Analysis of a Typical Traffic Accident Based on Trajectories Optimization

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Abstract : The task of traffic accident reconstruction is to find the pre-impact velocities of the vehicles involved in an accident. Any evidence left in the accident scene can provide important clues to the analysis of the accident. Usually tiremarks on the road and deflection of vehicles can be found in most accident scenes. So how to fully use this information is very important for accident reconstructionists. This paper presents a method of accident analysis using the information of tiremarks. The post impact trajectories of vehicles can be calculated using vehicle dynamic models if an initial velocity is assumed. The calculated trajectories are then compared to the tiremarks found in the accident scene. The objective of the optimization is to find a best match between them. When the match found, the pre-impact velocities are also found. Through the application of this method to a typical traffic accident, the results are proved to be accurate, and so can provide a scientific foundation for accident judgments.

Key words: Accident reconstruction; Simulation; Trajectories; Optimization; Tiremarks

1 Introduction

When investigating vehicle accidents, tiremarks on the road and deflection of vehicles are two very important kind of information an accident left in the scene. According to these two kinds of evidence, different ways are used to perform the accident reconstruction.

In this paper, only tiremarks are used to evaluate the pre-impact speed of accident vehicles. To calculate the movement of the vehicles, several kinetic time forward simulation programs in combination with different impact models are available. If an initial velocity is assumed, and all the pre-impact parameters specified, then the movement of the vehicles involved can be simulated using the vehicle dynamic models. The post impact trajectories and rest positions calculated is then compared to the real world case, the initial velocities are modified accordingly, and several simulation runs have to be performed, to find a solution, where post impact trajectories and rest positions correspond with the real accident. This task can be done through a multi-dimensional optimization process, wherein the pre-impact velocities are optimized, to get the best match between simulation results and real world data found on the accident scene.

2 Tiremarks

Tiremarks are a frequent part of a vehicle accident. They provide important clues to the analysis of an accident.

2.1 The classification of tiremarks

Reconstructionists classify tiremarks by the manner in which they are made. "Skidmarks" are made by a tire which is "locked" or rotating slower than the vehicle is moving. "Acceleration marks" are somewhat opposite since they are made by a tire which is rotating faster than the vehicle is traveling. A tire can also leave a mark if it is slipping perpendicular to the direction of travel. These are typically referred to as "yaw marks". Additionally, tires may leave marks if something unusual is

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occurring to create a wobbling of the tire tread. This can occur with a flat tire or a suspension problem. Tires leave marks as a result of movement during a collision. These are sometimes referred to as "collision scrubs".

Careful tiremark analysis is essential during vehicle accident analysis. It is often the most critical evidence of the accident.

2.2 How to get the tiremarks

With the application of photogrammetry, photographs of the accident scene are processed, and the tiremarks in the pictures are extracted and transformed into useful data. This data can then be used as a reference, which is to be compared with the simulation results.

3 Vehicle dynamic models

Vehicle dynamics simulation models are used to learn about the vehicles behavior in accidents.

3.1 The trajectory model

The vehicle is defined as a stiff body which moves under the influence of external forces. The following external forces are considered for the movement of a vehicle:

1. tire forces (normal, lateral, and longitudinal forces)
2. air resistance
3. gravity

3.1.1 The Equations of Motion for the Vehicle

After the determination of all external forces affecting the vehicle, the equations of motion can be summarized as follows:

For the balance of forces,

$$\boldsymbol{m\ddot{x}} = \sum \boldsymbol{F} \tag{1}$$

Which results in an equation for the acceleration,

$$\boldsymbol{\ddot{x}} = \sum \boldsymbol{F} \big/ \boldsymbol{m} \tag{2}$$

The conservation of the moment of momentum results in:

$$\boldsymbol{L} = \sum \boldsymbol{M} \tag{3}$$

or:

$$\boldsymbol{\theta_c \cdot \dot{\vec{\omega}} + \vec{\omega} \times (\theta_c \cdot \vec{\omega}) = \sum \vec{M}} \tag{4}$$

where $\boldsymbol{\theta_c}$ defines the mass tensor for the vehicle about its center of gravity.

3.2 The collision model

As defined by Newton the impact can be divided into two phases: The "compression" phase and the "restitution" phase. At the end of the compression phase the velocities for both vehicles at the "impulse point" are identical in case of a full impact.Due to a certain elasticity of the vehicle structures, the two vehicles will separate again.

Linear momentum and angular momentum are conserved, and energy loss is accounted for with a coefficient of restitution.

The “coefficient of restitution” is defined as ratio between restitution momentum and compression momentum.

$$\varepsilon = \boldsymbol{S}_R / \boldsymbol{S}_C \tag{5}$$

The total exchanged momentum is calculated from:

$$\boldsymbol{S} = \boldsymbol{S}_C + \boldsymbol{S}_R = \boldsymbol{S}_C(1+\varepsilon) \tag{6}$$

The balance of momentum can be formulated for both vehicles:

$$\boldsymbol{m}_1(\boldsymbol{v}_{s1t}{}' - \boldsymbol{v}_{s1t}) = \boldsymbol{T} \tag{7}$$

$$\boldsymbol{m}_1(\boldsymbol{v}_{s1n}{}' - \boldsymbol{v}_{s1n}) = -\boldsymbol{N} \tag{8}$$

$$\boldsymbol{m}_2(\boldsymbol{v}_{s2t}{}' - \boldsymbol{v}_{s2t}) = -\boldsymbol{T} \tag{9}$$

$$\boldsymbol{m}_2(\boldsymbol{v}_{s2n}{}' - \boldsymbol{v}_{s2n}) = \boldsymbol{N} \tag{10}$$

where $\boldsymbol{v}_{\sin}{}', \boldsymbol{v}_{sit}{}'$ is the velocity of center of gravity after impact in direction **n** and **t** for vehicle *i;* $\boldsymbol{v}_{\sin}, \boldsymbol{v}_{sit}$ is the velocity of center of gravity before impact in direction **n** and **t** for vehicle *i;* N, T is the total momentum in direction **n** and **t.**

The balance of angular momentum can be formulated:

$$\boldsymbol{I}_{1z}(\omega_{1z}{}' - \omega_{1z}) = \boldsymbol{T}\boldsymbol{n}_1 - \boldsymbol{N}\boldsymbol{t}_1 \tag{11}$$

$$\boldsymbol{I}_{2z}(\omega_{2z}{}' - \omega_{2z}) = -\boldsymbol{T}\boldsymbol{n}_2 + \boldsymbol{N}\boldsymbol{t}_2 \tag{12}$$

where $\boldsymbol{n}_i, \boldsymbol{t}_i$ is the position of impulse point for vehicle *i* in **n**,**t** coordinate system. As shown in Fig.1.

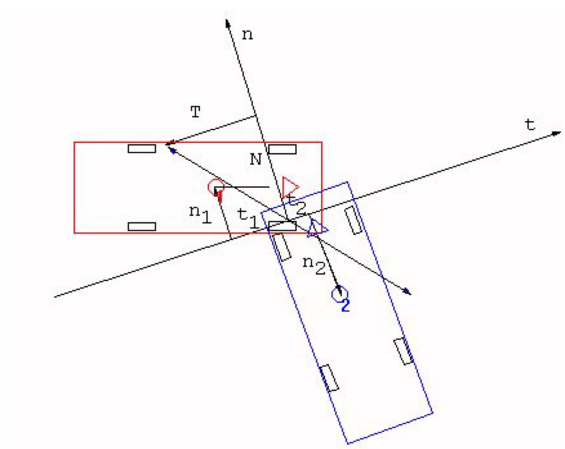

Fig.1 The collision model

4 Trajectories optimization

Before the optimization process can be done, a quality function has to be found. And before defining a quality function for the simulation results, the parameters, which can be used to describe the real accident, have to be defined.

4.1 Definition of post crash movement

Depending on the available data from the accident scene, some of these parameters may be uncertain. In many accident situations the approximate location where the vehicles collided can be found due to tire or scratch marks, shatter fields or dust marks. If the vehicles have not been moved from their rest positions when the scene investigations were made, these positions and the car directions are well defined. If skid marks were found on the accident scene, intermediate vehicle positions can be defined on the post impact trajectories. Therefore, from the trajectories, the impact position, rest positions and intermediate positions can be used to define the accident situation.

4.2 Quality function

For each vehicle, these parameters can be specified:

P_{Stop}	Vehicle rest position (coordinates)
$\vec{d}_{Stop}$	Heading vector at rest position
P_{impact}	Impact position
$P_{Inter}, \vec{d}_{Inter}$	Intermediate positions (location and heading of the vehicles on the post impact trajectories)

Once these parameters have been specified for the real accident, the following quality function can be used to calculate the quality of the simulation results. This quality function defines the target of the optimization process. The assumption has been made, that the lower the difference between simulation results and real accident data is regarding these values, the closer the simulation is to the real case. This formula is based on the least mean squares, as the quality function tends to zero the best match between simulation and real accident data has been found, and a “simulation error” can be calculated.

$$Q = \sqrt{\frac{\sum_i (w_i \cdot x_i)^2}{\sum_i w_i^{\,2}}} \times 100\% \tag{13}$$

The term x_i of the quality function are defined by the differences between real accident data and simulation results. These factors are normalized and a weighting w_i for each parameter can be specified to gain more control over the optimization process.

4.3 Optimization strategies

As for the optimization strategies, several different algorithms like the Coordinate Approach by Gauss-Seidel, the Simplex method, the Gradient and Newton approach, Monte Carlo and Evolutionary Methods deal with the problem of multidimensional optimization. Not all these methods are applicable, because some of these methods need derivatives of the target function to the input parameters. Thinking of the factors of robustness, numerical stability and high progress rates, the Evolutionary Method, that is, the genetic algorithm is chosen.

5 Simulation program

The program Pc-Crash is chosen to be used as the simulation tool. Pc-Crash is a momentum-based accident reconstruction program gaining popularity in Europe and America. It is a Windows-based accident-reconstruction program which combines the simulation of pre-collision, collision, and post-collision dynamics for multiple vehicles in a graphical environment.

6 Application to a typical traffic accident

6.1 Traffic accident scene

This accident happened in Hai Nan province as shown in Fig.2

Fig. 2 Scene of one accident

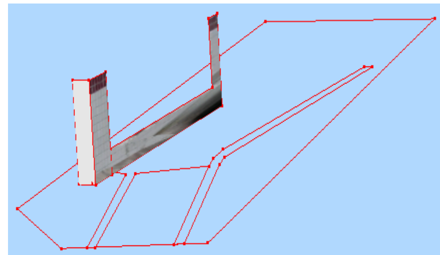

Fig.3 3D model of accident scene

6.2 Trajectories optimization using Pc-Crash

6.2.1 Preparation for optimization

With the help of photogrammetry programs, 3D model of the accident scene(As shown in Fig.3) can be obtained from photographs of the accident scene. This 3D model can be used as an input of Pc-Crash, and parameters defining post impact movement of the accident vehicles are all available in the model data.

6.2.2 Result of optimization

After trajectories optimization for this accident, we find that the pre-impact velocity is about 50 km/h with a simulation error of 1.0%. As shown in Fig.4. This result is quite coincident with the real accident.

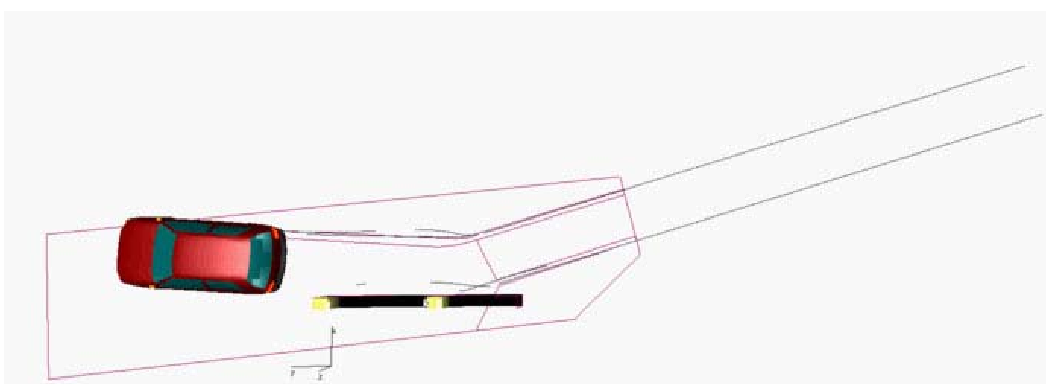

Fig.4 Result of trajectories optimization

7 Conclusions

This paper presents a method of accident reconstruction using trajectories optimization, and through application of this method to a typical traffic accident, it shows that the estimated pre-impact velocity using this method is quite coincident with the real accident. So the results can provide a scientific foundation for accident judgments. Since tiremarks are used by this method, it is fit for any traffic accident where any kind of tiremarks can be found in the accident scene. This method also has its limits in application, because for vehicles equipped with ABS systems, the tiremarks are more difficult to find.

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