Available online at www.sciencedirect.com
ScienceDirect
Advances in Engineering Software 39 (2008) 459–465
ADVANCES IN ENGINEERING SOFTWARE
www.elsevier.com/locate/advengsoft

Vehicle crash accident reconstruction based on the analysis 3D deformation of the auto-body

Xiao-yun Zhang *, Xian-long Jin, Wen-guo Qi, Yi-zhi Guo

Department of Mechanical Engineering, Shanghai Jiao Tong University, Room 909, No. 800 Dongchuan Road, Shanghai 200240, PR China

Received 17 July 2006; received in revised form 17 April 2007; accepted 3 May 2007
Available online 19 June 2007

Abstract

The objective of vehicle crash accident reconstruction is to investigate the pre-impact velocity. Elastic–plastic deformation of the vehicle and the collision objects are the important information produced during vehicle crash accidents, and the information can be fully utilized based on the finite element method (FEM), which has been widely used as simulation tools for crashworthiness analyses and structural optimization design. However, the FEM is not becoming popular in accident reconstruction because it needs lots of crash simulation cycles and the FE models are getting bigger, which increases the simulation time and cost. The use of neural networks as global approximation tool in accident reconstruction is here investigated. Neural networks are used to map the relation between the initial crash parameter and deformation, which can reduce the simulation cycles apparently. The inputs and outputs of the artificial neural networks (ANN) for the training process are obtained by explicit finite element analyses performed by LS-DYNA. The procedure is applied to a typical traffic accident as a validation. The deformation of the key points on the frontal longitudinal beam and the mudguard could be measured according to the simulation results. These results could be used to train the neural networks adapted back-propagation learning rule. The pre-impact velocity could be got by the trained neural networks, which can provide a scientific foundation for accident judgments and can be used for vehicle accidents without tire marks.

Keywords: Crash; Simulation; Finite element method; Neural networks; Accident reconstruction

1. Introduction

Vehicle accidents bring dramatic tragedy to people and have become serious social problems that threaten people and their property with an accelerating rate, particularly in developing countries such as China. Vehicle collision analyses and accident reconstructions have become increasingly popular in recent years due to the seemingly expanding rate of civil litigation. The most concern of vehicle crash accident reconstruction is to retrieve the pre-impact velocity.

The whole process of a vehicle accident can be divided into three phases: (1) post impact – the usual starting point of the reconstruction developed depending on the information obtained from the accident scene. (2) Impact – determination of the vehicle's impact speeds, impact directions and impact location, and so on. (3) Pre-impact – determination of speeds and trajectories (usually the unknowns). The main guideline of accident analysis is finding out the vehicle motions in collision phase through vehicle rest positions in post-collision phase, and then the vehicle motion in pre-collision phase, based on the collection, recording, investigation and analysis of the accident scene.

There are a variety of ways to evaluate a vehicle's speed. The evaluation of speed will usually be conducted with one or more of the following methods:

1. Momentum/energy analysis [1,2].
2. Damage/energy analysis [3,4].
3. Centrifugal force analysis.
4. Launch, fall or vault analysis [5,6].

* Corresponding author.
E-mail address: general_zhang@sjtu.edu.cn (X.-y. Zhang).

0965-9978/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.advengsoft.2007.05.002

5. Geometry and timing analysis [7].
6. Event data recorders [8].

The momentum/energy analysis method is limited in the accidents with fixed objects or between vehicles with large weight differences. On the other hand, the method need clear tire marks or the rest position of the vehicles in the accidents, but the tire marks form ABS are much fainter or non-existent now. The damage/energy analysis method reconstruct the accidents based on the 2D deformation of the auto-body. The other methods can only be applied in the extra traffic accidents.

Due to the variety, complexity and instantaneity of the traffic accidents, the precision of the quantitative analyses of the accidents manually is fairly low. For traffic accident, the objective is the pre-impact velocity and trajectory. Elastic–plastic deformation of the vehicle and other collision objects are the important information in the vehicle crash accidents, however, the computer simulation models now available for the reconstruction of the vehicle accidents seldom consider the deformation. With the development of simulation technology, the deformation can be fully utilized based on the finite element method, which plays an important role for the reconstruction of vehicle crash accidents. The explicit finite element algorithm takes not only the strain rate of materials in high speed but also the elastic and plastic characteristics into consideration by using a very small integration time step. Thus, researches on reconstruction of vehicle accidents based on the finite element method can get a relatively high precision of calculation. In addition, for an effective presentation of the results, 3D animation can be created using the post-processing software based on the finite element method, and direct observations of the deformation behavior of key energy absorbing parts can be taken in different types of accidents as well, such as mudguard and the front longitudinal beam. This cannot be finished well by other accident reconstruction programs. At present, the finite element method has been widely used for vehicle crashworthiness simulation. Unfortunately, the FEM never got a good application for accidents reconstruction because it needs lots of crash simulation cycles that will cost a great deal of time [9–11].

Therefore, this paper deals with the development of crash accident reconstruction technique by using neural network and the finite element method. In the present method, the non-linear explicit finite element code LS-DYNA is adopted to simulate the crash accidents. On the basis of the numerical results of the crash accidents, a three-layer feedforward neural network is applied to generate an approximated function of the initial crash parameter and the deformation index E.

The approximated function of E is then maximized under velocity and angle constraints by genetic algorithm. The procedure is applied to a typical traffic accident: the deformation of the key points on the frontal longitudinal beam and the mudguard could be measured according to the simulation results. These results could be used to train the neural network by back-propagation learning rule. The pre-impact velocity could be achieved by the trained neural network, which can provide a scientific foundation for accident judgments.

2. Nonlinear finite element method and neural networks

2.1. The nonlinear finite element method in crash simulation

For a point in a body, the time-dependent deformation can be found by seeking a solution to the momentum equation:

$$\sigma_{ij,j} + \rho f_i = \rho \ddot{x}_i \tag{1}$$

where σ_{ij} is the Cauchy stress, ρ is the current density, f is the body force density, $\ddot{x}_i$ is acceleration.

Eq. (1) satisfy the traction boundary conditions

$$\sigma_{ij} n_i = t_i(t) \tag{2}$$

on boundary ∂b_1, the displacement boundary conditions

$$x_i(X_\alpha, t) = D_i(t) \tag{3}$$

on boundary ∂b_2, the contact discontinuity

$$(\sigma_{ij}^+ - \sigma_{ij}^-) n_i = 0 \tag{4}$$

along an interior boundary ∂b_3 when $x_i^+ = x_i^-$.

The energy equation

$$\dot{E} = V s_{ij} \dot{\varepsilon}_{ij} - (p + q)\dot{V} \tag{5}$$

is integrated in time and is used for equation of state evaluations and a global energy balance. In Eq. (5), V is the relative volume, and s_{ij} and p represent the deviatoric stresses and pressure,

$$s_{ij} = \sigma_{ij} + (p + q)\delta_{ij} \tag{6}$$

$$p = -\frac{1}{3}\sigma_{ij}\delta_{ij} - q \tag{7}$$

respectively, q is the bulk viscosity, δ_{ij} is the Kronecker delta, if $i = j$, $\delta_{ij} = 1$, otherwise $\delta_{ij} = 0$, and $\dot{\varepsilon}_{ij}$ is the strain rate tensor [12,13].

It is known that,

$$\int_v (\rho \ddot{x}_i - \sigma_{ij,j} - \rho f)\delta x_i \, dv + \int_{\partial b_1} (\sigma_{ij} n_j - t_i)\delta x_i \, ds + \int_{\partial b_3} (\sigma_{ij}^+ - \sigma_{ij}^-) n_j \delta x_i \, ds = 0 \tag{8}$$

where δx_i satisfies all boundary conditions on ∂b_2, and the integrations are over the current geometry. By using the divergence theory it can lead to a statement of the principle of virtual work, i.e.:

$$\delta\pi = \int_v \rho \ddot{x}_i \delta x_i \, dv + \int_v \sigma_{ij} \delta x_{i,j} \, dv - \int_v \rho f_i \delta x_i \, dv - \int_{\partial b_1} t_i \delta x_i \, ds = 0 \tag{9}$$