supported by NSFC(NO.51275164)

After the simulation model is established, it is necessary to validate the model. Full vehicle crash test data are used for the simulation model. B pillar acceleration curve, in the following Figure 2, is used for model input and the simulation results, such as the dummy's head impact acceleration curve, chest acceleration curve and chest compression are utilized to compare with the test results.

Figure 1: Computer simulation model

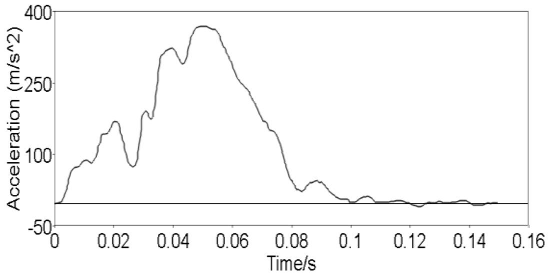


Figure 2: B pillar acceleration curve

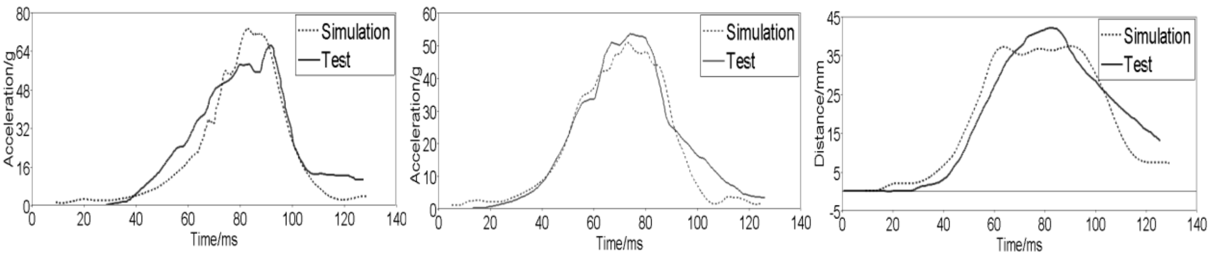
The comparisons of simulation and test results are indicated in Figure 3, from which it can be seen that the curve shapes, peak values and the corresponding time are coincident, errors are within the range of 15%. Therefore, the established simulation model can be used to replace the real car for further study.

2.2 Boundary Conditions for Simulation

In this study, the seat fore-and-aft position, dip angle of seatback and vehicle running speed are chosen as the boundary elements, the values of the boundary conditions are listed in Table 1.

Table 1: Values of boundary conditions

condition	Lower limit	Upper limit
Seat position / mm	-180	+20
Dip angle of seatback/deg	-12	+12
Running speed/(km/h)	40	100



Comparison of dummy's head acceleration

Comparison of dummy's chest acceleration

Comparison of dummy's chest compression

Figure 3: Comparison of model simulation and crash test

In Table 1, the values of seat position and seatback dip angle can be directly used as input data in the simulation model, while the values of running speed need to be transformed to a series of crash pulses in order to simulate collision in MADYMO[10]. A small part of sample crash pulses are shown in Figure 4.

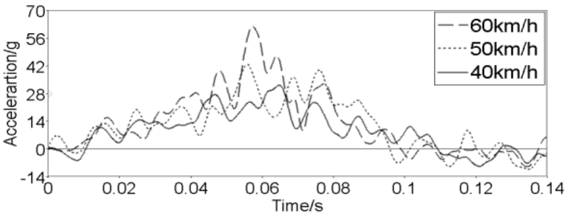


Figure 4: Simulated crash pulses

3. Metamodel

Since simulation model is incapable to predict all safe and unsafe conditions, metamodel is used to replace simulation model[11-13]. In this paper, Kriging model and RBF model[14] are constructed and the corresponding accuracies are compared, and RBF is proved to be the better one which used here to search for Pareto solutions.

However, static metamodel is difficult to get enough local accurate solution, thus, dynamic metamodel is proposed and constructed based on RBF model. The dynamic metamodel is used for the grey area which needs high accuracy[15].

The method of constructing metamodel is as follows:

(1) After boundary conditions are defined, optimized Latin experimental design method is used to take samples, so that the studied parameters are divided uniformly, then the divided parameters are randomly combined, thus the whole design space can be described by using lesser samples. The least samples which are needed to construct metamodel is shown as Eq.(1):

$$N_1 = 2n + 1 \tag{1}$$

Where, N_1 is the least sample number, and n is the design parameter's number.

(2) After static metamodel is established, NSGA-II optimization algorithm is used to search for Pareto solutions and the boundary region. By updating the boundary region and grey area samples, metamodel is updated. The updated samples are defined as follows:

It is assumed that for the q times, sample space is shown as Eq.(2), Eq.(3), Eq.(4):

$$S_q^i = (S_q^{iL}, S_q^{iU}) \tag{2}$$

$$S_q^{iL} = x_{q-1}^{i\ *} - \frac{1}{N_{q-1}} L_{q-1} \tag{3}$$

$$S_q^{iU} = x_{q-1}^{i\ *} + \frac{1}{N_{q-1}} L_{q-1} \tag{4}$$

Where, S_q^{iL} is the lower limit of parameter i for the q times iteration, while S_q^{iU} is the upper limit; $x_{q-1}^{i\ *}$ is the solution of parameter i for q-1 times iteration, and L_{q-1}^i is the design space of parameter i for q-1 times iteration.

(3) For each updated metamodel, validation is necessary. If the error is within 15%, then searching stops; if it is not, then searching continues until the model accuracy meets the requirement. The flow chart is shown as Figure 5.

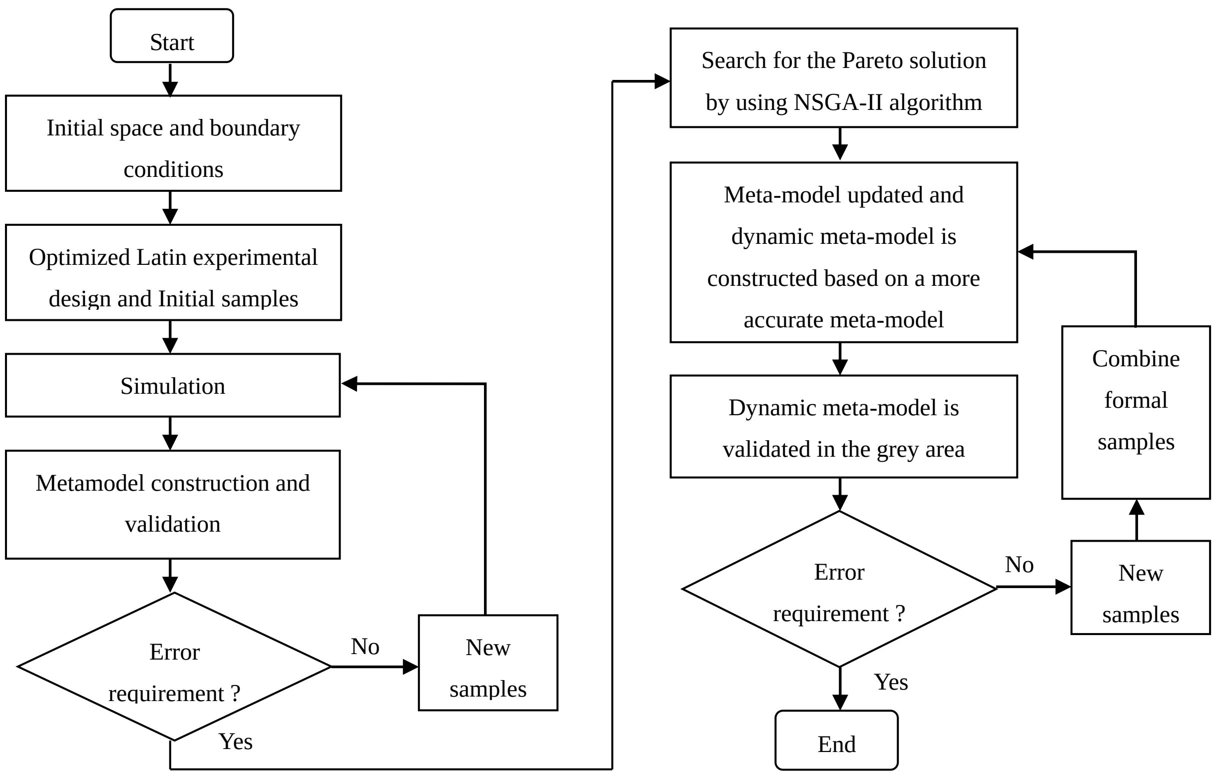


Figure 5: Flow chart of metamodel construction and solution

4. Prediction of Dangerous Conditions

Based on the constructed metamodel, dangerous conditions for the occupant in the running vehicle can be predicted. Head injury index (HIC≤1000), Chest 3ms acceleration value (C3ms≤60g) and Chest compression (D≤45mm) are chosen for the evaluating indicator of risk of danger. If the injury values are within follows, then it is considered that the occupant is in safe condition, otherwise, it is dangerous.

As described above, first step, two static metamodels of Kriging and RBF are constructed. Then, metamodel updated. The accuracies of both static metamodel and dynamic metamodel are compared as shown in Table 2 and Table 3 respectively.

Table 2: Comparisons of static metamodel accuracies

Static Model	Kriging model			RBF model		
	HIC	C_{3ms}	D	HIC	C_{3ms}	D
Sample 1	10.59%	12.21%	0.71%	11.54%	5.72%	10.27%
Sample 2	14.13%	4.53%	0.43%	2.90%	2.21%	0.43%
Sample 3	12.37%	2.64%	14.51%	15.78%	9.11%	4.37%
Sample 4	21.91%	20.46%	4.43%	8.34%	8.13%	1.72%
Sample 5	9.33%	20.59%	3.50%	2.77%	3.26%	0.05%

Table 3: Comparisons of static metamodel and dynamic metamodel accuracies

Static Model	RBF model			Dynamic Model	RBF model		
	HIC	C_{3ms}	D		HIC	C_{3ms}	D
Sample 1	11.54%	5.72%	10.3%	Sample6	0.91%	1.2%	1.05%
Sample 2	2.90%	2.21%	0.43%	Sample7	3.24%	0.66%	0.68%
Sample 3	15.78%	9.11%	4.37%	Sample8	6.5%	2.42%	4.46%
Sample 4	8.34%	8.13%	1.72%	Sample9	4.66%	2.16%	2.28%
Sample 5	2.77%	3.26%	0.05%	Sample 10	5.91%	6.91%	0.86%

From Table 2 and Table 3, it can be seen that the local accuracy of dynamic metamodel is higher than that of static metamodel, RBF model is more accurate than Kriging model, and the dynamic metamodel gets high accuracy in grey area, therefore, RBF model is used for searching the Pareto solution.

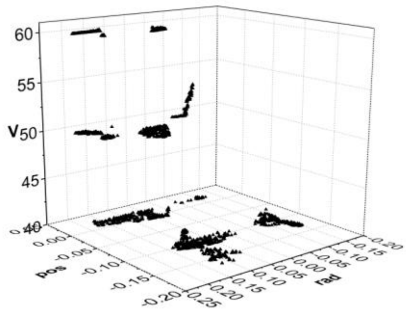


Figure 6: Pareto solution - Safe conditions

Figure 6 shows the Pareto solution, which means the shadow areas are the safe conditions. That is to say, for those areas that is out of the shadows, the occupant faces a high risk of danger if frontal crash happens.

From Figure 6, it can be seen that in most cases for the running vehicle, occupant will face a high risk of danger if frontal collision happens. Thus this study is important and meaningful for protecting occupant by warning based on the simulation data, and it can be sure that future intelligent restraint system is bound to have this function.

5. Conclusion

This paper conducted a study to predict dangerous conditions for occupant in a running vehicle by using computer simulation and metamodel techniques, the results can be a good reference for future further intelligent restraint system development.

6. Acknowledgements

This study is financially supported by National Nature Science Foundation of China, the project number is 51275164.

7. References

[1] Crandall C S, Olson L M, Sklar D P. Mortality reduction with air bag and seat belt use in head-on passenger car collisions. *American journal of epidemiology*, 153(3): 219-224, 2001.

[2] Iyota, Teru, and Toshihiro Ishikawa. The effect of occupant protection by controlling airbag and seatbelt. *Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles*, NHTSA, Nagoya, Japan. 2003.

[3] Braver E R, Scerbo M, Kufera J A, et al. Deaths among drivers and right-front passengers in frontal collisions: redesigned air bags relative to first-generation air bags. *Traffic injury prevention*, 9(1): 48-58, 2008.

[4] National Highway Traffic Safety Administration. Federal Motor Vehicle Safety Standards; Occupant Crash Protection. Washington, DC:National Highway Traffic Safety Administration, US Department of Transportation; 1997.

[5] T. W. Kim and H. Y. Jeong, Stochastic analysis of the variation in injury numbers of automobile frontal crash tests, *Int. J. Autom. Technol*., vol. 11, no. 4, pp. 481–488, Aug. 2010.

[6] Yeh, Isheng, Brian Kachnowski, and Thiag Subbian. *An expert system for vehicle restraint system design*. No. 2005-01-1304. SAE Technical Paper, 2005.

[7] Fu Yan, et al. *A multi-objective optimization and robustness assessment framework for passenger airbag shape design*. No. 2007-01-1505. SAE Technical Paper, 2007.

[8] Deb, Kalyanmoy, et al. A fast elitist non-dominated sorting genetic algorithm for multi-objective optimization: NSGA-II. *Lecture notes in computer science*1917 (2000): 849-858.

[9] Bai Z, Jiang B, Zhu F, et al. Optimizing the passenger air bag of an adaptive restraint system for multiple size occupants. *Traffic injury prevention*, 15(6): 556-563, 2014.

[10] National Crash Analysis Center (NCAC). *Public finite element model archive*; 2001 <www.ncac.gwu.edu/archives/model/index.html>.

[11] Seo Y D, Chung S H, Yoh J J. Automotive airbag inflator analysis using the measured properties of modern propellants. *Fuel*, 90(4): 1395-1401, 2011.

[12] Abdel-Nasser Y A. Frontal crash simulation of vehicles against lighting columns using FEM. *Alexandria Engineering Journal*, 52(3): 295-299, 2013.

[13] Teng T L, Chang F A, Liu Y S, et al. Analysis of dynamic response of vehicle occupant in frontal crash using multibody dynamics method. *Mathematical and Computer Modelling*, 48(11): 1724-1736, 2008.

[14] Hou, S., Tan, W., Zheng, Y., Han, X., & Li, Q. Optimization design of corrugated beam guardrail based on RBF-MQ surrogate model and collision safety consideration. *Advances in Engineering Software*, 78, 28-40, 2014.

[15] Peng, L., Liu, L., & Long, T.Optimization strategy using dynamic radial basis function metamodel. *Chinese Journal of Mechanical Engineering*, 47(7), 164-170, 2011.

[16] ZHONG Zhihua， ZHANG Weigang. *Automobile collision safety technology*. Beijing:China Machine Press， 2003.