PHOTOGRAMMETRY AND MOTION ANALYSIS METHODOLOGIES FOR DUMMY HEAD BEHAVIOUR OBSERVATION

David, Company Molina
Applus IDIADA Group
Spain

Paper Number 19-0233

ABSTRACT

While the airbag is essential for occupant protection, is it also an obstacle to visualizing the distance between the dummy head and rigid objects on the car or other occupants. During the restraint system development process, it is important to understand where the dummy head is in order to modify the restraint systems and avoid bottoming out.

Photogrammetry and motion analysis combined with 3D software enables the minimum distance between the 3D scanned dummy head and any other 3D surface to be calculated. Using the videos from the high-speed cameras the 3D position of any visible point can be obtained. As the head is a rigid object, it is possible to determine where the entire head is relative to the steering wheel with just the position of any point on the back.

With the arrival of 3D high-resolution scanners, HD high-speed cameras and new tracking algorithms, the results obtained from this methodology have increased in precision up to the millimetre scale. This methodology shows the behaviour of a rigid object during a crash or sled test in a 3D environment and can be used as a strong tool in passive safety laboratories. In this particular case, displacement and rotations of the head dummy relative to the car coordinate system determine if the head is too close to the dashboard, “B” pillar, steering wheel, etc.

This methodology requires two high-speed cameras. During a passive safety development process, it is essential to have all high-speed cameras available to monitor critical parts of the car. To reduce the number of cameras required to calculate the behaviour of the head relative to the car, the 6DoF tracking method can be used. This method uses the static position of a group of points in a rigid object to calculate the 3D rotation and displacement of the centre coordinate system. There are some difficulties that limit this process, which will be dealt with here.

This methodology is not commonly applied in every test, usually because the two cameras and the digital process required increase the cost of the crash or sled test. Reducing the number of cameras needed to only one can reduce the cost of this methodology and its implementation for all related tests. Also, there is the possibility of calculating this methodology by using on-board cameras, which is very helpful when the car deploys the curtain airbag.

With the coming of the autonomous car, the Passive Safety Department must have all measurement tools available to understand how dummies behave inside new car morphologies. This tracking methodology could us help to understand how dummies interact with rigid parts of the car in order to modify the restraint systems so as to be adapted to new technologies.

INTRODUCTION

Currently, due to the introduction of new regulations such as Euro NCAP Far Side or the development of future occupant protection systems regarding autonomous driving such as the OSCCAR project or NHTSA protocol modifications, experimental restraint systems to prevent occupant injuries are appearing, and the airbag has become one of the most important passive safety protections inside the car.

The development process of the airbag morphology, time of deployment, vent-hole strategies, etc. are some of the most important parts during occupant protection development. If the airbag has not been tested correctly, bottoming out of the airbag will cause serious injuries to the occupant's head. To avoid bottoming out it is necessary to know the position of the head with respect to any rigid part behind the airbag during the crash test.

It is impossible to understand the distance between the head and the rigid parts by looking at the movies because the airbag is always in the way. Although it is known when the head has hit a rigid part by looking at the accelerometers and neck load-cell results, this information only tells us if it has hit or not. It is difficult to understand the behaviour of the head or the minimum distance between the head and any rigid part of the car. The following study on photogrammetry resolves these difficulties and helps the development of efficient restraint systems by exploring the behaviour of the head during crash and sled tests.

EVALUATIONS FOR DUMMY HEAD POSITION ANALYSIS

There have been different ways of comparison and measurements to try to understand how the airbag was working related to bottoming out, but none have enough accuracy or repeatability to truly inform about the behaviour of the head or its minimum distance between the rigid parts of the car.

Acceleration to Displacement

As this paper is based on film positional calculation, this section will not enter into too much detail. It will just mention the common problems regarding obtaining a dummy head position using acceleration data and clarify that this particular method is discarded for this case.

The use of accelerometer data is a common procedure for calculating the displacement of an object. But that does not mean it is a perfect, accurate solution. A position cannot be calculated directly from an accelerometer. It is necessary to calculate a displacement regarding the first position offset of the head. This is the first problem regarding accelerometer to displacement calculation.

Double integral from acceleration samples will provide a displacement difference from one state to the next relative to the frequency data acquisition. This means that one displacement calculation needs four data acceleration samples. As with all calculations, acceleration has an uncertainty that will be accumulated on every displacement result.

When this calculation is made from the centre of gravity (COG) of the dummy head, we can say that this calculation is relative to the entire head as a solid object. To determine the direction of the tri-axial accelerometer it is necessary to mount a gyroscope on the COG dummy head.

As the accelerometer inside the head can rotate in very different ways, the gyroscope calculation must notify the direction of the head. As with the acceleration, the angular velocity of the gyroscope also has an uncertainty that will be added to the previous. Vibrations and small errors will add more uncertainty to the displacement calculation.

Other related problems are the position of the accelerometers and gyroscope between each other and the COG. The calculations to fix these offsets will increase the uncertainties.

Because the final objective is to compare the head against any rigid part of the car, the displacement calculated must be relative to the coordinate system of the car. That will add another problem, as the car moves in a different direction to the head and should also be calculated by the sensors on the car.

FILM BASE DUMMY HEAD POSITION ANALYSIS

The analysis of the head bottoming out or rollerblading the airbag during a crash test is an important matter for occupant protection. The airbags are changing their morphology functionalities because of newly arriving protocols. The complexities of the new crash tests and new dummies, such as the Small Overlap and the THOR dummy, are demanding more precise and fast tools to analyse the behaviour of the dummy.

The Minimum Distance of the Head (MDH) is the calculation performed by the combination of photogrammetry and 3D software to find the minimum distance between the dummy head and a rigid object. This calculation provides the information needed to understand how the head is performing against the rest of the car.

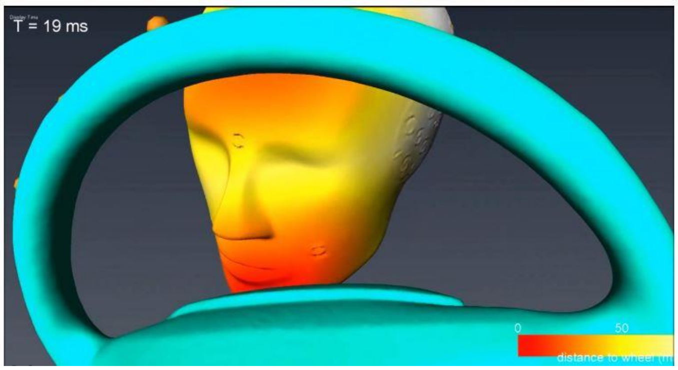

Figure 1. Calculation of the minimum distance between a scanned dummy head and steering wheel.

The dummy head position calculation is based on the 3D position of three points on the head. The position is relative to the car's coordinate system. For a better understanding of the dummy head behaviour, the application exports an animation of the head and the solid object to be compared with. This animation is the real movement of the head relative to the car in a 3D software environment.

A 3D scanner is used to provide the 3D mesh of the dummy head and the parts of the car that will be compared to the head. It is very important that the head is scanned, because the 3D points position are relative to the surface of the real object. When the animation is completed, the complete mesh vertices of the head mesh are measured the distance against any other mesh on the test, such as the steering wheel or the pole barrier.

3D Tracking

To deal with the demand for more accurate tools to understand the behaviour of a dummy head during crash and sled tests, a film analysis using photogrammetry and centre point detection on the movies recorded during the test was developed. This tool has the requirement of placing two cameras with different angle relative to the point that will be measured.

The combination of photogrammetry and centre point detection on two synchronized cameras provides three coordinates of the same exact point. The calculated point must be viewed by the two cameras. And at least four reference points in a cube form must be viewed by the two cameras. This calculation is commonly named as 3D Tracking.

There are different types of algorithms to detect the centre of a real point represented as white and black pixels on the movie. But the most important matter is that the algorithm provides a subpixel position. The algorithm gathers information of contrast pixels and calculates where the centre of the target inside the pixel is. The uncertainty of this measurement will be represented as a percentage gap of the pixel. Further on, the paper will mention the uncertainties of the most common algorithms.

Reference to a Coordinate System A high-precision machine is used to calculate positions of targets with respect to the coordinate system of the car. The centre of the target is represented by a point or intersection, depending on the type of target. The 3D position of the target centre will be used as a reference to calculate the camera orientation with respect to the coordinate system of the car.

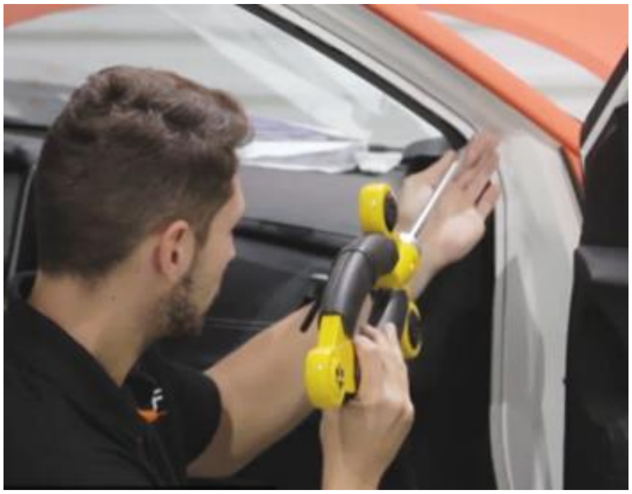

Figure 2. Measurement of 3D points on the car by a CMM operator.

The camera orientation is used to calculate the 3D position of any point on the image. Two cameras between 20–45º of difference are needed to calculate the position of any 3D point on the picture. The point position on the picture compared to the reference points determines the camera orientation that will enable the calculation of the 3D position of any visible point by the two cameras.

Camera orientation can be static or dynamic. The static camera orientation fixes an orientation to one frame of the video. These make it possible to calculate how a point moves with respect to a fixed coordinate system. A dynamic camera orientation has the same calculation, but with respect to a moving coordinate system. Tracking of the reference points must be done to perform a dynamic camera orientation. The dynamic coordinate system also helps to counteract the camera vibration.

On the minimum distance to head calculation, a dynamic camera orientation is required to represent the movement of the head with respect to the car's coordinate system. The final real animation head will be represented as if the head was moving towards the car and the car was static. This procedure reduces time consumption and the number of cameras.

Photographic Quality Strategic position of the cameras and targets is essential to ensure that the tracking quality of the points is the best possible. As well as the camera position, the filming configuration will also increase the accuracy. It is required to reduce the ghosting effect of the picture to a minimum to avoid having pixels represented as something that they are not in reality.

Regarding the pixel information, depending on the video format, the pixels could have false information generated by the compression of the file format. Software must read RAW formats of the movie to avoid this kind of problem. Cameras must not interpret the reality; they must show exactly the light information that is arriving to the camera frame.

Post-processing the video files must be done carefully, as any deformation will change the pixel information and the calibration coordinates of the camera, affecting the photogrammetry calculations. Cutting or extending the number of pixels will also affect the camera calibration. Further on, the paper will mention how camera calibration is performed.

The lens quality provides better light information arriving to the camera frame. Best quality glass on the lens will enable more realistic information and less aberration light caused by the lenses. The aberration caused by the lens can provide different pixel information more common in the perimeter of a bad quality lens mount.

The contrast between pixel information determines a figure of a target. That difference is used by the algorithms to provide centre target detection. A high dynamic range camera provides more information that the user will use to obtain a better contrast. The target quality printing is also important to have true black printing for a better contrast light.

Distance between the object and the image and lens distance is important to have a smaller pixel representation of the reality. The precision of the point detection is calculated by a percentage of the pixel size, so the smaller the representation of the reality as a pixel, the smaller the error.

Camera-Lens Calibration A calibration panel is normally used to calibrate a lens and camera group. This panel is prepared with measured targets. Different angle captures are taken to provide the maximum information to the calibration software. The differences between the real position of the targets and the positional targets on the picture are the information needed to provide a calibration file. Those files are unique for each camera and lens group.

Figure 3. Calibration panel and high-speed camera with exchangeable lenses.

The Wand calibration method is an alternative calibration process that provides 100 times more points than the calibration panel. To perform this methodology, it is required to use a “Wand Calibration” that has a measured and calibrated distance between two lighting balls that will be filmed by two cameras.

The camera lens calibration is important to provide the same uncertainty result in any part of the image. All lenses modify the light coming into the camera and deform the image. They must be calibrated to inform about this deformation on the photogrammetry algorithms. The calibration is very important to have the best accuracy possible.

3D Scanner Surface New technologies and lower cost of high-resolution cameras have provided the possibility of 3D hand scanner to be available for everyone. The scanner consists of the representation of every impurity of a real object as a point. A consecutive high quantity of points will generate a consistent 3D mesh.

The 3D mesh provides the information of any point of the real surface. Comparing any point of the 3D digital surface of the head against the car surface can provide the calculation of the minimum distance. Because we are calculating the position of the head on every frame of the crash test movies, the behaviour and minimum distance will be calculated at every state during the crash test.

Figure 4. Head dummy to 3D mesh performed with a scanner.

3D Point Displacement Calculation The 3D position of at least three targets on the dummy head is used to calculate the exact position of the full head with respect to a coordinate system. To achieve the real animation of the head, high-speed videos of the test are used. Normally a 1000 frames per second movie is used, having a sample position of the head at each millisecond.

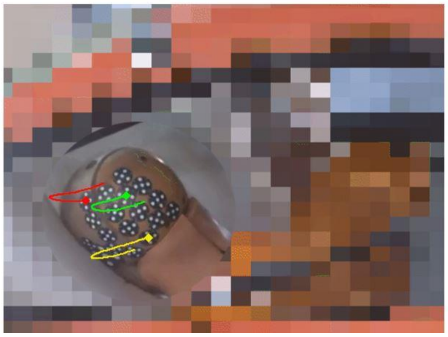

Figure 5. Trajectory of three points. Consecutive point position represented as a curve.

Tracking a point on the movie requires an algorithm that follows the same pattern for every sample. A revolutionary new algorithm has the possibility to follow the same pattern with 1% uncertainty of the pixel. That means that if the pixel represents 1 mm of the reality, the uncertainty will be 0,01 mm.

6DoF Point Displacement Calculation The 3D position of the head can also be calculated by only one camera. This methodology requires non-deformable objects and known position of the points to be measured. The Six Degree of Freedom (6DoF) algorithm uses at least four points of a rigid object to calculate its position. The methodology that the 6DoF uses to calculate the 3D position of the points is able to measure points not visible in the movie.

The 6DoF methodology requires the static measurement of all the points on the rigid object. These measurements must be referred to the same coordinate system. At least four of these points must be seen on movie to be tracked. If the points disappear but other points are visible instead, those can be used as new ones to continue the calculations. All the points measured on the rigid body will have 3D position during the time that at least four points were tracked.

The difficulties of the 6DoF methodology are mostly referred to the coordinate system. The final objective is to compare the car against the head dummy, therefore both of them must be on the same coordinate system. Until now the 6DoF algorithms worked on one coordinate system. A recent improvement allows two different coordinate systems to be compared. The update has an important impact on the camera preparation of a crash test: the number of cameras can be reduced to half and it facilitates the camera framing. Also, it opens the possibility to use on-board cameras.

Tracking point algorithms The tracked points on the head dummy must be exactly the same point on both camera views. The tracking algorithms calculate the centre point of the target with high precision. Then the followed points must be perfectly fixed to the same point in reality, then tracking algorithms work to ensure that these followed points have the best accuracy possible.

This algorithm calculates the position of the target by every frame so there are not cumulative errors on the calculated position of the point. That is essential to avoid problems of wrong displacements of the points. At every frame the position of the point is referred to the coordinate system of the car.

Table 1.
This table represents the uncertainty of the most used tracking algorithms

Point Detection Algorithm	Uncertainty (% of the pixel)
Correlation	50%

Centre of Gravity	20%
MXT	20%
Quadrant symmetry	10%
Correlation advanced	1%

Computation Minimum Distance Every three point's position on the head is represented as a virtual state of the head. The representation has the orientation of the virtual 3D head mesh with respect to the vehicle. The head will have the rotation and position as in the real crash test but in the virtual environment. From the calculation of three points of the head at every frame of the picture and then represented as a step of displacement on a virtual software program, it will have the exact animation head as in reality.
The point's position head are calculated relative to the vehicle at every movie frame using the dynamic coordinate system. On the animation "GIF", the vehicle will be represented as if it were not moving and the head will be moving along with respect to the car.

The minimum distance is the resultant of the 3D distances to the objects around the head dummy. This calculation is represented as a graphic of minimum distance by time.

Because the orientation of the camera to the vehicle is previously calculated, it is possible to represent the 3D head animation overlap with the video file. This file provides the visualization of the full head coordinated with the rest of the video and provides the opportunity to observe and understand the behaviour of the head and the airbag.

As long as this methodology is performed in every development test, it is possible to compare the behaviour of the head dummies for different types of restraint systems. The evolution of minimum distance graphs is also a tool to be determined when and how the head is acting towards the object it is compared to. This kind of analysis provides the information needed to provide the changes to the restraint systems on a development process of the car.

VALIDATION PROCESS

Validation of the full process determines the precision of this analysis, depending on every aspect that was analysed in this paper. The uncertainty is less than ~1.5mm in perfect conditions. This precision is achieved by carefully preparing all influence parameters of the measurement.

A full process validation test with different conditions is performed to determine if the final result, minimum distance comparison, has the best result possible. As well as providing a perfect condition environment and non-destructive test that allows repetitive tests.

The validation will prove if the resultant of minimum distance is the correct one. Two scanned parts, head and a plane surface, are filmed with a known distance object in between. The minimum distance result should be the same as that object, 14.9mm in this case. The best result achieved in these tests is 13.51mm, a 9.3% uncertainty.

Improvements for Better Accuracy

To provide the perfect accuracy in the calculations many tests were performed and three variables were tested: 3D mesh model, the angle between cameras and the tracking algorithms.

Angle Between Cameras On a 3D methodology, the angle between the two cameras will provide the best results in a 90º difference. But at that differential degree, the flat sticker target will not be seen by the two cameras. So the best degree condition will offer a good visibility of the target and enough angle to calculate the 3D position. It is proven that a 20º differential is ideal for providing perfect tracking and 3D position of the point. Less than 20º will produce high errors on the perpendicular to the camera axis.

The 6DoF methodology does not have this angle problem, but can be compared to the triangulation of the points measured. The four points tracked on the head must be as separated as possible between them. That will provide the triangulation needed to calculate the position of the coordinate system with more efficiency. If the points tracked are too close to each other, the small errors of the tracking algorithm will affect the 6DoF calculation more.

The tests performed regarding the 6DoF accuracy in the same conditions as the 3D methodology has proven that the last one is the most accurate. The 6DoF has a 13% increase uncertainty respect to the 3D methodology.

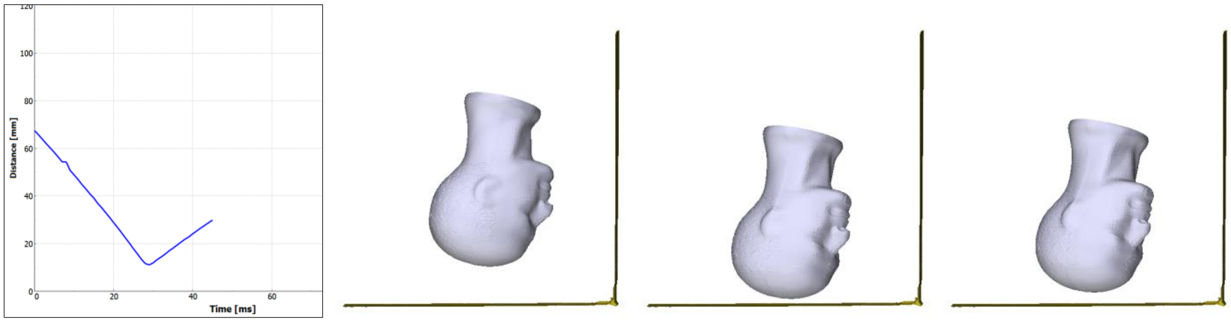

Figure 6. Minimum distance head graph representation. 6DoF tracking methodology. Followed by three states of the animation. The centre state is the minimum distance.

<u>Tracking Algorithms</u> The best tracking algorithm must be defined by the user taking into consideration the conditions of the movie. It is essential, as shown in the next graphs, that some tracking algorithms provide noise to the result.

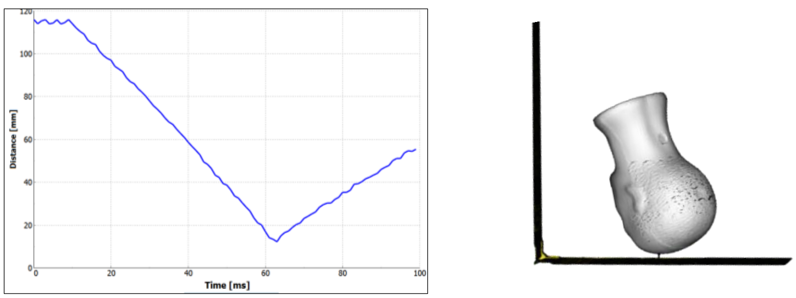

Figure 7. Minimum distance head graph representation. This tracking was performed by an MXT algorithm (20% uncertainty). The animation has noise and can be noticed on the graph.

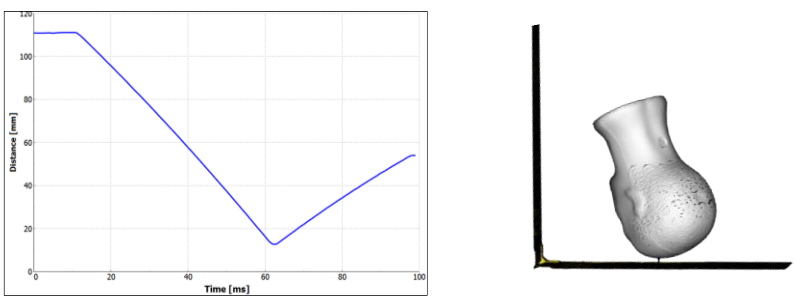

Figure 8. Minimum distance head graph representation. This tracking was performed by a correlation advanced algorithm (1% uncertainty). The noise was reduced dramatically and represents a faithful animation.

Choosing the right algorithm will increase accuracy, a 3.4% incremental accuracy in this test. The benefit may not be much, but the animation of the head is represented with higher precision. The comparison between different animation, movie or even simulation occupant behaviour will be more efficient.

<u>3D Mesh Model</u> The 3D mesh model is related to the 3D scanned surface of the head. The comparison to calculate minimum distance is related to the nodes of the mesh. Part of the uncertainty of the minimum distance is related to the separation of the nodes. The 3D mesh should have the most compacted node mesh possible to reduce the uncertainties. It is important to notice how the mesh is calculated. Increasing the mesh density by software calculations instead of the point cloud from the scanner, could generate more uncertainties.

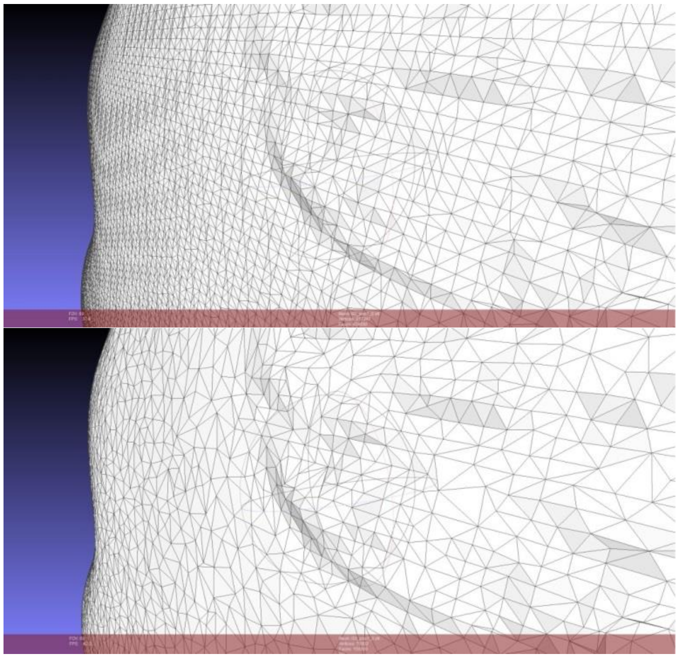

Figure 9. Mesh density comparison. Above picture represents a directly exported mesh from the scanner, above a reduced mesh density. The first has more precision result and the second will process faster.

The validation process notices that these changes provide a 4.8% incremental accuracy. This was the best result yet, with a total of 9.3% uncertainty, in this particular case it is around 1.5mm uncertainty.

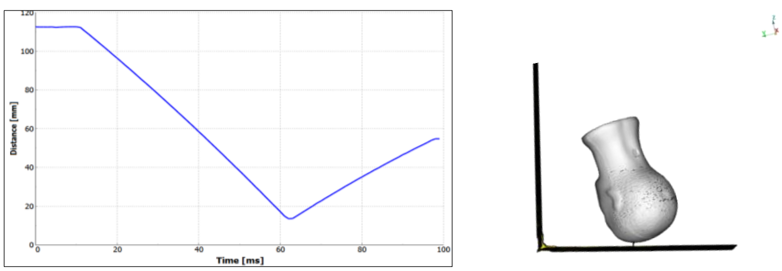

Figure 10. Minimum distance head graph representation. This graph should be compared with figure 8. The mesh used here is the original taken directly from the scanner.

CONCLUSIONS

Photogrammetry and motion analysis is becoming an important tool to analyse crash and sled tests for occupants and the vehicle itself. The minimum distance to the head tracking methodology is becoming an important assessment to provide the right information and allow comparison of different configuration tests and restraint systems.

Improvements in this methodology are continually being made and more improvements will be made in the future. On-board tracking is a big step forward as many different tests will be introduced with autonomous driving as the complexity of new car models with new occupant positions will need a fast and accurate way to analyse restraint systems. This tool could help many development procedures.