Intelligent Methods for Car Deformation Modeling and Crash Speed Estimation

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Abstract: Car body deformation modeling plays a very important role in crash accident analyses, as well as in safe car body design. The determination of the energy absorbed by the deformation and the corresponding Energy Equivalent Speed can be of key importance, however their precise determination is a very difficult task. Although, using the results of crash tests, intelligent and soft methods offer an automatic way to model the crash process itself, as well as to determine the absorbed energy, the before-crash speed of the car, etc. In this paper a modeling technique and an intelligent expert system are introduced which together are able to follow the deformation process of car bodies in car crashes and to analyze the strength of the different parts without any human intervention thus significantly can contribute to the improvement of the modeling, (automatic) design, and safety of car bodies.

Key-words: crash analysis, 3D modeling, EES determination, car body deformation, fuzzy filtering, fuzzy and neural network based modeling, intelligent systems

1 Introduction

Crash and catastrophe analysis has been a rather seldom discussed field of traditional engineering in the past. In recent time, both the research and theoretical analyses have become the part of the everyday planning work [1][2][3]. The most interesting point in crash analysis is that even though the crash situations are random probability variables, the deterministic view plays an important role in them. The stochastic view, statistical analysis, and frequency testing all concern past accidents. Crash situations, which occur the most frequently (e.g. the characteristic features of the crash partner, the direction of the impact, the before-crash speed, etc.) are chosen from these statistics and are used as initial parameters of crash tests. These tests are quite expensive, thus only some hundred tests per factory are realized annually, which is not a sufficient amount for accident safety. For the construction of optimal car-body structures, more crash-tests were needed. Therefore, real-life tests are supplemented by computer-based simulations, which increases the number of analyzed cases to 1-2 thousands. The computer-based simulations – like the tests – are limited to precisely defined deterministic cases. The statistics are used for the strategy planning of the analysis. The above mentioned example clearly shows that the stochastic view doesn't exclude the deterministic methods [4][5].

Crash analysis is very helpful for experts of road vehicle accidents, as well, since their work requires simulations and data, which are as close to the reality as possible. By developing the applied methods and algorithms we can make the simulations more precise and so contribute towards the determination of the factors causing the accident.

Through the analysis of traffic accidents we can obtain information concerning the vehicle which can be of help in modifying the structure/parameters to improve its future safety. The energy absorbed by the deformed car body is one of the most important factors effecting the accidents thus it plays a very important role in car crash tests and accident analysis. There is an ever-increasing need for more correct techniques, which need less computational time and can more widely be used. Thus, new modeling and calculating methods are highly welcome in deformation analysis.

With the help of the methods introduced in this paper we can construct a system, which is capable to determine the energy absorbed by the car-body deformation using only digital photos taken from the crashed car, as inputs.

The proposed technique is based on the combination of new methods of digital image processing and intelligent techniques and as a result the system fulfills the above mentioned requirements: the necessary computational time is decreased (furthermore, it can adapt to the temporal circumstances coping with the available time), it produces more correct results, it can be used more effectively, and the obtainable information offers a way for wider usage.

New methods of computer based digital image processing (see e.g. [6]) offer a possibility to analyze and evaluate visual information gained from the environment in such a way that we can obtain the information easily by which the security systems of a vehicle can be shaped in order to make the passenger security more and more effective and also the reconstruction of car accidents becomes realizable.

Intelligent computing methods (like fuzzy and neural network (NN) based techniques) are of great help in this. Based on them we can construct systems capable to determine the energy absorbed by the car-body deformation using digital pictures as inputs.

Furthermore, the system can be more effective than the traditional algorithmic computing systems and is very advantageous in obtaining the necessary information.

The paper is organized as follows: In Section II. the determination of the absorbed energy is discussed. Section III. is devoted to the details of the digital photo based 3D modeling of the crashed car body, while Section IV. presents the determination of the direction of the impact together with the amount of absorbed energy. Section V. shows an example to illustrate the effectiveness of the presented methods. Conclusions are summarized in Section VI.

2 Deformation Energy Estimation from Digital Pictures

Recent methods of car crash analysis analyze the extent of the deformation from the top view of the car body however in some cases the deformation can not be seen from the top view at all. This problem could be eliminated by constructing the spatial model of the deformed car-body elements. It means that during the local accident analysis pictures are taken of the damaged car body from different points of view. Based upon these photos we can construct the spatial model of the deformed car body by using recent methods of digital image processing (see e.g. [6]-[9]) combined with intelligent techniques. In the followings a new intelligent 3D modeling and deformation analysis method will be introduced.

Modern computers can efficiently analyze digital photos. In contrast of the analog photos, digital ones are constructed of pixels (in other words, it is defined only by certain points of the plane). In addition, the brightness or color of these pixels does not change continuously and only certain predefined colors may occur. Each point has its brightness-code, so a digital picture can be viewed as nothing else then a matrix with as many lines as the picture has and within a line with as many elements (columns) as many picture points a line has. Thus, the well-developed methods of matrix algebra and mathematical analysis can be applied to the analysis [9].

Methods for 3D reconstruction from point or line correspondences in a sequence of images have achieved a high level of sophistication with impressive results [10], [11].

In our proposition the evaluation of the car-body deformation is done in two steps. First, the 3D shape of the deformed car-body is created with the help of digital pictures taken from different camera positions. As the second step, the 3D car-body model is processed by an intelligent computing system. The system needs only the above mentioned digital pictures, as inputs, while as outputs, we get the direction of the impact and the deformation energy absorbed by the car-body elements from which the direction and the speed of the crash can be determined. The system works automatically, i.e. it does not need any external (human) intervention during the calculations. The processing time of this method is much less than the processing time of the past methods, i.e. it can supply the outputs already at the accident plotting time. This property is very advantageous in supporting the work of road accident experts.

3 3D Car-Body Model Estimation Using a Sequence of Digital Images

The topic of building 3D models from images is a relatively new research area in computer vision and, especially when the objects are irregular, not finished at all. In the field of computer vision, the main work is done at one hand on the automatization of the reconstruction while on the other on the implementation of an intelligent human-like system, which is capable to extract relevant information from image data and not by all means on building a detailed and accurate 3D model like usually in photogrammetry is. For this purpose, i.e. to get the 3D model of the deformed car body, to limit/delimit the objects in the picture from each other is of vital importance [12].

As the first step, the pictures, used in the 3D-object reconstruction are preprocessed. As a result of the preprocessing procedure the noise is eliminated. For this purpose we apply intelligent fuzzy filters [6], [8].

After noise-filtering, the edges - object boundaries – are detected with the help of a fuzzy based edge detector [7] and the corners (vertices) are also determined by a new method which combines classical and fuzzy techniques (for details see [13]).

The next step is the determination of the 3D coordinates of the car-body edge points. First the vertex correspondences are determined which is followed by the determination of the edge correspondences. This latter can be based on the comparison of a well-defined small region around the analyzed image point with the corresponding regions around each of the candidate image points in the other image. For this purpose we need several images taken from different camera positions. If the angle between the camera positions is relatively small then after the evaluation of the projection matrices of the images the corresponding points can be calculated automatically with high reliability in each image. The problem to overcome is that a point determines not another point but a line (the so called epipolar line) in the other images, so the searching procedure can be reduced to 1D (along a line). First, we assign the edge points of the epipolar line, i.e. those points which belong to an edge of the image, then the fuzzy measure of the differences of the environment of the points are minimized. The next step is the determination of the perspective projection matrix for each image.

It can be calculated with the help of six given (3D; 2D) point correspondences [14]. After this we can calculate the 3D position of the image points and in the knowledge of the 3D coordinates and the correspondences of the significant points the spatial model of the car body can easily be built [14].

4 Estimation of the Impact-Direction and the Absorbed Energy

The block diagram of the intelligent system is illustrated by Fig. 1. The spatial model of the deformed car-body is created with the help of the module “Image Processing” (see Fig. 1). The inputs of this module are digital pictures of the deformed car-body taken from different camera positions and as a result (output of the module) we obtain the 3D deformed car-body model.

After constructing the 3D model of the deformed car body we have to determine the volume of the detoriated car body which means the comparison of the deformed and the undamaged 3D car-bodies. This calculation is performed by the module named “comparison of models” (see Fig. 1) and as result, we obtain the volumetric difference between the two models.

The spatial model of the deformed car-body serves as input of the module named expert system, as well. This module produces the direction of the impact. For the

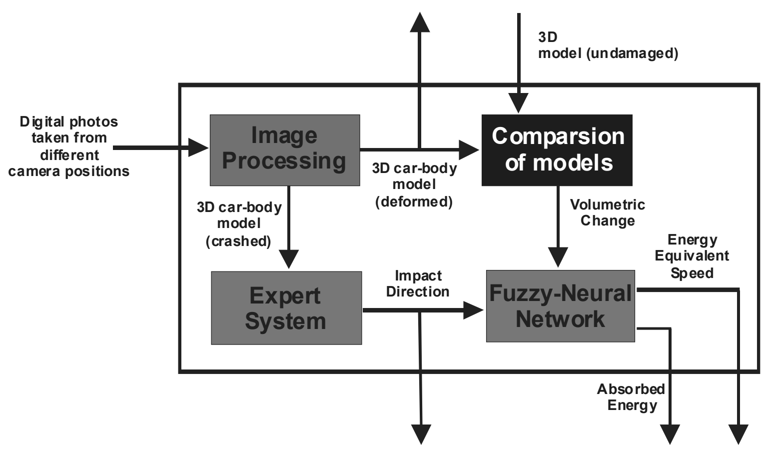


Figure 1. Block-structure of the system

determination of this direction we use the so called “energy-centers” of the undamaged and deformed car bodies and the direction is estimated from the direction of movement of the energy-center. (During the deformation the different 3D cells of the car-body absorb a certain amount of energy. The energy-center can be determined by weighting the cells by the corresponding energy values.) From the volumetric difference and from the direction of impact an intelligent, hierarchical fuzzy-neural network based system evaluates the energy absorbed by the deformation and the equivalent energy equivalent speed (EES). For the training of this part of the system simulation data can be used.

The relation among the direction of impact, volumetric change, and the deformation energy is illustrated by Fig 2.

This surface is symmetric (to the longitudinal axes of the vehicle) so it is enough to deal with its half part. The mapping is approximated by a hierarchical fuzzy-NN system (subsystem “Fuzzy-Neural Network” in Fig. 1). The surface is divided into domains, which can “easily” be modeled. Each domain is modeled separately by a small NN. Because of the uncertainties in the transitions among the domain, a fuzzy system is applied for the determination of the fired domain(s). The mapping in Fig. 2 needs only to be divided into two domains according to the impact direction (see Fig. 3), thus in this very simple case the fuzzy rulebase “above” the NN system contains only two rules (The input fuzzy sets are shown in Fig. 4.):

IF the direction *IS* D1 *THEN* use NN1
IF the direction *IS* D2 *THEN* use NN2

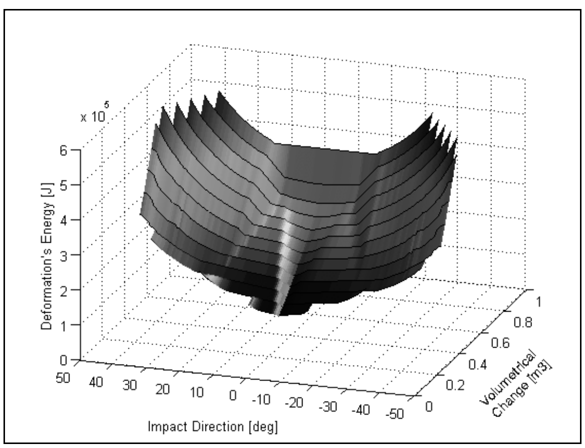


Figure 2. Relation among the direction of impact, volumetric change, and the deformation energy based on simulation data (based on the test data of Mercedes 290)

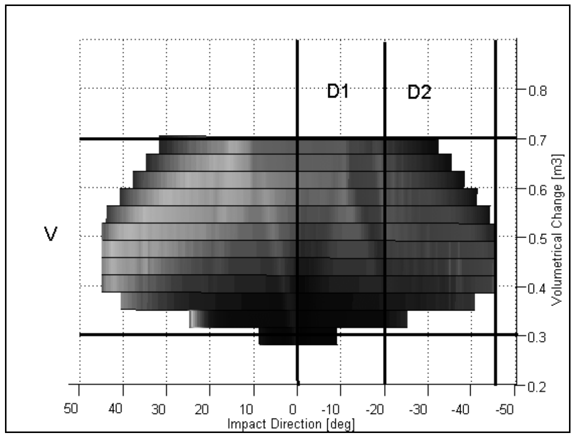


Figure 3. Segmentation of the surface in Figure 2.

Here we would like to remark two things: 1. In general the mapping is more complex and it can be advantageous to define more domains using both inputs to keep the complexity of the used NNs low.

2. The module responsible for the determination of the absorbed energy applies a pre-classification step according to a hierarchical decision-tree (Fig. 5), because for choosing the correct set of neural networks we have to pre-determine the category and the type of the analyzed vehicle and the main character of the crash (frontal impact, side impact, rear impact). Side impact means that neither the front nor the rear of the vehicle is touched.

For approximating domains D1 and D2 we applied simple feed-forward backpropagation NNs with one hidden layer and three hidden neurons. The NNs are used to determine the deformation's energy and EES. During the tuning (teaching period) of the system, the determined EES values were compared to known test results and the parameters of the expert system were modified to minimize the LMS error (the error surface can be followed in Fig. 6).

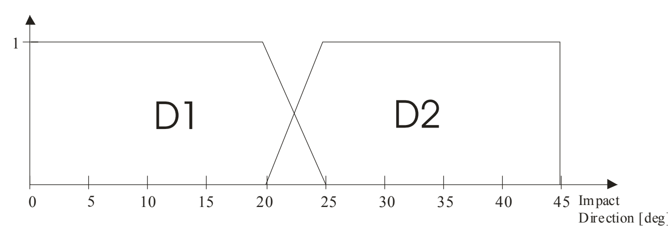


Figure 4. Membership functions defined on the universe of impact direction

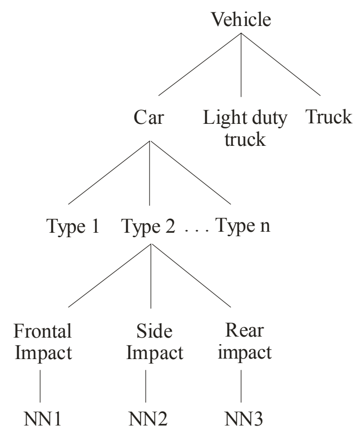


Figure 5. Hierarchical structure of the pre-classification in the EES determination

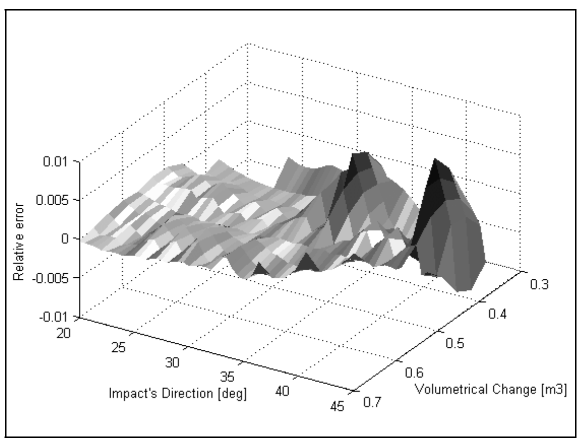


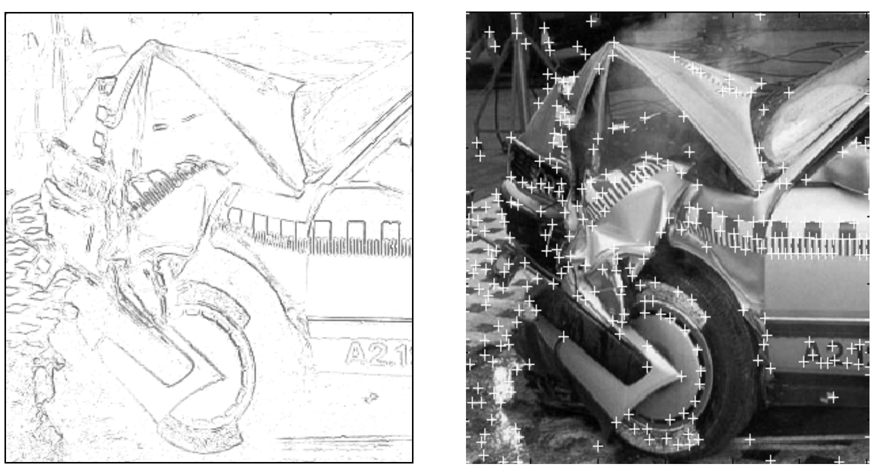
Figure 6. Error surface of mapping in Fig. 3 approximated by the hierarchical fuzzy NN system

5 Example

In this Section the operation of the introduced intelligent crash analysis system is illustrated on a crashed car. The parameters of the car are as follows:

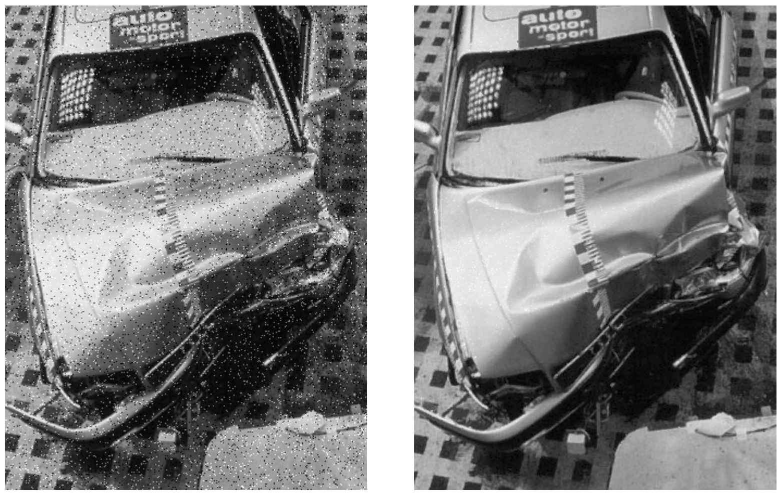
(a) (b)

Figure 7. (a) Original photo of the crashed car (Audi) corrupted by noise, (b) Fuzzy filtered image of the photo in Fig 7a



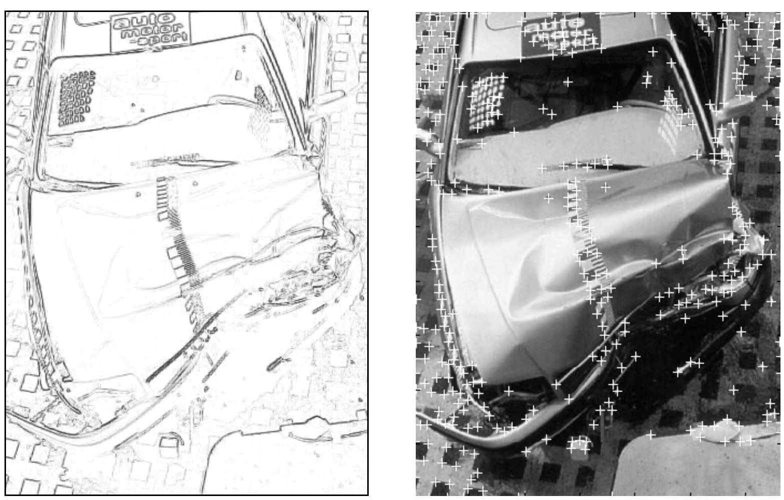
(a) (b)

Figure 8. (a) Image of the photo in Fig. 7b after fuzzy based edge detection, (b) Image of the photo in Fig. 7b after fuzzy based corner detection



(a) (b)

Figure 9. (a) Original photo of the crashed car (Audi) corrupted by noise (viewpoint 2), (b) Fuzzy filtered image of the photo in Fig. 9a



(a) (b)

Figure 10. (a) Image of the photo in Fig. 9b after fuzzy edge detection, (b) Image of the photo in Fig. 9b after fuzzy based corner detection

Vehicle/Mass of the vehicle: Audi 100/1325 kg
Volumetric change/Absorbed deformation energy (evaluated): 0.62 m^3/171960 Joule
Real/evaluated direction of impact: 0/2 Degree
The real EES of the vehicle: 55 km/h
The calculated EES of the vehicle: 58 km/h

The photos taken from two different camera positions are processed in Figs. 7, 8 and 9, 10. Fig. 7a shows the original photo of the crashed car corrupted by noise. In Fig. 7b the fuzzy filtered image while in Fig. 8a the image after fuzzy based edge detection can be followed. In Fig. 8b the assigned vertices are shown. Figs. 9, 10 illustrate a different camera position of the car.

For the determination of the deformation energy the hierarchical NN system taught by the test data of a Mercedes 290 were used. This caused only a tolerable amount of error because the two cars belong to the same class within the category “normal car”.

6 Conclusions and Future Work

This paper introduces a new intelligent method for the deformation’s energy determination of crashed cars, as well as for the automatic photo-based determination of the deformation’s spatial shape. Based on it, an intelligent expert system is presented which makes easy to determine the amount of the energy absorbed by the deformation and further important information, e.g. in car crash analysis the car-body deformation and the energy equivalent speed. The system can also advantageously be used in 2D-3D modeling.

In our future work, on one hand we plan to extend the system with a differential equation system based EES determination and modeling part which is too complex and thus not a useful tool for our purposes however we can apply it for rough approximation and for checking the measure of correctness of the results, i.e. in the improvement of the reliability of the modeling. On the other hand, based on the already obtained results we would like to model the crash and deformation process itself in time, which may be advantageous in safe automatic car design.

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