AUTOMATED MOTION ANALYSIS OF SIMULATED PEDESTRIAN IMPACTS WITH THE AID OF DIGITAL HIGH SPEED FILM PROCESSING

by

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INTRODUCTION

Motions of a human surrogate, which are observed in a simulated crash situation, often cannot adequately be analysed on the basis of a planar approximation. Even more, in real accidents nonplanar events are sometimes of decisive importance. Because this is especially true in the case of vehicle - pedestrian collisions, the spatial trajectories of the surrogate in simulated pedestrian impacts are to be documented.

For this purpose, the method of high-speed cinématography can be extended such that a reconstruction of a spatial motion is obtained from planar views which are taken simultaneously from different view angles. While the photogrammetric problem of calculating object space coordinates from central projections using nonmetric cameras was solved by Das (1949), Abdel-Aziz and Karara (1974), Walton (1981), and others, cost-effective computer assisted hardware to analyse high-speed films which lends itself to be utilized for our needs has not been available. The amount of image processing and data manipulation involved in tracking markers on a pedestrian surrogate over several hundred film frames as well as performing the reconstruction algorithms is such that manual methods are no longer feasible. Moreover, an additional requirement follows from the fact that in case of a complex motion markers appear and disappear in an unpredictable fashion in the different films, such that an interactive image analysis needs to be facilitated.

In this paper a method is described which allows to efficiently calculate spatial motions from high speed films by using a newly developed digital image analysis system. The method is applied to a series of simulated pedestrian impacts whereby a modified part 572 dummy was used as pedestrian surrogate. The main objective of this series of tests is to document the properties of the resulting motions in space when the surrogate is hit by the corner area of a vehicle. Because such a configuration represents a relatively frequent type of collision (Gaegauf et al., 1981), documentation of such trajectories is also of importance in view of accident reconstruction.

RECONSTRUCTION OF SPATIAL TRAJECTORIES FROM PLANAR PROJECTIONS

Das (1949) showed that any finite sequence of central, i.e. photographic projections is described by a mapping of the object space $\underline{R} = (X,Y,Z)$ onto the image space $\underline{r} = (u,v)$ by

$$\underline{r} = \frac{(\underline{\underline{A}}\ ,\ \underline{R}) + \underline{B}}{(\underline{C}\ ,\ \underline{R}) + 1} \qquad (1)$$

The elements of the matrix $\underline{\underline{A}} = \begin{pmatrix} \underline{A}_1^T \\ \underline{A}_2^T \end{pmatrix}$ as well as of the vectors $\underline{B}$ and $\underline{C}$ represent a set of 11 parameters which uniquely determine the photographic projection. For high speed cinécameras these parameters are not known a priori. Therefore, they have to be calculated by applying the formula (1) to an object whose dimensions are measured in object as well as in image space. A spatial grid consisting of 14 ping-pong balls was found to provide adequate accuracy, as according to (1) it yields 28 equations for the 11 unknown parameters. The grid which measures approximately 1.5 m x 1.5 m x 1.5 m in space is installed prior to a test at the anticipated location of impact (figure 1), filmed from each camera, and then

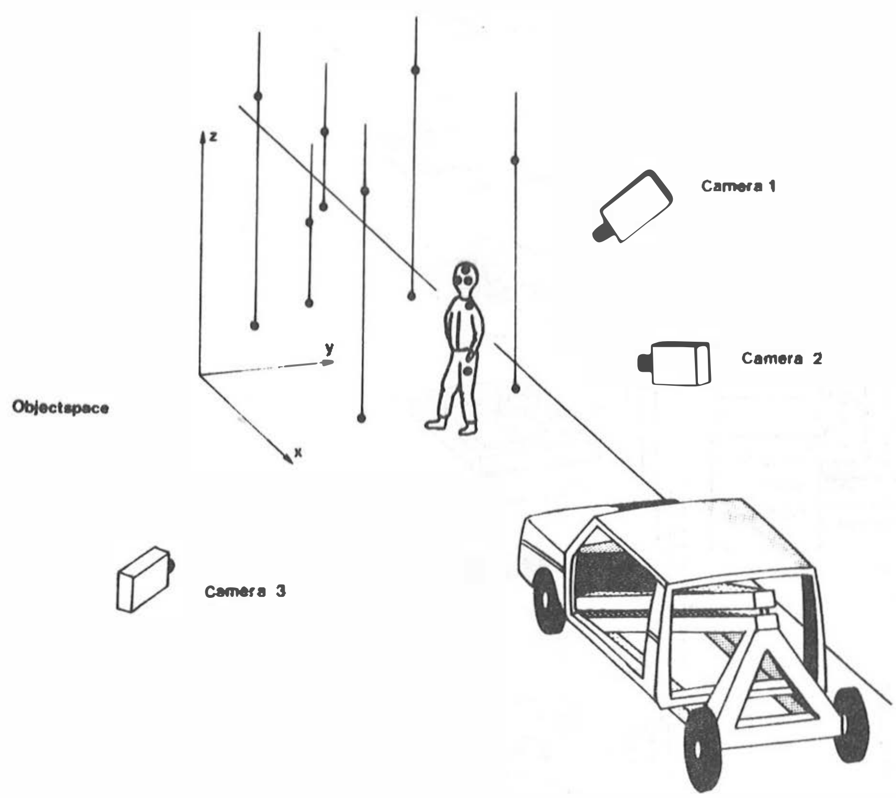

Fig 1: Schematic overview over test and calibration configuration.

removed. Based on this calibration the spatial coordinates $\underline{R}$ of a marker can now be calculated from (1), provided that the marker is visible at least from two cameras, because then a sufficient number of equations results from (1) for the three unknowns $\underline{R} = (X,Y,Z)$. Moreover, the frame sequences of the cameras have to be synchronized in order to ascertain that only projections taken at the same time are utilized for the reconstruction. Finally, spatial trajectories of markers are obtained by applying the described reconstruction process on a frame-to-frame basis.

DIGITAL FILM ANALYSIS

In a typical test, four films at 500 frames/sec are taken. The interesting sequence spreads over approximately 300 frames, whereby up to 20 markers may be visible on a single frame. Moreover, for each determination of a spatial location, a regression calculation has to be performed. As is mentioned in the introduction a system based on manual methods cannot be applied for this purpose. Therefore, a low-cost digital film analysis system was developed which allows for an efficient film evaluation. It consists of (figure 2)

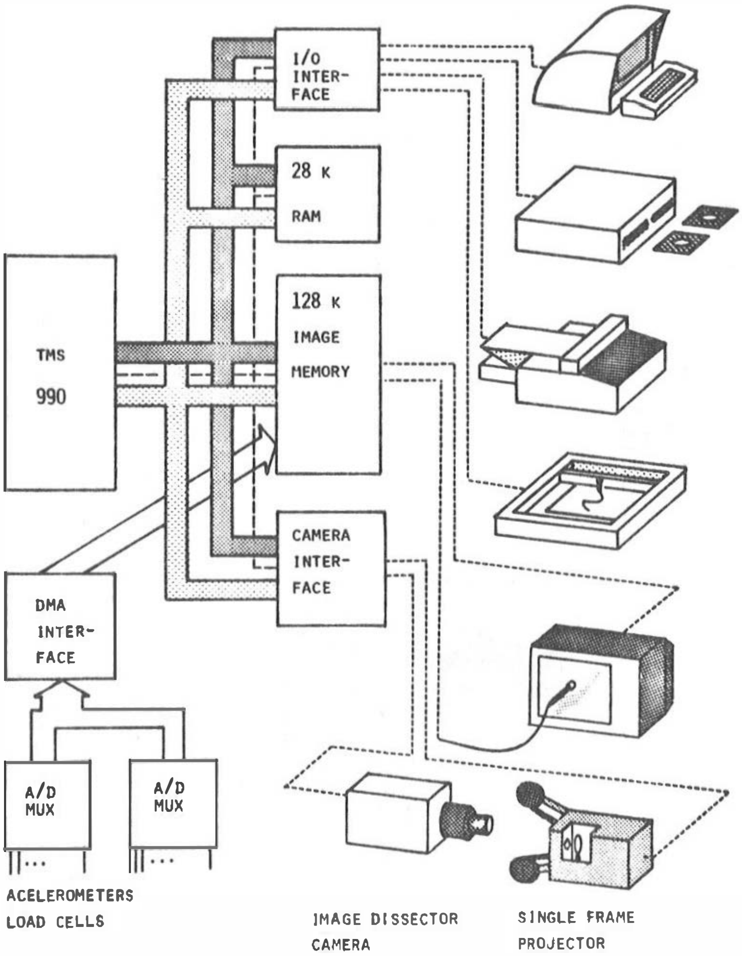

Fig 2: Elements of digital image analysis system.

- a TI 990/4 microcomputer with peripherals (floppy disk, printer, plotter)
- a single frame film projector, which was modified to facilitate a computer controlled frame advance
- a video-dissector camera, on whose photocathode the film frames are projected (ODD 658 A, EMR Photoelectric),
- two video-speed RAM image memories at 64K each,
- a control monitor with light pen, and
- a camera and projector controller

The image dissector dissects a film frame into 4096 x 4096 pixels, part of which are read by the computer in a random access manner. The image memories which are used for this purpose as a high speed storage device are designed to accommodate a matrix of 256 x 256 (= 65 K) pixels (picture elements) and to constantly display its contents on a control monitor. Only 1/256 of the addressable dissector pixels are therefore stored in the memory. For overview purposes, the selection of pixels to be stored and displayed on the monitor is such that the whole image is seen. Thereby, only every 16th element in the u- and v-direction is addressed and a correspondingly low resolution results. In order to obtain details of an image at a higher resolution, e.g. to determine the center of marker, less pixels are skipped such that only part of the image is treated ("digital zooming", figure 3).

Frame-to-frame tracking of all markers is performed automatically. Thereby the computer detects all visible markers in a frame and attempts to correlate their locations with the ones of markers detected in previous frames (tracking). After completion of these operations for all frames the marker identification has to be performed semi-automatically. For this purpose, the interactive features of the image analysis system are essential. The three-dimensional reconstruction is initiated after evaluation of all views. As mentioned earlier, the necessary camera synchronization has to be observed during this process. For this purpose the time sequences of the pulses generated by the rotating camera shutters indicating exposure of a frame are stored in the computer, such that an interpolation procedure can be applied.

ACCURACY OF THE RECONSTRUCTION

A simple method of establishing the accuracy of the reconstruction in case of a static object space consists in verifying the spatial coordinates of one of the calibration spheres by applying the reconstruction algorithm to it. It has been shown that the resulting accuracy of the calculated coordinates is representative for that obtained within or in the neighbourhood of the calibration grid (Walton 1981). With our method it was found that this "static" accuracy is better than 3 mm in each reconstructed space coordinate if a scene of approximately 6 m in diameter is filmed.

It should be noted that the accuracy of the whole method is usually limited primarily by an insufficient image contrast rather than by the resolution of the film material or the lenses. In order to increase the marker/background contrast, directly illuminated markers made from SCOTCHLITE reflective tape are used in our application.

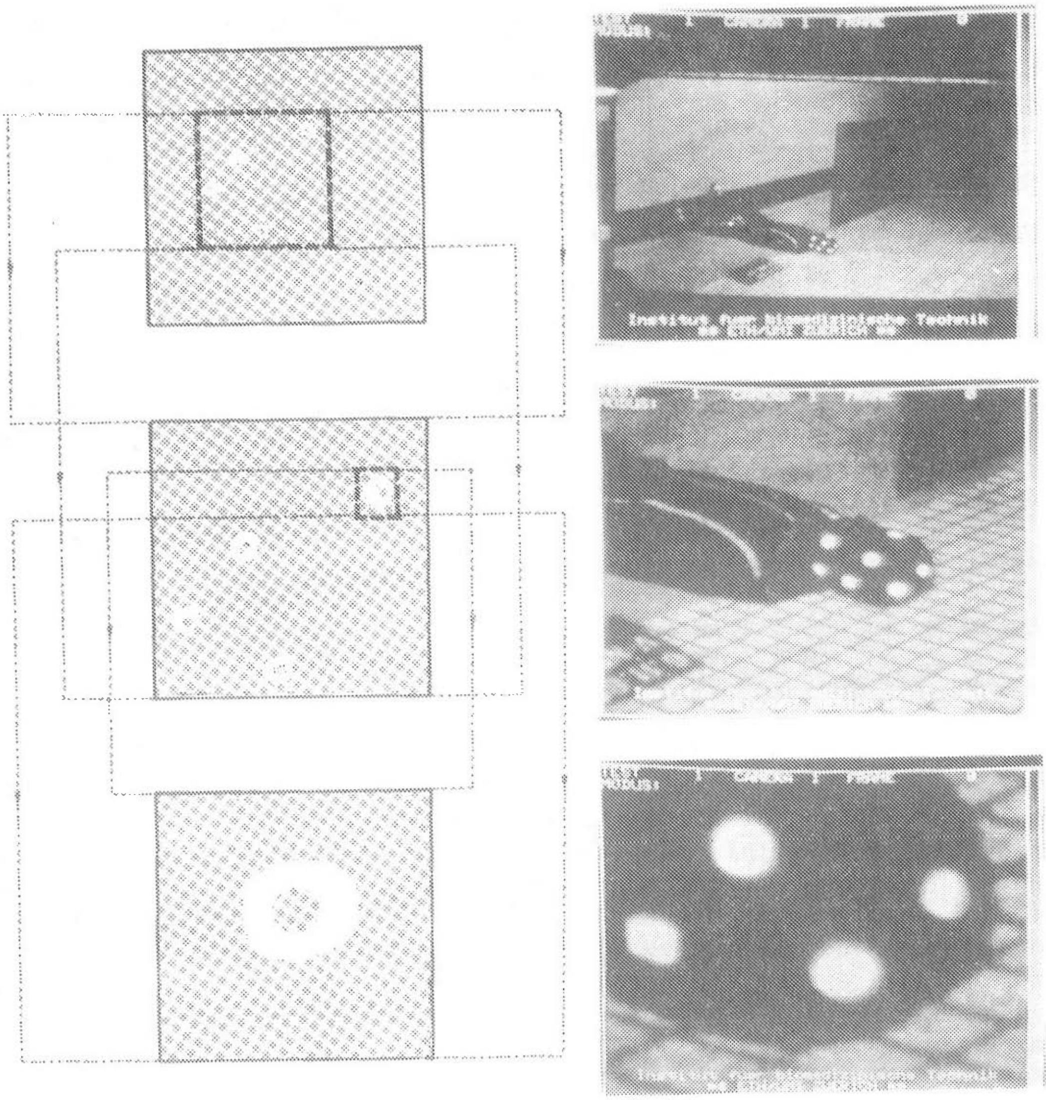

Fig 3: Principle of "Digital Zooming": From the total of 4096 x 4096 dissector points a submatrix of 256 x 256 pixels with increasing density but correspondingly smaller area is selected.

When the trajectory of a moving object is determined from a frame-to-frame analysis, the accuracy of the reconstruction decreases due to motion blurring. Moreover, interpolation errors resulting from the synchronization process are present.

Another problem arises whenever a marker on a rotating body is in the process of appearing or disappearing in a certain view. Under such circumstances it is only marginally visible and a considerable error in determining the center of its projection in that view may occur. To some extent this can be prevented by using ring-shaped markers because a simple "validity" criterion can then be applied: the image of a marker is valid only if there exists a closed path around the dark center. In spite of that, accuracy problems may be present whenever the camera combination changes, from which the spatial location of a marker is calculated. However, by monitoring the mutual spatial distance between markers, a sudden loss in accuracy is usually detected (figure 4). In general the typical "dynamic" accuracy is better than 7 mm in each coordinate.

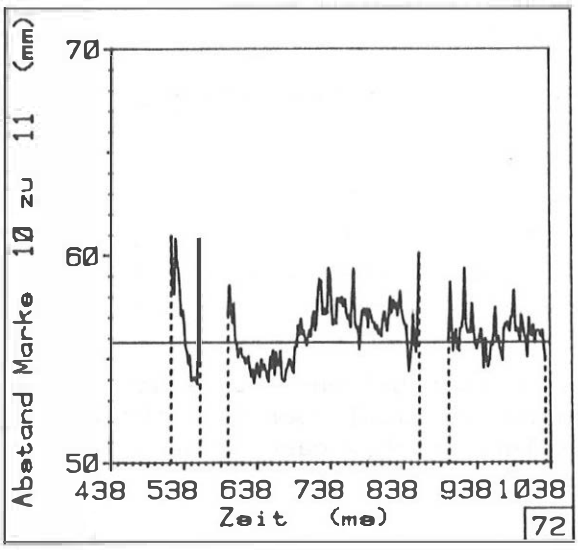

Fig 4: Calculated spatial distance (in mm) between two markers on the head as a function of time (in msec), determined from their reconstructed 3-dimensional trajectories. The solid horizontal line indicates the correct value, while the vertical dashed lines document changes in camera combination. In this case, the maximal deviation from the correct (constant) value of 56 mm is 5 mm which confirms the accuracy of the reconstruction.

RESULTS FOR SELECTED COLLISION CONFIGURATIONS

The test results which are presented in the following were obtained as part of a pedestrian accident simulation program with our crash facility at the Institute of Forensic Medicine in Zurich. As impacting vehicle a modified VOLKSWAGEN RABBIT buck was used and a modified Part 572 dummy (HUMANOID) served as pedestrian surrogate.

From an analysis of real accidents within the city of Zurich (Gaegauf et al 1981) it was concluded that one of the collision configurations to be used in a representative experimental simulation consists of an impact on the pedestrian surrogate with the corner area of a braking vehicle front at 25 km/h. For practical reasons it was not possible to simulate pedestrian motion which would however be desirable because in most real cases the pedestrian is walking or running.

In order to evaluate the motion patterns and their sensitivity to the exact locations of impact on the vehicle, a test series was conducted whereby the initial position of the dummy was displaced in intervals of 3 cm such that the location of impact varied from the center of the hood to the side. The pedestrian was facing outward and leg positioning was such that the dummy executed a rotation on its back during the impact.

In view of the significance of head injuries, head kinematics were given special attention. Whenever the spatial location of more than three markers on the head is known at a given instant of time, the coordinates of its center of gravity as well as its spatial orientation can be determined.

From the reconstructed head trajectories three types of motion patterns can be discerned (figure 5):

a) trajectories which are comparable to the ones resulting from an impact with the center of the hood
b) "side swipes" whereby the dummy is no longer entirely carried along by the vehicle but the head still experiences an impact on the lateral edge of the hood
c) side swipes whereby finally no other body part but one leg is hit by the vehicle corner (the dummy is in a walking position) such that the body executs a somersault motion. In particular, in this case no head impact on the vehicle front occurs any more.

As a result of the extreme "box" contour of the modified vehicle front, as well as of the fact that the dummy was initially at rest in these tests, the lateral component of the head trajectories is relatively small and increases only little with increasing distance of the impact location from the center of the vehicle front. Finally, a relatively large variation is found in the rotating movement of the head during impact as can be seen from figure 6 which exhibits the reconstructed head orientation in intervals of 25msec for two typical examples. In general, it is found that the head rotation may vary substantially even in cases where the trajectories of the head c.g. are similar.

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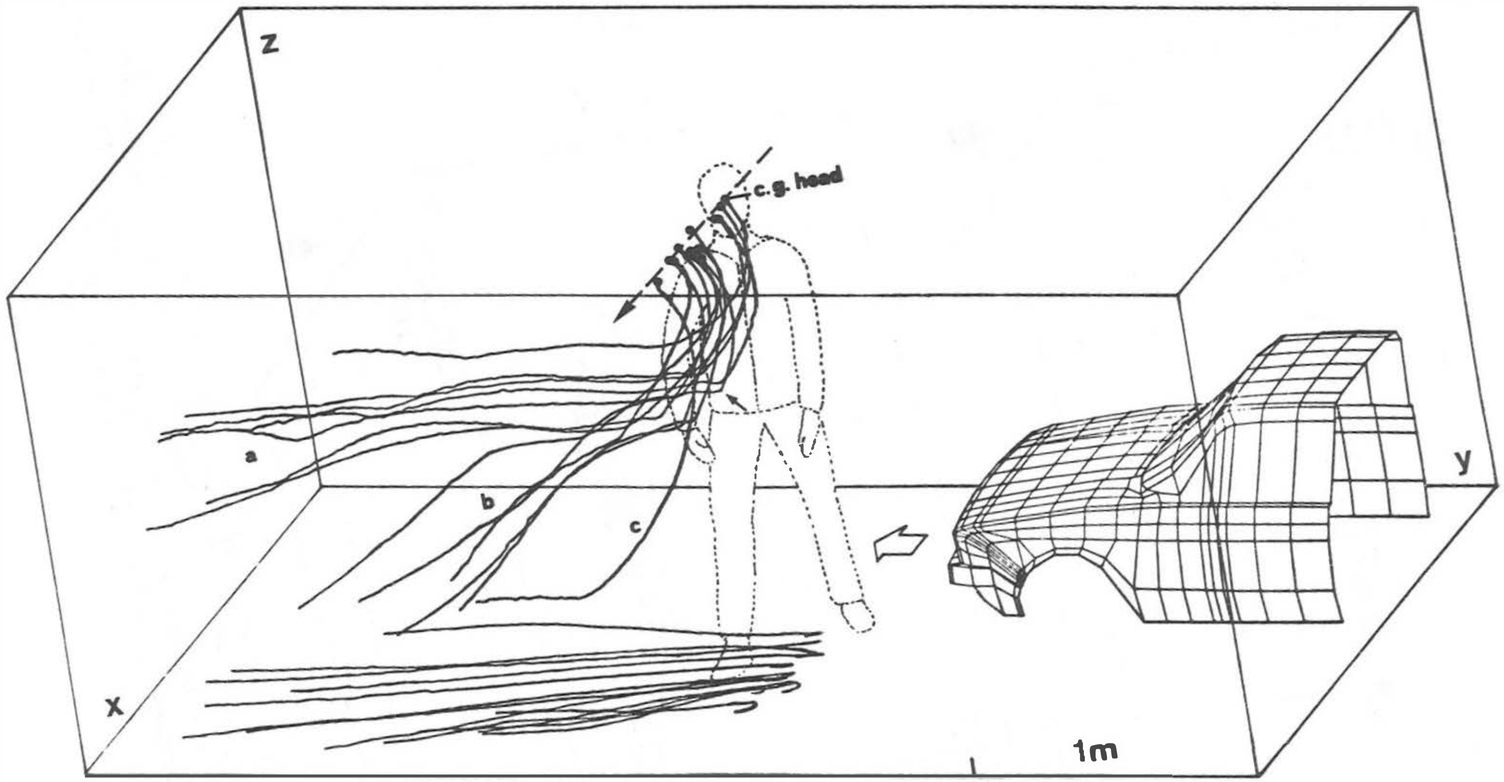

Fig 5: Perspective representation and projection on x-y plane of the reconstructed trajectories of the c.g. of the head in corner impacts. The dummy was displaced in intervals of 3 cm in the direction of the dashed line. Deviations from this line indicate the accuracy of dummy repositioning. The small arrow shows the location of a head impact on the hood. Further comments are given in the text.

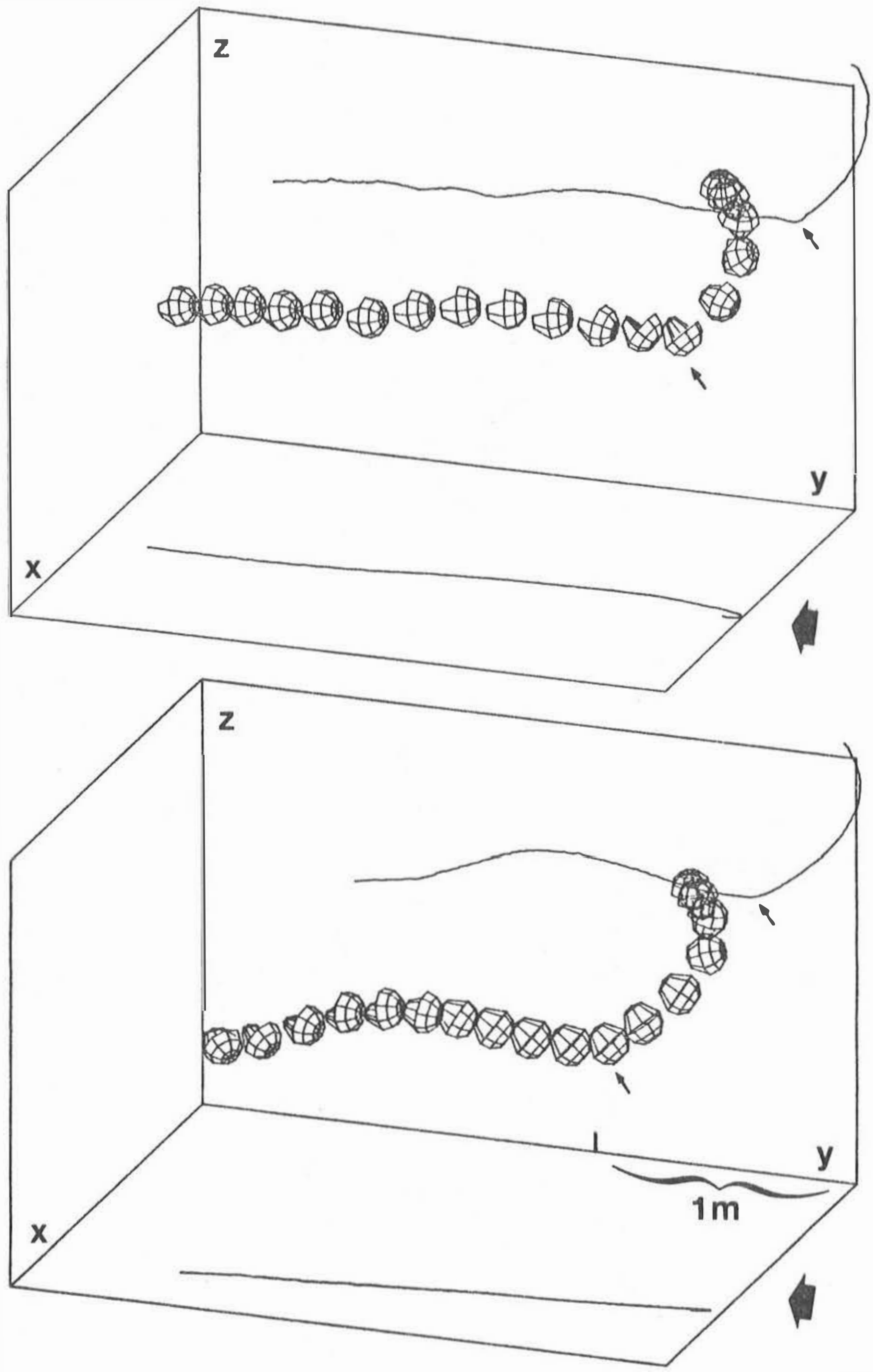

Fig 6: Schematic view of reconstructed spatial head orientations in intervals of 25 msec together with the projections on the x-y, and y-z plane, respectively of the head c.g. for two typical tests. Note the relatively large difference in the head orientation at the moment of impact on the hood (arrow).