Forensic Science International 270 (2017) 200–210

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Methods for analyzing the uncertainty of a reconstructed result in a traffic accident with interval and probabilistic traces

Tiefang Zou[a,b,*], Xulong Peng[b], Wenguang Wu[a,b], Ming Cai[c]

[a] School of Automobile and Mechanical Engineering, Changsha University of Science and Technology, Changsha 410004, China
[b] Key Laboratory of Safety Design and Reliability Technology for Engineering Vehicle, Hunan Province 410004, China
[c] School of Engineering, Sun Yat-sen University, Guangzhou, Guangdong 510275, China

ARTICLE INFO

Article history:
Received 26 April 2016
Received in revised form 29 September 2016
Accepted 11 October 2016
Available online 20 October 2016

Keyword:
Accident reconstruction
Uncertainty
Probabilistic traces
Interval traces
Grey number

ABSTRACT

In order to make the reconstructed result more reliable, a method named improved probabilistic-interval method was proposed to analyze the uncertainty of a reconstructed result in a traffic accident with probabilistic and interval traces. In the method, probabilistic traces are replaced by probabilistic sub-intervals firstly; secondly, these probabilistic sub-intervals and those interval traces will be combined to form many new uncertainty analysis problems with only interval traces; thirdly, the upper and lower bound of the reconstructed result and their probability were calculated in each new uncertainty analysis problem, and an algorithm was proposed to shorten the time taken for this step; finally, distribution functions of the upper and lower bound of the reconstructed result were obtained by doing statistic analysis. Through 2 numerical cases, results obtained from the proposed method were almost the same as results obtained from the Monte Carlo method, but the time taken for the proposed method was far less than the time taken for the Monte Carlo method and results obtained from the proposed method were more stable. Through applying the proposed method to a true vehicle–pedestrian accident, not only the upper and lower bound of the impact velocity (v) can be obtained; but also the probability that the upper bound and the lower bound of v falls in an arbitrary interval can be obtained; furthermore, the probability that the interval of v is less than an arbitrary interval can be obtained also. It is concluded that the proposed improved probabilistic-interval method is practical.

1. Introduction

The whole traffic accident can be reconstructed by accident reconstruction, and then more evidences such as the impact velocity and/or the impact position can be provided to the judger and victims who were involved in the accident, which will provide help to identify the accident responsibility. Traces in a traffic accident are the foundation of accident reconstruction, people who are expert in accident reconstruction can reconstruct an accident reliably according to those accurate traces, such as the braking distance of the vehicle [1], the deformation of the vehicle [2], the throw distance of the pedestrian [3], the injury of the pedestrian [4,5] or all traces [6,7]. Unfortunately, because of the influence of the environment, such as other people, other vehicles, the rain, the snow, the dust, and so on, traces in a traffic accident will be faded away slowly, which results in uncertain traces. In order to make the reconstructed results more reliable, uncertain evidences should be reflected in the accident reconstruction result.

There are at least two kind uncertain traces in traffic accidents, the first kind is interval traces, in which only the upper and lower bound of a trace can be given; while the other is probabilistic traces, in which the probabilistic information of a trace can be given. As for measured traces, such as the braking distance of the vehicle, which had been faded away before policemen arrived at the accident scene, they are considered as interval traces often [8–10]. As for empirical traces, such as the coefficient of the friction between the vehicle and the road, they can be considered as interval traces also in some cases [9], but they should be considered as probabilistic traces if the police or other experts provide enough information [11]. If all traces in an accident are interval traces, there are many methods can be employed to analyze the uncertainty of the reconstructed result, such as the upper and lower bound method [1], the finite difference method [12] and the response surface method [13,14]. If all traces in an accident are probabilistic traces, there are many other methods

* Corresponding author at: School of Automobile and Mechanical Engineering, Changsha University of Science and Technology, Changsha 410004, China.
E-mail address: tiefang@163.com (T. Zou).

http://dx.doi.org/10.1016/j.forsciint.2016.10.007
0379-0738/

that can be employed to analyze the uncertainty of the reconstructed result, such as the Monte Carlo method [11,15,16], the classical statistical method [1,17,18]. Though many methods can be employed to analyze uncertainty of the accident reconstruction result, there are few methods that can be employed if an accident with both interval and probabilistic traces. Probabilistic traces can be simplified to interval traces in some researches [9] and then the only assignment of uncertainty analysis is to find out the interval of the reconstructed result, it is reasonable if there are not enough information about probabilistic traces. But if the police or other experts provide enough information about some probabilistic traces, as for a technician in accident reconstruction, such mixed uncertain traces (probabilistic and interval traces) should be reflected in the reconstructed result objectively in order to make the reconstructed result more reliable. New methods need to be studied.

Hence, a new method for analyzing the uncertainty of the reconstructed result in an accident with probabilistic and interval traces will be proposed in the paper, and then new technique will be introduced to reduce the calculation time.

2. Problem description and a simple method

2.1. Problem description

All models within accident reconstruction can be presented as:

$$y = f(X) = f(X_I, X_p),\ X_I = (x_{I1}, \ldots, x_{Is})^T,\ X_P = (x_{P1}, \ldots, x_{Pn})^T \quad (1)$$

where X_I are interval traces, X_p are probabilistic traces, and y is an accident reconstruction result. In most cases, y represents the vehicle velocity and/or the impact position, s represents the number of interval traces, while n represents the number of probabilistic traces. The next assignment is to analyzing the uncertainty of y.

Situation 1. In some cases, probabilistic traces can be converted to interval traces, e.g. in a traffic accident, if the friction coefficient between the vehicle and the road obeys normal distribution, its mean value being 0.8 and variance being 0.03, and then the trace can be converted to the interval [0.71, 0.89], after that all methods used for calculating the interval of y according to the interval of X can be employed to analyze the uncertainty of y under such condition. The problem is why do we have to convert probabilistic traces to interval traces? Are there any other substituted solutions under such condition? Especially, as for a technician in accident reconstruction, we need to analyze the accident based on traces provided by the police or other accident investigation agencies and all traces (including the uncertain information) should be reflected in the result objectively.

Situation 2. In some other cases, interval traces can be converted to probabilistic traces, e.g. in one accident, if the braking distance of the vehicle is [15, 18] m, and then this trace can be considered as a probabilistic trace which obeys uniform distribution, the lower and upper bound is 15 m and 18 m, respectively. The same problem as the problem raised in the situation 1 is why do we have to do that? The only and most important assignment of a technician in accident reconstruction is to obtain a more reliable reconstructed result according to evidences provided by the police or other accident investigation agencies.

After the discussion in situations 1 and 2, new methods should be proposed in order to obtain a more reliable reconstructed result according to interval and probabilistic traces.

2.2. A simple method––The probabilistic-interval method

Based on the idea of Monte Carlo method, a simple method can be given. In order to make the discussion more convenient, the simple method is named as the probabilistic-interval method. Its steps are:

Step 1. As for all probabilistic traces, n sample sets (N sample points in each set) are generated according to their distribution, respectively. The N should be greater or equal to 10^7 according to Zou's practice [9,11,13,14]. As for interval traces, all are still considered as interval numbers.

Step 2. New sample set with only n sample points is combined by taking one sample point orderly in each sample set generated in step 1, and then this new sample set is combined with all s interval traces. And then a new uncertainty analysis problem with only s uncertain interval numbers is produced. As for N sample points in step 1, there will be N such uncertainty analysis problems.

Step 3. For each uncertainty analysis problem, find out the upper and lower bound of y. According to step 2, there will be N upper and lower bounds of y after this step.

Step 4. Do statistical analysis of the N upper and lower bound of y, and then give out the density function and distribution function of the upper and lower bound, respectively.

The flowchart of the method was given in Fig. 1.

2.3. A numerical case—case 1

A simple numerical case will be given here to demonstrate the four steps of the probabilistic-interval method. The model of the case is

$$y = x_1 x_2 \quad (2)$$

where x_1 obey normal distribution, its mean value being 5 and variance being 0.33; x_2 is an interval number, its upper and lower bound are 5 and 3, respectively. The next assignment is to analyze the uncertainty of y.

Step 1. Make $N = 10^7$, N sample points were generated according to the distribution of x_1.

Step 2. For each sample point generated in step 1 and the interval of x_2, a new uncertainty analysis problem was produced,

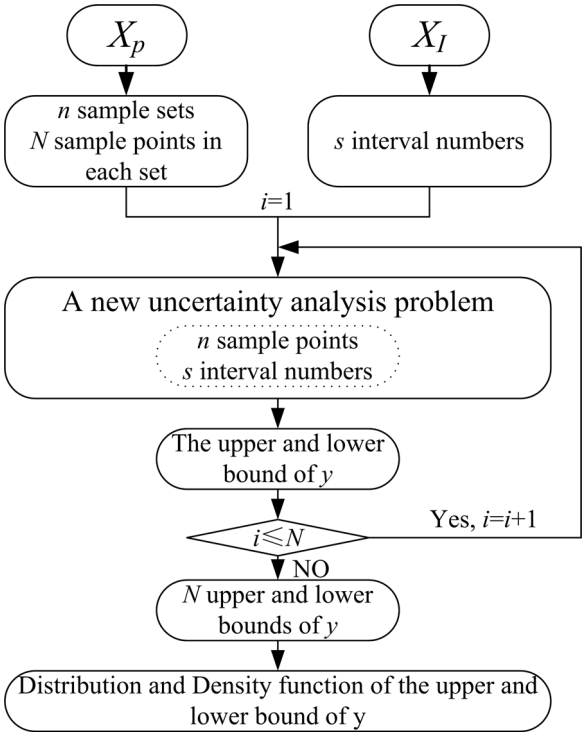

Fig. 1. The flowchart of the probabilistic-interval method.