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Edited by

E C Chirwa
Automotive Engineering,
The Bolton Institute,
Bolton, United Kingdom

D Otte
Medical University of Hannover,
Hannover, Germany

London, United Kingdom

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Using Digital Photogrammetry to Determine Crash Severity

Stephen Fenton, P.E., Richard Ziernicki, P.E., Nathan Rose, Wendy Johnson
Knott Laboratory, Inc., 7185 South Tucson Way, Englewood, Colorado, 80112 USA

ABSTRACT - This paper presents a new method of determining the severity of vehicular accidents using digital photogrammetry. A state-of-the-art documentation technique called close-range photogrammetry allows engineers and accident reconstructionists to create a three-dimensional computer model of a damaged vehicle utilizing accident scene photography. Utilizing photogrammetric software, engineers can digitize accident scene photographs to create an accurate three-dimensional computer model that can be used to quantify structural damage. Critical data such as crush deformation, roof collapse, and occupant compartment intrusion can be analyzed and evaluated to determine the accident dynamics. Understanding the accident dynamics helps engineers determine the severity of the crash and assists in engineering safer vehicles. Knott Laboratory, Inc. has utilized photogrammetric techniques on cases worldwide including the Princess Diana accident in France [1][2].

INTRODUCTION

Understanding how vehicles interact during a collision is of great importance to accident reconstructionists and automotive engineers. Clues about the interaction of the vehicles during the accident are hidden in the structural damage. When all that is left of the vehicles are photographs, photogrammetry can be used to reveal those clues. This paper examines crash severity by analyzing various types of accident configurations, vehicle damages, and occupant injuries. The photogrammetric process will be described and then applied to the analysis of several accidents. Three accidents differing in classification will be examined, which include a sedan, van, and heavy truck. The structural damage to each class of vehicle is unique and includes frontal, side, and roof.

DISCUSSION

Photogrammetric Analysis

There are several photogrammetric software programs available on the market today. Knott Laboratory engineers typically use PhotoModeler [3] software to perform photogrammetric analysis.

Analyze the Photographic Data – The first step of the photogrammetric analysis is to determine whether or not there are enough photographs to complete an accurate project. A minimum of two photographs is needed to perform the analysis. Higher quality photographs that capture the details of the vehicle are preferable. For example, 35mm photographs that capture the entire vehicle up close are preferable compared to Polaroid photographs that are taken from a distance.

Scan Photographs – The second step in the computer process is to scan the photographs of a crushed vehicle into the computer, which can be done utilizing a flatbed scanner. PhotoModeler will accept both color and black and white photographs. It is Knott Laboratory's experience that color photographs are easier to use when identifying damage, but the file size of the color photographs is approximately three times larger than black and white photographs.

Camera Characteristics – The next step is to input characteristics of the camera from which the picture was taken. The focal length is an important input value. The vehicle can appear quite different while looking through the camera and adjusting the focal length. Knott Laboratory's experience is that photographs are usually taken with one camera at one focal length. Investigators should input the focal length if it is known. If the focal length is not known, the software has a utility called "Inverse Camera" that will assist in determining the camera's focal length. The camera characteristics can be determined if there are known dimensions in the photographs. The process of determining unknown camera characteristics has been published by Knott Laboratory, Inc. [4]

Identify Similar Points – In this step, a three-dimensional computer model is created. In order for the software to determine the three-dimensional position of key points in the photographs, common points on the photographs must be identified. In general, the more photographs that are used to identify a selected point, the greater the accuracy; however, a minimum of two photographs must be used to identify a single point in order to create a three-dimensional model.

Process the Information – Once at least four points have been identified on each photograph, the software is capable of determining the three-dimensional position of the identified points and the position of the camera. It is advisable to process the project when 7 to 10 points have been identified on at least two photographs. If more than 10 points are added, the processing becomes cumbersome because the computer is performing an iterative process in which it is repositioning the points and camera positions in three-dimensional space and determining the error after each iteration. With a greater number of points there are often too many solution sets generated by the iterative process for the processing to be successful.

Add Points to Increase Model Detail – In order to increase the detail of the model, additional points can be identified on each of the photographs ensuring that the points show up on at least two different photographs. It is Knott Laboratory's experience that the project should be processed each time that an additional 7 to 10 points have been added to the project.

Analysis of Passenger Sedan Accidents (Frontal Impact)

In order to determine a vehicle's speed at impact, it's important to quantify the extent of deformation. Using photogrammetry, photographs of the vehicle can be used to quantify the vehicle deformation. Knott Laboratory engineers used photogrammetry to measure the crush to the front of the Mercedes S280 involved in the fatal crash that involved Princess Diana.

Step 1: Gather Photographs and Digitize – The first step in quantifying the crush to the Mercedes was to gather several photographs of the vehicle from different angles. Photographs from *Time Magazine*, *Newsweek*, and from the Internet were used in the project.

Step 2: Identify Points and Process – Similar points between the photographs were identified in all the photographs. Point identification was concentrated on the Mercedes front end where impact with the tunnel pillar occurred. See Figure 1.

Step 3: Measure Extent of Crush – Once the processing was complete, a computer model of the crushed vehicle was prepared. Then engineers measured the amount of crush to the front end. See Figure 2. Knott Laboratory engineers determined that the greatest amount of crush occurred to the front left corner of the vehicle and measured approximately 52 inches. See Figure 3.

Step 4: Determine Speed of Vehicle – From the crush measurements and other physical evidence, a determination of the energy absorbed by the Mercedes during impact was made. Then engineers at Knott Laboratory used stiffness data derived from vehicle crash tests and the post impact travel distance to determine the vehicle's speed.[5] Knott Laboratory engineers determined that the Mercedes was traveling approximately 85 mph when it impacted the tunnel pillar.

Step 5: Analyze Occupant Kinematics – Understanding the vehicle dynamics during a collision provides data to analyze occupant kinematics during the accident. Engineering analysis showed that the impact to the tunnel pillar occurred to the Mercedes left front corner, causing occupants to move forward and to the left at an eleven o'clock direction. Princess Diana, who was seated in the right rear passenger seat and was unbelted, was propelled forward and to the left, impacting the driver seatback at approximately 55mph. See Figure 4. This impact placed an approximate force of 10,000 pounds onto her chest, causing her aorta to tear resulting in death.

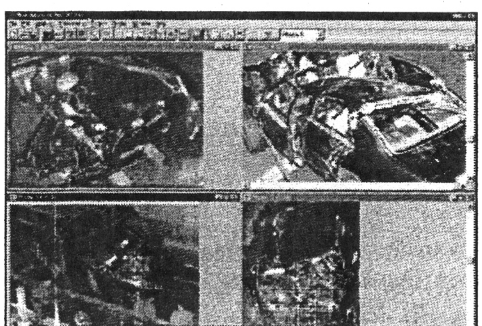


Fig. 1- Point Identification

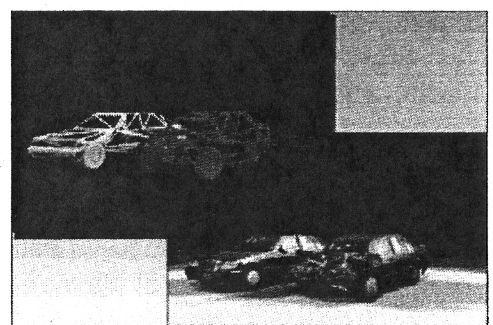


Fig. 2 - Computer Model Production

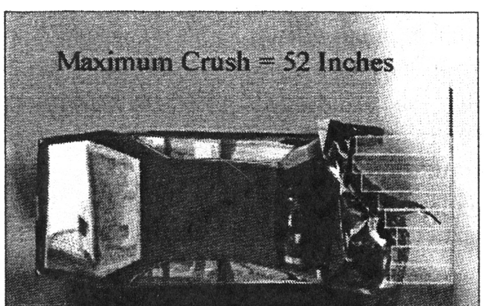


Fig. 3 - Crush Measurement

Fig. 4 – Occupant Kinematics

Analysis of Passenger Van Accidents (Side Impact)

When determining how an occupant was injured in a motor vehicle accident, it is important to accurately identify how the vehicles interacted during the collision. Using photographs of the damaged vehicles, the impact configuration can be determined. In this case study, a truck with a snow plow lift arm mounted on the front end impacted the left side of a Chrysler minivan, causing serious injuries to the occupants. Photogrammetry was used to determine the role that the snowplow lift arm played in the injuries to a rear seat occupant.

Step 1: Gather Photographs and Digitize - Photographs from the crash scene were used to create three-dimensional models of the Chrysler minivan and the truck. See Figures 5 and 6.

Step 2: Identify Points and Process – Point identification was concentrated along the left side of the minivan to accurately model the point where the snowplow lift arm came into the occupant compartment.

Step 3: Determine Impact Configuration – Using the three-dimensional models of the damaged minivan and the truck, an accurate determination of the impact configuration was performed. By placing the vehicles together such that their crush profiles matched in a three-dimensional computer environment, an accurate determination of the location where the snow plow lift arm entered the minivan occupant compartment was completed. See Figure 7.

Step 4: Analyze Occupant Kinematics – Knott Laboratory engineers determined that the lift arm entered the left side rear passenger window at the eye level of the rear seat occupant. Due to the impact, the rear seat occupant moved towards the encroaching lift arm, impacting the leading edge of the lift arm with the left side of his face. The rear seat occupant suffered extensive facial injuries. See Figure 8.


Fig. 5 - Accident Scene Photograph

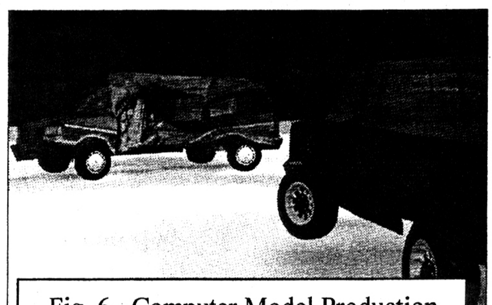


Fig. 6 - Computer Model Production

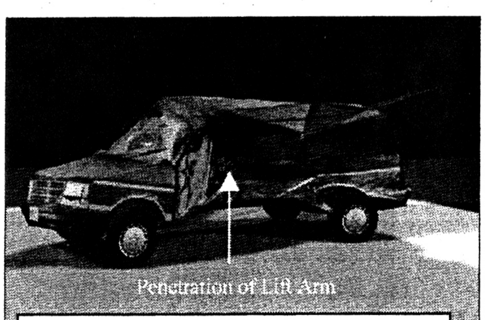


Fig. 7 - Photogrammetric Model

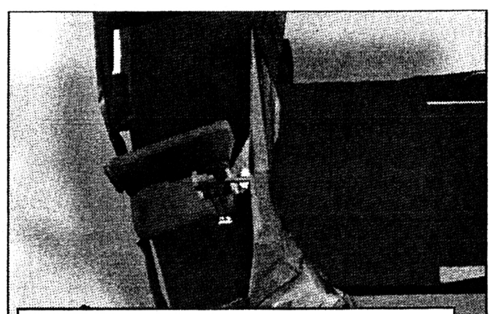


Fig. 8 - Occupant Kinematics

Analysis of Passenger Heavy Truck Accidents (Roof Impact) –

Many fatal motor vehicle accidents involve vehicle rollover [6] [7]. During the rollover phase, roof crush can be extensive and can play a roll in the occupant's injuries. However, it is important to quantify the extent of the roof crush and determine the phase in which the crush occurred. In this case study, a semi tractor-trailer lost control and rolled on its left side off the roadway. The occupant was not wearing a seatbelt and was ejected from the vehicle and was subsequently killed when the semi rolled over him. An analysis of the roof crush was performed to determine the likelihood of survival had the occupant been wearing a seatbelt and prevented from exiting the vehicle.

Step 1: Gather Photographs and Digitize – In this case, the vehicle was available to inspect, but the towing company had altered the post-accident shape of the semi roof. Photographs from the accident scene were used to create a three-dimensional model of the truck. See Figures 9 and 10.

Step 2: Identify Points and Process – Point identification was concentrated to the truck cab.

Step 3: Determine the phases of the roll – Using the three-dimensional computer model, the phases of the roll were determined. The first phase of the accident occurred when the truck lost directional control, yawed into a sideways orientation and tripped. The second phase occurred when the front left corner of the roof impacted the ground as the truck began its roll. See Figure 11. The final phase of the accident occurred when the top and right side of the truck rolled along the ground and the semi came to rest on its wheels.

Step 4: Analyze the Occupant Kinematics – Knott Laboratory engineers determined that maximum deformation to the roof occurred to the left front portion of the roof in the amount of 23 inches. Less severe damage occurred to the right front corner of the roof in the area above the driver's head. Had the occupant been restrained by the seatbelt when the left front corner impacted the ground, it is unlikely that his head would have come into contact with the roof. See Figure 12.

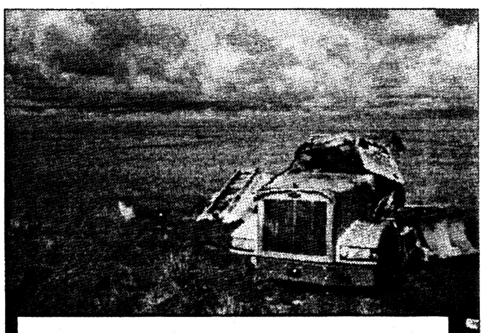


Fig. 9 - Accident Scene Photograph

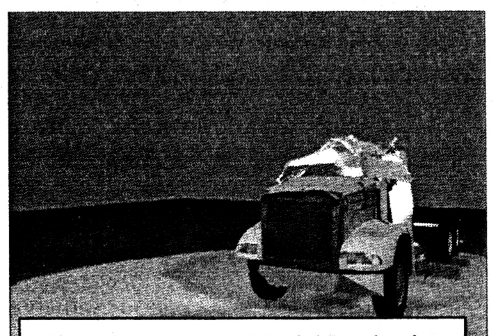


Fig. 10 - Computer Model Production

Fig. 11 - Occupant Kinematics

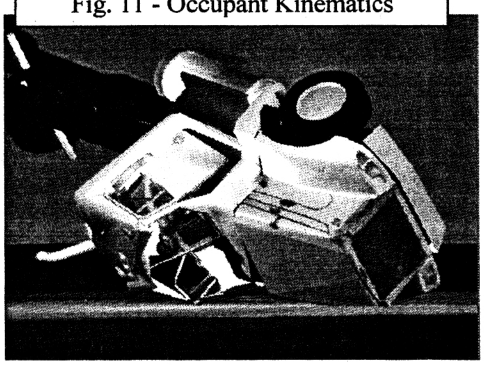
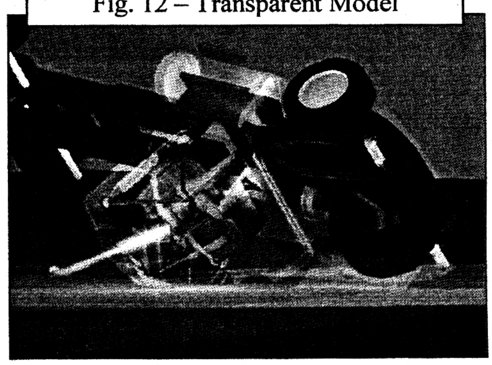


Fig. 12 – Transparent Model



CONCLUSIONS

Utilizing close-range photogrammetric techniques, engineers can measure vehicle crush utilizing photographs instead of physically measuring the vehicle. This is a valuable tool since many times the vehicles are no longer available for physical inspection. By creating a computer model, the engineering analysis can be more thorough, allowing engineers to maneuver the models in three-dimensional space to analyze the severity of the impact. By understanding the sequences of the accident and the interaction of the vehicles, engineers can better understand how occupants are injured. Understanding the interaction between vehicle damage and occupant injuries allows engineers to establish criteria important in designing safer motor vehicles.

ABOUT THE AUTHORS

The authors have been utilizing PhotoModeler software since it was first introduced in 1993. The authors can be reached at the following address:

Knott Laboratory, Inc.
7185 South Tucson Way
Englewood, Colorado 80112-3987
Phone (303)925-1900
Fax (303)925-1901
www.knottlab.com

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