# Intelligent 3D Deformation Modeling in Vehicle System Dynamics

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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 (EES) can be of key importance in both cases, however their precise determination is a very difficult task. Although, using the results of crash tests, intelligent methods offer an automatic way to model the deformation of the car-body as well as the crash process itself, based on which we can determine the absorbed energy, the before-crash speed of the car, and other important features of crashes.*
*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 can significantly contribute to the improvement of the modeling, (automatic) design, and safety of car-bodies.*

*Keywords: crash analysis, 3D modeling, car-body deformation modeling, EES determination, intelligent systems, soft computing based image processing, fuzzy and neural network based modeling, fuzzy edge detection, fuzzy corner detection, fuzzy point correspondence matching*

## 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 (see e.g. [1][2]). 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.

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.

The results of the analysis of crashed cars, among which the energy absorbed by the deformed car-body is one of the most important, are of significance at other fields, as well. They also carry information about the deformation process itself and may have a direct effect on the safety of the persons sitting in the car. Thus, through the analysis of traffic accidents and crash tests we can obtain information concerning the vehicle which can be of help in modifying the structure/parameters to improve its future safety. The ever-increasing need for more correct techniques, which use less computational time and can widely be applied results in the demand and acceptance of new modeling and calculating methods.

The techniques of deformation energy estimation used up till now can be classified into two main groups: The first one applies the method of finite elements [3]. This procedure is enough accurate and is suitable for simulating the deformation process, but this kind of simulation requires very detailed knowledge about the parameters of the car-body and its energy absorbing properties, which in most of the cases are not available. Furthermore, if we want to get enough accurate results, its complexity can be very high.

The other group covers the so called energy grid based methods, which starts from known crash test data and from the shape of the deformation or from the maximum car-body deformation [4]. The distribution of the energy, which can be absorbed by the cells, is considered just in 2D and the shape of the deformation is described also by a 2D curve which equals the border of the deformation visible from the top view of the car-body. The accuracy of this technique is not acceptable: In many of the cases, the shape of deformation can not be described in 2D and furthermore, the energy absorbing properties of the car-body change along the vertical axis as well causing serious impreciseness in the results.

In this paper new methods are introduced which avoid the above discussed disadvantages of the recently used techniques. First, the energy distribution is considered in 3D. Secondly, for the description of the shape of deformation spline surfaces are used, which are very suitable for modeling complex deformation surfaces. Third, the computational time and cost need is significantly decreased while the accuracy is increased by the application of intelligent and soft computing techniques. Last, the deformation surface is obtained by a new 3D reconstruction method using only digital photos of the crashed car-body as input.

With the help of the methods presented in this paper we can construct a system capable to automatically build the 3D model of the crashed car as well as to determine the energy absorbed by the car-body deformation and the speed of the crash.

The paper is organized as follows: In Section 2 the block scheme of the intelligent car crash analysis system is discussed briefly. Section 3 shows how to evaluate the shape of the deformation and based on it the deformation energy from digital pictures. Section 4 presents the extraction of the 3D car-body model from digital images. Section 5 discusses how to determine the direction of impact, the absorbed energy, and the energy equivalent speed while in Section 6 is devoted to an example illustrating the effectiveness of the presented methods are illustrated by an example shows an example while Section IV is devoted to the conclusions.

## 2 The Intelligent Car Crash Analysis System

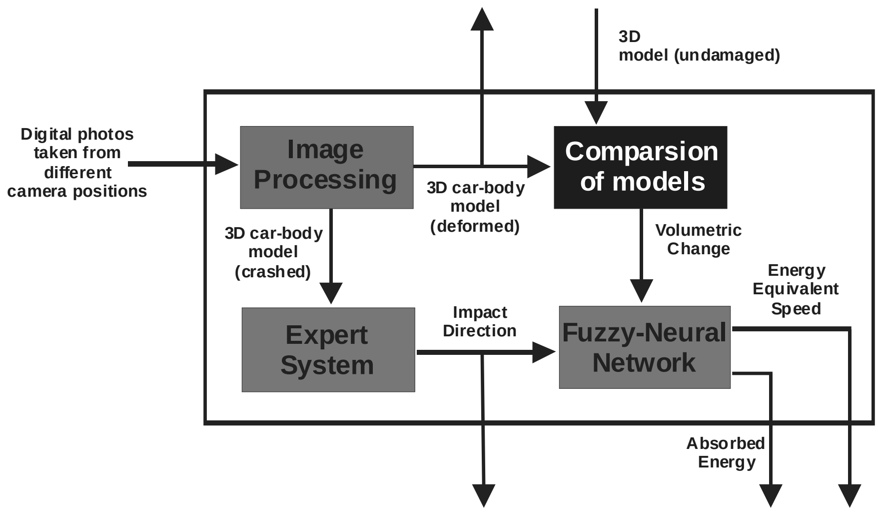



Figure 1
Block-structure of the intelligent car crash analysis system

The block structure of the proposed new car crash analysis system can be followed in Fig. 1. It contains four well defined sub-blocks. The first (image processing) is responsible for the pre-processing of the digital photos (noise elimination/filtering, edge detection, corner detection) and for the 3D modeling (including the point correspondence matching and the 3D model building). The second part of the system (comparison of models) calculates the volumetric change of the car body from the deformed and the original 3D models of the car. Parallel with it an expert system (Expert system) determines the direction of the impact. Based on the direction of impact and volumetric change a hierarchical fuzzy-neural network system (Fuzzy-Neural Network) determines the absorbed energy and the energy equivalent speed of the car. The main steps of the procedure are outlined in the next sections.

# 3 Determination of the Shape of the Deformation and the Deformation Energy from Digital Pictures

Recent methods of car crash analysis deal with 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 meaning that during the local accident analysis pictures are taken of the damaged car-body from different points of view and based upon these photos the spatial model of the deformed car-body can be constructed by using recent methods of digital image processing (see e.g. [5]-[7]) combined with intelligent techniques. In the followings, for this purpose, a new intelligent 3D modeling and deformation analysis method will be introduced.

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 based upon 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 input, while as output, 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.

# 4 Extraction of the 3D Car-body Model from 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 [8].

As the first step, the pictures, used in the 3D-object reconstruction are preprocessed, which starts with noise elimination and edge detection by applying the fuzzy filters and fuzzy edge detection algorithm described in [5], [6].

For our modeling system the determination of the corners are very important. Therefore, starting from the principle of Russo's fuzzy filters and edge detection algorithms, we have developed a new corner detection algorithm which utilizes the idea that a corner is indicated by two strong edges. It also applies fuzzy reasoning and we have improved (extended by fuzzy decision making) the used local structure matrix composed of the partial derivatives of the gray level intensity of the pixels (basics about the local structure matrix can be found e.g. in [9]). As input, we consider the noiseless and smoothed image, while as output the corners are got. The algorithm assigns also a new attribute, the fuzzy measure of being a corner, to the analyzed pixel. This property of the corners can advantageously be used at the searching for the corresponding corner points in stereo image pairs. For details see [10].

The next step is the determination of the 3D coordinates of the car-body edge points. First the corner point correspondences are determined which is followed by the determination of the edge correspondences in the different images. If the angle between the camera positions is relatively small then after the estimation of the projection matrices of the images (necessary for the calibration) the corresponding points can be calculated automatically with high reliability in each image. The main problem is that a point determines not another point but a line (the so called epipolar line) in the other images. To overcome this problem, first we search for the characteristic corner or edge points lying (in fuzzy sense) on the epipolar line and then the point correspondence matching is done by minimizing the fuzzy measure of the differences of the environment of the points with the help of a fuzzy supported searching algorithm (see Figs. 2 and 3) [11]. The similarity of the above mentioned 'cornerness1 is also considered. (The corresponding corner points keep their 'cornerness' property in the pictures near to each other with high reliability). Having the point correspondences we can calculate the 3D position of the image points (the camera calibration is solved by the determination of the Perspective Projection Matrix [8]) 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. For details see [12].

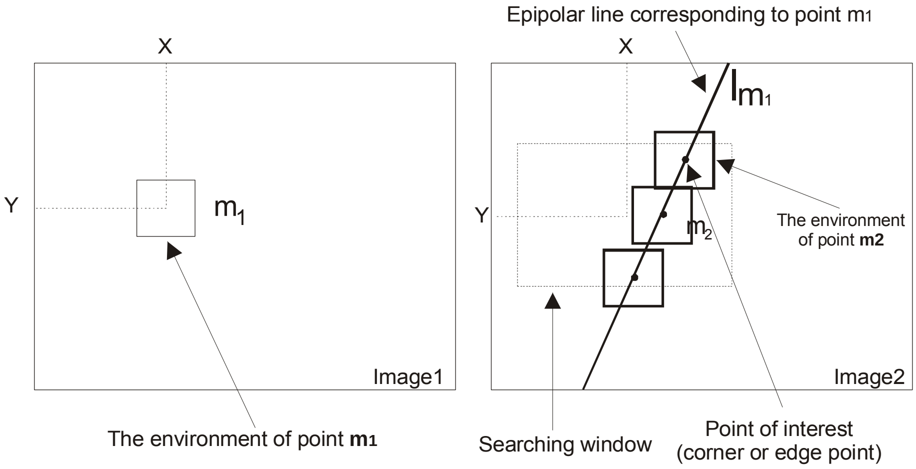



Figure 2
Illustration of the point correspondence matching algorithm

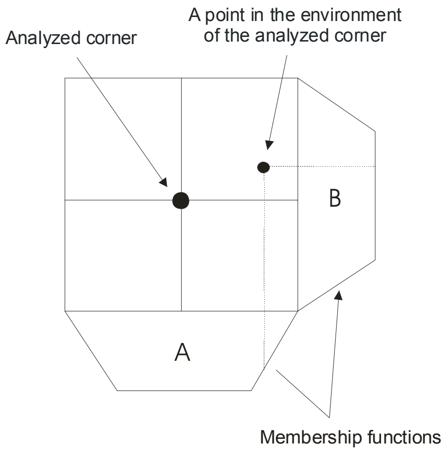



Figure 3
The fuzzy comparison (minimization) of the differences of the environments take into account the fuzzy distance of point m1 and candidate point m2 by weighting the intensity differences of the pixels with fuzzy membership functions A and B representing the closeness of the points

# 5 Determination of the Direction of the Impact and the Absorbed Energy

After constructing the 3D model of the deformed car body we have to determine the volume of the detoriated car body which means that it is necessary to compare the deformed and the undamaged 3D car-bodies. This calculation is performed by the module named 'Comparison of models' (see Fig. 1). The inputs of this module are the spatial models of the damaged and undamaged car-bodies. As result, we obtain the volumetric difference between the two models.

The spatial model of the deformed car-body serves as input of another module, as well. This module applies an expert system and produces the direction of impact. For this 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.)

The energy absorbed by the deformation and the equivalent Energy Equivalent Speed (EES) is determined by an intelligent fuzzy-neural network system modeling the relation among the direction of impact, volumetric change, and deformation energy (Fig. 4). The applied fuzzy-neural network is chosen according to the pre-classification of a hierarchical decision-tree and uses the volumetric difference and direction of impact as input. The pre-classification serves for pre-determining the category (car, light duty truck, truck) and class (according to weight groups) of the analyzed vehicle and the main character of the crash (frontal, front-side, rear impact, etc.) (see Fig. 5).

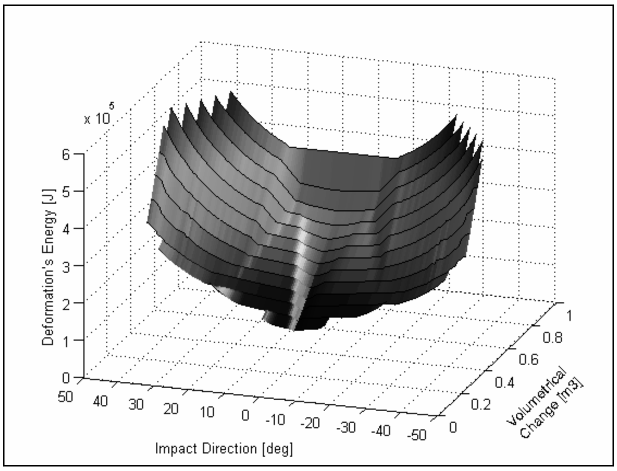



Figure 4
Relation among the direction of impact, volumetric change, and the deformation energy based on simulation data (Mercedes 290)

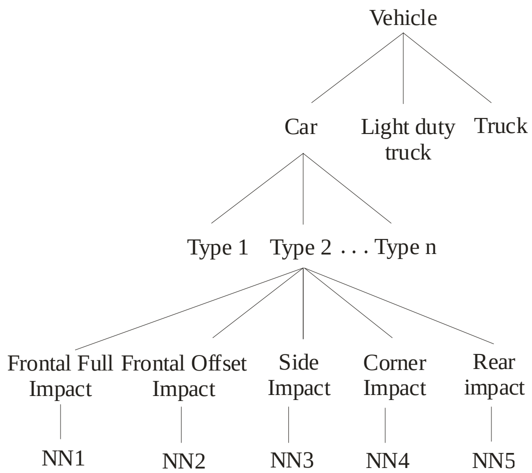



Figure 5
Hierarchical structure of the pre-classification in the EES determination

# 6 Example

In the followings the operation of the introduced intelligent crash analysis system is illustrated on a crashed car. An Audi 100 is analyzed based on the NNs taught by the simulation data of a similar class but Mercedes 290 car. The parameters of the car are as follows:

Vehicle / Mass of the vehicle: Audi 100 / 1325 kg

Real direction of impact: 0 Degree

Real EES of the vehicle: 55 km/h

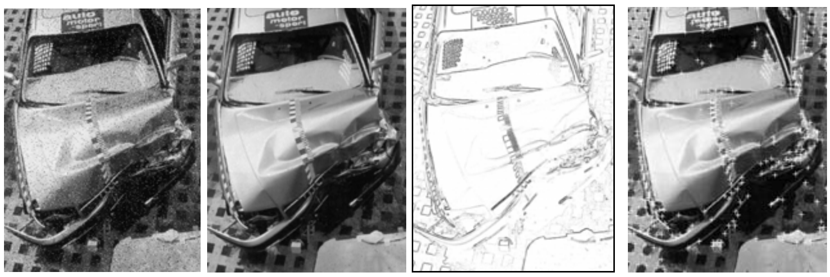
Fig. 6a shows the original photo of the crashed car corrupted by noise. In Fig. 6b the fuzzy filtered image while in Figs. 6c and 6d the images after fuzzy based edge and corner detection can be followed. Figs. 6e-6h illustrate a different camera position of the car. The 3D model of the deformed part of the car-body and the 3D energy cells are shown in Figs. 7a-7c. In Figs. 7d-7f the corresponding figures of the undeformed car-body part are presented. As a result of the analysis the following values are got:

Volumetric change/Absorbed deformation energy (evaluated): 0.62 $m^3$/171960 Joule

Evaluated direction of impact: 2 Degree

The calculated EES of the vehicle: 58 km/h

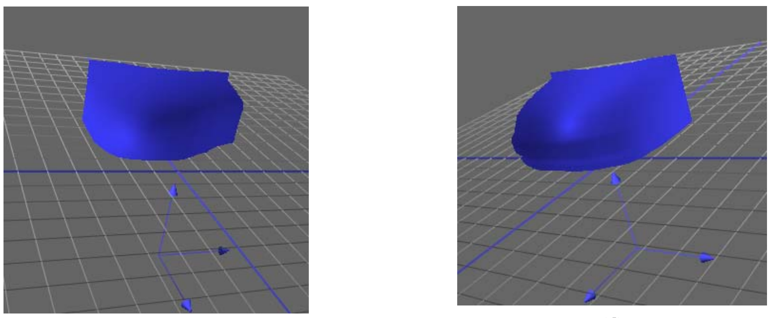
(a) (b) (c) (d)



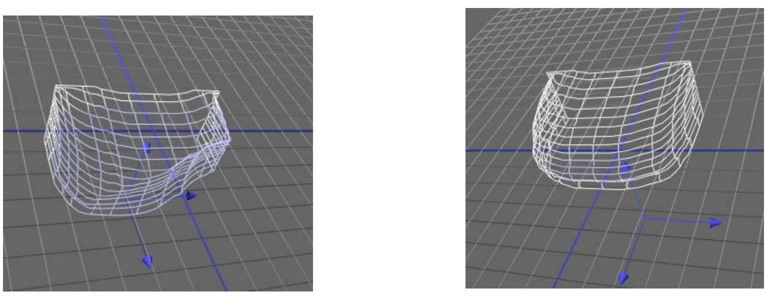
(e) (f) (g) (h)

Figure 6

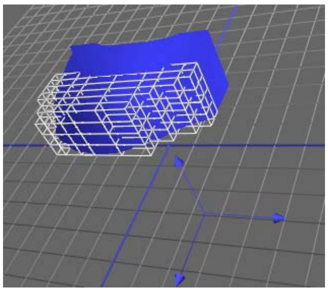
2 examples of the (a), (e): original photos, (b), (f): fuzzy filtered images, (c), (g): results after edge and (d), (h): corner detection of a crashed Audi 100



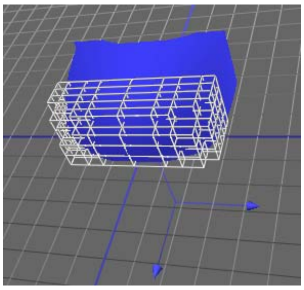
(a) (d)



(b) (e)



(c)



(f)

Figure 7
3D model of the (a), (b): deformed and (d)-(e): undeformed parts of the car body, (c), (f): the 3D energy cells

## Conclusions and Future Work

This paper introduces a new intelligent method for automatic photo-based determination of the spatial shape of deformation of car-bodies. 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 energy equivalent speed and the direction of impact. The system can also advantageously be used in 2D-3D modeling at other fields.

In our future work, we would like to extend the system to be able to analyze crashes in which more than one car is attached. We also plan to improve the system by a differential equation system based EES determination and modeling part which itself is too complex and thus not useful tool for our purposes however it's rough approximation results can advantageously be applied for checking the measure of correctness of the results, i.e. for improving the reliability of the modeling.

Furthermore, based on the already obtained results we would like to model the crash and deformation process itself in time, which may be helpful in safe automatic car design.

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