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Identification of Car-Body Crash Deformation Using Computational Intelligence Methods

Ph.D. thesis summary

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1. Background and objectives

Nowadays, unfortunately we face the recent growth of road accidents caused by the never foreseen increase in the number of vehicles on the roads. Annually 1,2 million people die in car accidents around the world. Another hundred thousands people are injured, some of them became invalids for life [1]. Because of the growing intensity of the traffic on the roads, it is essential to develop active and passive safety systems in the process of car body design in order to reduce the number of car-crash accidents. To be able to modify the vehicle safety systems, we need to identify in detail the circumstances, the process, and the results of accidents. These identifications help us to simulate the process of accidents so as to be able to correct the security parameters of the crashed car-body according to the determined data. To be able to evaluate the accidents objectively and precisely, we need methods which determine the accidents using as many elements as possible. Nowadays, both experimental and theoretical (simulating, compounding) investigations have become parts of the everyday design-process. Although the crash situations are accidental probability variables, the deterministic view is still dominant in them. This is the most interesting result of accident analysis [2]. Stochastic views and statistics-evaluations concern accidents which already have happened. The typical, most frequently happening crash situations (characteristic features of the accident-partner, the direction of the impact, the before-crash speed, etc.) are chosen from the above mentioned after-crash statistics. These experiments are quite expensive and only about a hundred of such experiments per factory can be realized, which number is not sufficient for the necessary traffic-security [1].

It is well known, that some methods determine the process of car-body deformation and the absorbed deformation energy with the method of finite elements, which works with quite precise results. The problem is that these methods are so complex, that they are not able to present data in efficient time, therefore cannot be used in crash analyses. For the determination of the deformation energy, other methods were developed (see for example [3,4]) – using crash-experiment data and information about the shape of deformation [5].

Taking into consideration the advantages and disadvantages of the recently used methods, the author of this dissertation presents new methods for the determination of the deformation energy, which enable the spatial evaluation of the deformed car body from their pictures using digital image processing and 3D reconstruction. The deformed surface reconstructed by the new method is based on the spatial 3D model of the damaged car body. For the preparation of the spatial model the author uses fotogrammetric methods and increases its effectiveness by soft computing methods [6,7,8].

The author worked out a new method for the detection of corner points, which are very important in spatial reconstruction [9][10][11]. As a result of deformation faults arise**,** which can effectively be used to determine the deformation surface. Based on fuzzy reasoning and epipolar geometry the author has worked out a method for determining the corresponding image points in the stereo image pairs [12].

The author also presents a more precise computing method for camera calibration, which is important in spatial reconstruction [13,14] and influences the determination of spatial coordinates.

Concerning the second objective, the author recommended two methods, based on the spatial model of the deformation surface of the damaged car-body, mentioned in the first objective.

The first method is based on the spatial extension of energy-nets of different types of vehicles, determined by crash tests [3, 5]. The energy absorbed by the deformation is determined by adjusting the energy-grid to the deformed car-body. In contrast to the previously used methods, this one determines the distribution of the absorbed energy spatially, therefore reducing the error. The main idea of the second method is to divide the car body into volumetric elements and assign a back-propagation neural network to each of them, which approximates the characteristics of the deformation of the element [15-18]. The input of the neural network is the volumetric difference in a concrete element and the impact direction.

Targeting the second objective the author recommended the determination of the direction of the impact based on the deformation surfaces of the spatial car-body models reconstructed from digital images. This method can be effectively used in such cases, where the direction of the impact serves as the input parameter [19].

2. The completed examinations and the applied methods

The basic method in examinations carried out was the development and completion of the results of the given sources. I examined the methods of the determination of deformation energy [1-5],[19], studied the soft computing methods and digital image processing theory, as well as the 3D reconstruction based on digital images, in order to find the possibility for the quick and intelligent evaluation of deformation energy based on digital images. [20-25][26-33].

The second part of the thesis examines the recently used methods of car crashes and EES determination.
The third part introduces the basic terms concerning fuzzy systems, neural networks and digital image processing.
The fourth part summarizes the results of classical and fuzzy methods used in digital image processing. I present a new method for the preprocessing of the image, which makes the quality of images better. I also introduce a method for the detection of corner points in digital images.
In the fifth part a new method is presented for matching the corresponding image points in a stereo image pair and an iterative method for determining the 3D world coordinates of a point using the 2D coordinates (image coordinates) of the point as input.
The sixth part introduces two new methods for the determination of the Energy Equivalent Speed (EES) in case of impact with a solid object, which can be extended to crashes with more cars and different directions of impact.
In the seventh part I present the application possibilities of the new results, while the eighth part contains some examples.
The ninth part summarizes the new results of the thesis. Here I also deal with questions connected to the topic and which need further examination to be answered. The last two parts contain the list of signs and references.

3. New scientific results

1. Developing and implementing new methods based on classical and fuzzy techniques concerning image processing.

1.1 I have developed a new Hermite based procedure for determining the deformation surface using its boundary curves as input [J1, C1].

1.2. I have worked out a new method for the detection of corner points in images using fuzzy reasoning [C5,C7,C8].

1.3. By combining fuzzy filtering technique with Gauss smoothing procedure I have worked out a new method for increasing the quality of image processing (edge and corner detection) algorithms [C4, C5].

2. Developing the new elements of 3D recontraction from digital images

2.1. I have made a proposal for developing of such methods, which are able to approximate 3D models from their edges and corner points detected in the pictures of the models [C4, C6, C7].

2.2. I have developed a method for determining the 3D coordinates of points using the corresponding image points in stereo image pairs [C4, C7].

2.3. I have developed a new method for decreasing the number of image points candiding as corresponding image points in stereo images [C9].

3. Estimating the impact direction and the energy equivalent speed (EES) in case of collision of vehicle with any stiff object.

3.1. I have made a proposal for the estimation of the impact direction of the vehicles using their deformation surfaces as input [C2, C6].

3.2. I have developed a new method for determining the energy equivalent speed using the 3D model of the crashed vehicle [C1, J1].

3.3. I have worked out a fuzzy-hierarchical neural network based method for determining the energy equivalent speed, which uses as input the volumetric change occurred by the deformation and the impact direction [C2, C3, C6, C10].

4. Application of the results

Recently, car crash and catastrophe analysis has become an important research topic. Crash tests and simulations offer a way to gain information about the causes of accidents and how to improve the safety of car bodies. Although, the used methods (crash tests, simulations, etc.) are very expensive thus their usability is limited. Image processing and, closely related to it, the automatic 3D reconstruction of the objects from their digital images can be widely applied for solving the certain tasks of different areas. The developed methods described in the previous sections can very advantageously be used for increasing the flexibility of car-crash accident analysis, resulting in more safe car body constructions. With the help of these algorithms the reliability of machine vision can be increased as well. The developed methods can also effectively be used for monitoring the states of buildings, bridges, roads, and for detecting their abnormal changes.

Using the presented methods we can build a system which is able to determine the absorbed energy of the deformation, the before-crash speed of the car and the direction of the impact, without any manual intervention. As input, it needs only digital images of the crashed and undamaged cars (see Fig 4.1).

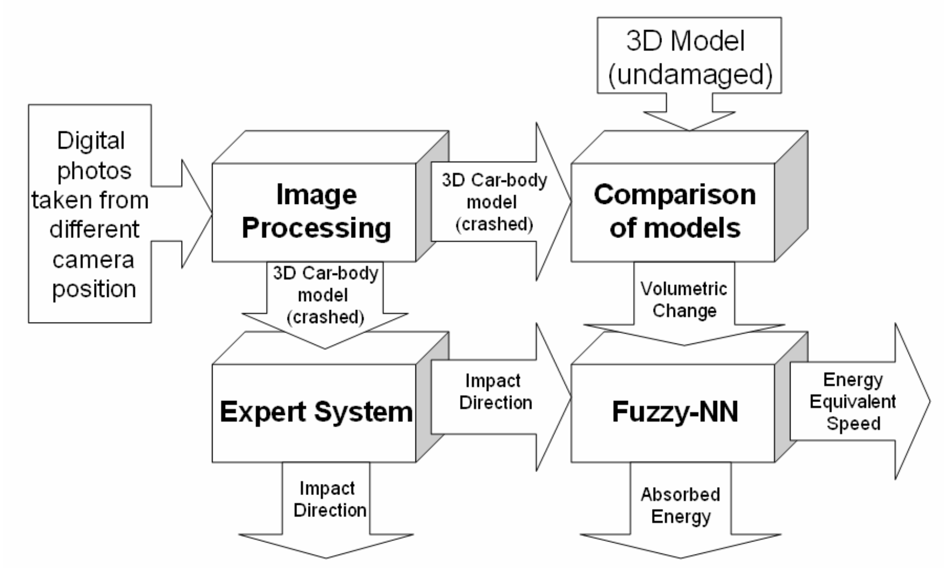

Figure 4.1: The block structure of the intelligent car-crash analysis system

5. Publications which have been worked out in the framework of this Ph.D. work

Foreign language journal articles:

[J1] Rövid, A, Melegh, G., "Modeling and Identification of Road Vehicle Body Deformation," *Periodica Polytechnica Transportation Science*, Vol. 32, NO. 1-2, 2004, pp. 135-148

[J2] Rövid, A., Várkonyi-Kóczy, A.R., "Soft Computing Based Point Correspondence Matching for Automatic 3D Reconstruction," Acta Polytechnica Hungarica, Hungary, Vol. 2, NO. 1, 2005, pp. 33-44

Articles published in international conference proceedings:

[C1] Rövid, A., Melegh, G., "Modeling of Road Vehicle Body Deformation Using EES Values Detection, *"In Proc. of the IEEE International Symposium on Intelligent Signal Processing*, Budapest, Hungary, 4-6 September, 2003, pp: 149-154

[C2] Rövid, A., Várkonyi-Kóczy, A.R., Várlaki, P., Michelberger, P., "Soft Computing Based Car Body Deformation and EES Determination for Car Crash Analysis Systems," *In Proc. of the 2004 IEEE Instrumentation and Measurement Technology Conference*, IMTC/2004, Como, Italy, 18-20 May, 2004, pp. 1674-1679.

[C3] Rövid, A., Várkonyi-Kóczy, A.R., Várlaki, P., "Intelligent Methods for Car Deformation Modeling and Crash Speed Estimation," *In Proc. of the 1st Romanian-Hungarian Joint Symposium on Applied Computational Intelligence*, Timisoara, Romania, May 25-26, 2004, pp. 75-84.

[C4] Rövid, A., Várkonyi-Kóczy, A.R., Várlaki, P., "3D Model Estimation from Multiple Images," *In Proc. of the IEEE International Conference on Fuzzy Systems, FUZZ-IEEE'2004*, Budapest, Hungary, July 25-29, 2004, pp. 1661-1666.

[C5] Rövid, A., Várkonyi-Kóczy, A.R., "Corner Detection in Digital Images Using Fuzzy Reasoning," *In Proc. of the 2nd IEEE Int. Conference. on Computational Cybernetics*, Vienna, Austria, August 30 - September 1, 2004, pp. 95-99.

[C6] Rövid, A., Várkonyi-Kóczy, A.R., "Car Body Deformation Modeling based on Soft Computing Techniques and Image Processing," *In Proc. of the 3rd International Conference on Global Research and Education in Intelligent Systems INTER-ACADEMIA,* Budapest, Hungary, September 6-9, 2004, pp. 75-84

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[C8] Várkonyi-Kóczy, A.R., Rövid, A. Samu, G., "Soft Computing Techniques for the Improvement of Signal Processing Algorithms," *In Proc. of the 2nd Serbian-Hungarian Joint Symposium on Intelligent Systems, SISY2004,* Subotica, Serbia and Montenegro, October 1-2, 2004,
[C9] Várkonyi-Kóczy, A.R., Rövid, "Fuzzy Logic Supported Point Correspondence Matching for 3D Reconstruction," *In Proc. of the 5th International Symposium of Hungarian Researchers on Computational Intelligence,* Budapest, November 11-12, 2004
[C11] Rövid, A., Várkonyi-Kóczy, A.R., Várlaki, P., "An Application of Intelligent 3D reconstruction in Vehicle System Dynamics," *In Proc. of the International Conference on Artificial Intelligence in Science and Technology*, Tasmania, Australia, November 21–25, 2004
[C13] Rövid, A., Várkonyi-Kóczy, "Iterative Neural Network Model Inversion," *In Proc. of the 3th Slovakian-Hungarian Joint Symposium on Applied Machine Intelligence*, Herlany, Slovakia, January 21-22, 2005
[C14] Rövid, A., Várkonyi-Kóczy, "Point Correspondence Matching for 3D Reconstruction Using Fuzzy Reasoning," *In Proc. of the IEEE 3rd International Conference on Computational Cybernetics*, Mauritius, April 13-16, 2005
[C15] Rövid, A., Várkonyi-Kóczy, "Observer Based Iterative Neural Network Model Inversion," *Accepted Paper of the IEEE International Conference on Fuzzy Systems 2005*, Reno, Nevada, USA, May 22-25, 2005

Foreign language papers presented at local conferences:

[C10] Rövid, A., Várkonyi-Kóczy, A. R., Melegh, G., "Car Body Deformation Determination Based on Soft Computing Techniques," *In Proc. of the 11th IEEE PhD Mini-Symposium*, Budapest, Hungary, February 3-4, 2004, pp, 12-13
[C12] Rövid, A., Várkonyi-Kóczy, "Soft Computing Based 3D Model Estimation from Digital Images," *In Proc. of the 12th IEEE PhD Mini-Symposium*, Budapest, Hungary, February 8-9, 2005, pp, 66-67

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