MEASURING ACCIDENT SCENES USING LASER SCANNING SYSTEMS AND THE USE OF SCAN DATA IN 3D SIMULATION AND ANIMATION

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ABSTRACT

The Investigations and Risk Management Group of TRL Limited has been researching and developing applications for 3D laser scanning technology in traffic accident investigation and reconstruction. Laser scanning systems can rapidly capture vast amounts of data thereby allowing such systems to 'preserve' incident scenes. This data also provides a source for the construction of detailed three dimensional models which can be used in vehicle dynamics simulation and incident animation.

Applications of this technology in accident investigation and reconstruction include the spatial measurement of physical evidence at traffic accident scenes, including: vehicle positions, vehicle damage, tyre and other road marks, debris, the road geometry and that of the surrounding environment. Preliminary studies have determined that the use of laser scanning systems could allow significant time savings to be made in the measurement of complex road traffic accident scenes as well as capturing significantly more spatial data at such scenes than is possible using surveying systems such as total station.

Laser scan data has been used to generate detailed road surface models, in the form of dense three dimensional meshes. These surfaces can be used for complex vehicle dynamics simulations where the precise geometry of the road surface is important to the simulation. Laser scanning systems also allow detailed geometric data to be captured at sites where such data is difficult or impractical to measure using other means.

As the use of laser scanning systems at incident scenes (or sites) typically involves the measurement of areas surrounding the road such as topography, buildings, vegetation etc., this information can be used to construct detailed three dimensional environments to enhance computer simulations, or within which to animate the circumstances of an incident.

This paper describes the use of laser scanning systems at incident scenes and presents examples of the use of 'scan' data in the development of complex vehicle dynamics simulations and animated incident sequences. Through the work carried out by TRL, laser scanning has been found to provide a valuable tool for accident investigation, analysis, and the presentation of accident reconstruction.

1. INTRODUCTION

In December 2000, the Investigations and Risk Management (IRM) Group of TRL Limited acquired a RIEGL LMS-Z210 laser scanner and ISiTE 3D analysis and visualisation software, in order to investigate the potential for such systems in incident investigation. In particular, it was envisaged that laser scanning systems could increase both the speed and detail of data capture at major incident scenes. Such systems could therefore assist investigators, and also fulfil one of the key aims of the UK Highways Agency, which is to reduce congestion associated with major incidents on the UK's motorway and trunk road network.

Since the system was acquired it has been deployed to the scenes of major transport incidents (e.g., the rail crash near Selby, Yorkshire, UK, in February 2001), to road traffic accident scenes (as part of the 'On the Spot' (OTS) accident research project), and to sites of road traffic incidents being investigated by the IRM group. In work currently in progress the system has been assessed against other measurement systems, such as reflectorless total station and photogrammetry, in a series of comparative trials on TRL's research track. This work may be followed by on-road trials with UK police forces and/or maintaining agents for the Highways Agency trunk road and motorway network.

One benefit of the detail in which data is captured by laser scanning systems is the ability to build complex three dimensional road surfaces (as well as the verge/shoulder surfaces surrounding the road). Such surfaces can be created within minutes of completing the laser scan of a subject site. The resulting surfaces can be highly detailed (subject to user requirements), and can be imported into computer simulation systems for vehicle dynamics simulation. In addition to detailed road surface models for computer simulation, the data captured by laser scanning systems can be used to construct full environment models for computer animation (or visualisation).

In addition to the geometry of the road and surrounding topography, the environment models can accurately reflect the position and extent of all vegetation, street furniture, buildings and infrastructure at the incident site.

2. LASER SCANNING TECHNOLOGY

Laser scanning systems such as the RIEGL LMS-Z210 laser scanner and the ISiTE 3D analysis software (Figure 1), are designed for the acquisition and management of large volumes of three-dimensional point data.

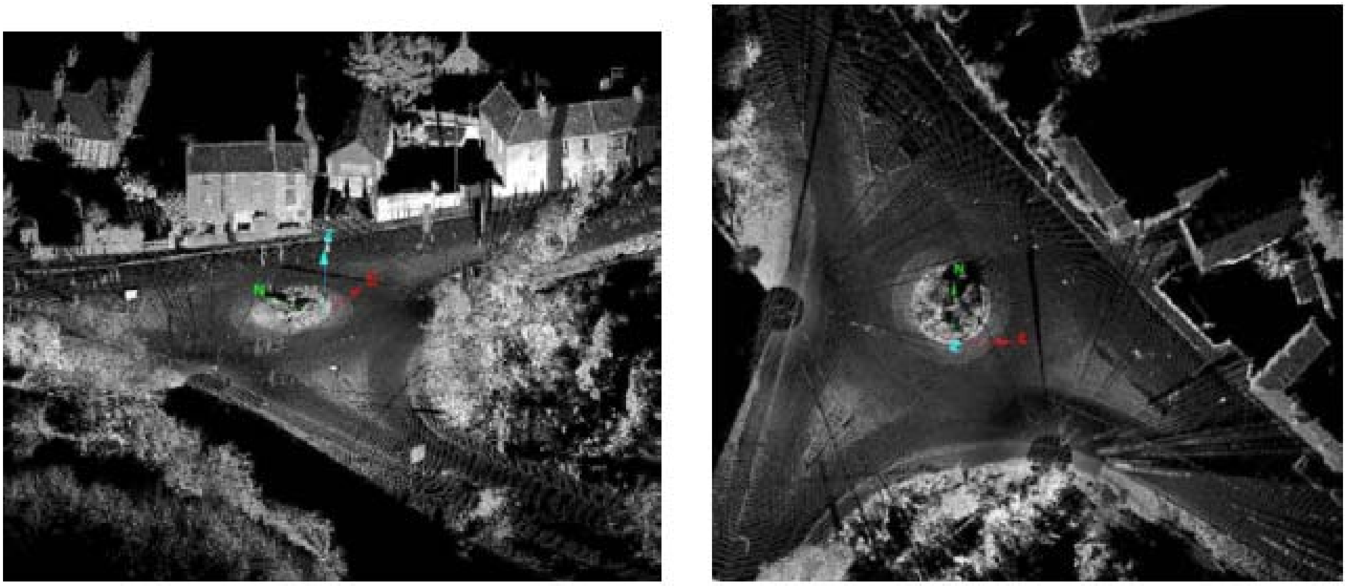
Figure 1. RIEGL LMS-Z210 laser scanner, and the ISiTE 3D analysis software.

Such systems have the capacity to acquire data points extremely rapidly: the LMS-Z210 scanner, for example, measures data at a rate of around 6,000 points per second, and more recent systems can achieve greater rates. Thus, in the course of a six minute ‘fine’ detail scan, the LMS-Z210 scanner can measure around 2.2 million data points. Such a scan would involve the LMS-Z210 scanner recording to its maximum extents of 340 degrees horizontally and 80 degrees vertically. At maximum resolution the LMS-Z210 scanner can measure over 5 million points in one scan. This relates to 169 points per every 1 X 1 degree (horizontal and vertical) ‘window’ around the scanner.

In the case of the RIEGL LMS-Z210 laser scanner, data collection is achieved by way of a vertically mounted rotating mirror system. These mirrors, coupled with the horizontal rotation of the scanner ‘head’, reflect out and receive in the beam of the scanner’s internal range finding laser (infra-red wavelength 0.9µm, or ‘photo IR’). Thus, the emitted laser pulse is directed through a precise angular pattern in a ‘window’ of measurement. The angular data and range measured by the scanner is then downloaded in real time to a laptop or ‘tough book’ type PC, where the resulting three dimensional scene model can be visualised and manipulated.

Laser scanning software calculates X, Y and Z co-ordinates from the angular and distance information recorded by the laser scanner. These points represent the surfaces of features and objects within the scan ‘window’ and in line of sight of the scanner. The numbers of individual point data collected for any one scan will vary with respect to the size of the scan window and the user-defined resolution of the scan. Using the RIEGL LMSZ210 system a few hundred thousand to over two million points would typically be measured in each scan.

This data is presented to the user as a precisely defined cloud of three dimensional points. In the case of the LMS-Z210 scanner and the ISiTE software, indices of reflectivity (the intensity of the reflected beam) and ‘RGB’ (red, green and blue) colour, are also recorded for each point. Figure 2 presents example laser scan data of a road environment. These images are two-dimensional representations of three-dimensional data. Such data can be collected equally well under daytime or night time conditions.



(a) Bird’s eye view of laser scan data

(b) Plan view of data

Figure 2. Example point cloud data from a typical road environment, viewed using ISiTE software.

Note that many features within the laser scan data in Figure 2 can be easily discerned. This is due to colouring of the data points according to the intensity of the reflected laser signal. The more reflective objects (or areas) in the area being measured will reflect a more intense laser pulse back to the scanner. A higher reflectivity value is assigned to such points by the laser scan software. The reflectivity value is then used to colour the data which allows objects and areas to be discerned when the data is viewed.

The LMS-Z210 laser scanner also records a colour value for data points, which when operating in good light conditions can improve the discernment of objects and areas within the scan data.

The resolution of objects or environments measured using the laser scanner decreases with the distance of the object (or portion of the environment being measured) from the scanner. The beam divergence of the LMS-Z210 scanner is 3mrad, which equates to a beam width of 30mm at 10 metres, and 300mm at 100 metres.

Thus, whilst the LMS-Z210 laser scanner can measure objects at distances of up to 350 metres, at this distance such objects have a very limited resolution. A more reasonable maximum distance for medium sized object discernment and basic road cross-section measurement has been found to be around 50 metres. Where laser scanning systems are used at incident scenes to measure debris and tyre marks etc, distances between scan locations of between 20 and 30 metres have been found to be effective. To achieve detailed coverage of key areas (and evidence) at an incident scene several laser scans may, therefore, be required.

Multiple scans of target objects or environments taken from different positions can generally be merged or ‘registered’ together in software packages designed to analyse laser scan data, such as ISiTE. Figure 2, for example, presents data from two scans registered together. Once scans are registered they share a common coordinate system and measurements can be taken from any point in one scan to any point in any other scan.

By using the laser scan point data as a base, lines and surfaces can be created either manually or automatically using the Computer Aided Design (CAD) functionality of the analysis software.

In the case of the ISiTE software, detailed plan drawings, cross-sections and long sections, three dimensional building models and three dimensional road surface models can be constructed and exported in a CAD compatible format (i.e. .dxf). An example of such data is provided in Figure 3.

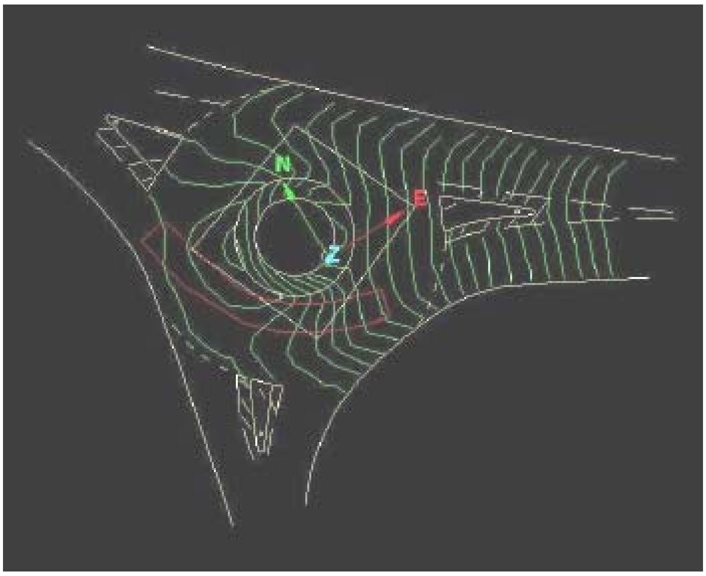


Figure 3. CAD plan of a road environment with line marking and road contour detail.

In the course of normal laser scanning in a road environment, vehicles and pedestrians may pass through an area that is being scanned and therefore be measured by a scanning system whenever they meet the beam of the scanner. It has been found that these points can be filtered from a data set quite effectively by the ISiTE software (using techniques such as multiple scanning).

Thus, surveys of busy roads can be undertaken without the need to close the road, or traffic lanes. Figure 4 presents an example of a site measured using the LMS-Z210 without closing the road to traffic.

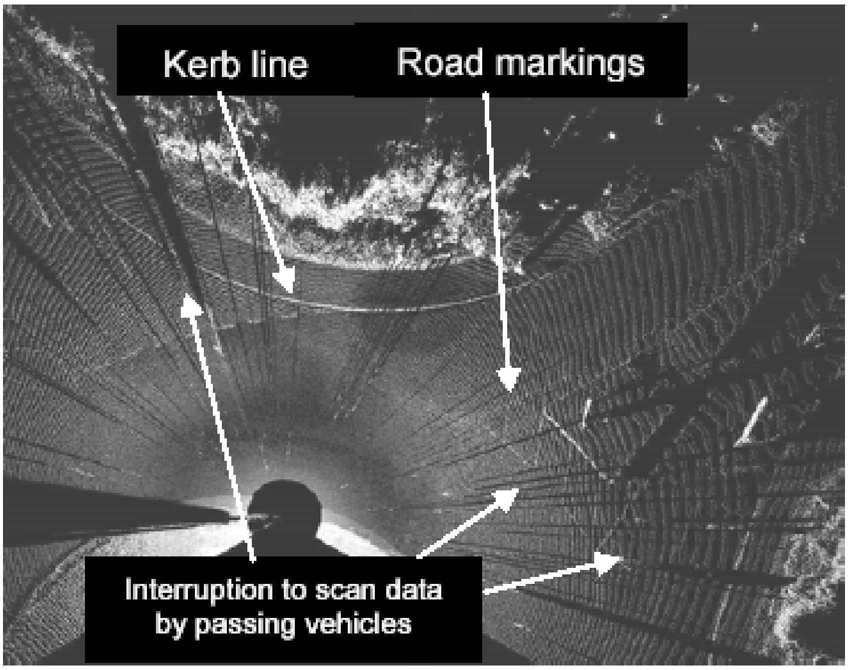


Figure 4. Plan view of ‘raw’ laser scan data at a highly trafficked roundabout junction.

The RIEGL LMS-Z210 scanner was developed for static use in macro applications requiring centimetre measurement accuracy.

Techniques developed within the ISiTE software have, however, increased the accuracy to which measurements can be made. The most important of these is multiple scanning and the ‘averaging’ of the data. This technique offers the possibility of improving data accuracy (and thus the accuracy of 3D models) to sub centimetre levels.

3. LASER SCANNING AT INCIDENT SCENES

One of the main applications for laser scanning technology, investigated by TRL, is the use of such systems at the scenes of road traffic accidents for both the purposes of accident investigation, and road safety research (through TRL’s ‘On The Spot’ accident investigation research).

This work has been undertaken to assess the implications of the use of laser scanning technology at accident scenes. Possibly the greatest benefit of using laser scanning systems at complex road traffic accident scenes is for the speed of data capture to allow reduced road closure times, thereby reducing the costs of road traffic incidents to the economy, and the travelling public.

Obviously the key to the effective on-site use of laser scanning equipment is an understanding of how such systems record data and how that data will be analysed.

Considerations on-site include:

- Identifying the best location for the laser scanner. Laser scanning systems are designed to measure data remotely, without the need for reflectors or surveying prisms. Thus, laser scan measurements of road carriageways, for example, can be taken from remote locations such as the road shoulder, embankments, bridges, etc.
- Positioning of the laser scanning equipment to minimise ‘shadowing’. Shadowing is typically caused by physical obstructions such as accident-involved vehicles, road furniture, emergency vehicles, personnel and vegetation.
- Elevation of the scanner position above the ground/road surface. The higher the elevation, the greater the spread of high intensity measurement over the road surface. However, in the case of the LMS-Z210 scanner, greater scanner elevation also increases the area directly below the scanner which cannot be measured due to the +/-40 degree (above and below the horizontal) measurement window of the system.
- Scanning intensity. Higher intensity captures more detailed information, but increases scanning times and data storage requirements.
- Horizontal and vertical field of view of the scanner system. Typically both can be defined; rotating scanner systems (such as the LMS-Z210) can record up to 360 degrees in the horizontal plane, with varying extents in the vertical plane, typically a minimum of +/- 40 degrees above/below the horizon. Greater fields of view require longer scan times and generate increased volumes of data, but reduce the need for continual scanner realignment.
- Number of scans required to provide the required level of data. In some cases all relevant information may be captured in one or two scans. In other situations up to half a dozen laser scans may be required.
- Reflectivity and/or colour of the areas/features being scanned. In some cases marker paint or evidence markers (raised or reflective) may be used to identify the location of certain features within a laser scan which may not otherwise be discernible, but which will need to be identifiable within the scan data. The experience gained in using laser scanning systems at road traffic accident and other major incident scenes, and by undertaking preliminary research in this area, suggests that laser scanning systems could reduce the time associated with data measurement at complex accident, and major incident, scenes. This could provide a positive cost benefit to regional economies where road traffic incidents cause significant costs to road users.

4. CONSTRUCTING 3D ENVIRONMENT MODELS USING LMS-Z210 DATA AND ISITE SOFTWARE

TRL’s work in this area has included the development of 3D models for computer simulation and animation (visualisation) using laser scan data.

In the case of 3D modelling for the simulation of vehicle dynamics, laser scan data can be analysed using ISiTE software to create 3D surfaces. The individual triangular facets of the surface model link the 3D laser scan points used in the process of surface creation (not all points need to be used). Once created the surface model can be exported in .dxf format.

To ensure that size of the .dxf geometry file is not excessively large a certain amount of data thinning is required before creating the model. Rather than deleting data, however, this process simply masks points temporarily (an important consideration for evidential purposes).

There are two main methods for the measurement and thinning of data in preparation for creating a surface model for computer simulation from LMS-Z210 scanner data. These techniques depend on whether the site data was captured in single scans, or using the multiple scanning technique.

In the single scan technique, data is captured to the accuracy limits of the LMS-Z210 scanner, i.e. +/- 2.5cm point accuracy (in terms of line-of-sight distance from the scanner). The subsequent preparation of this data for surfacing involves both the 'smoothing' of the point cloud and the thinning of the point data by highest or lowest elevation values. These processes are discussed in greater detail below.

In the multiple scan technique, up to 16 scans are captured from each scan location. This process provides up to 16 measured values for each point within the scan window. From these multiple scans an 'average' scan is calculated in which the three dimensional co-ordinates of every point are averaged from the repeated measurements (i.e. up to 16 values).

4.1 Creating the Road Surface Model

Once the preparation of the laser scan data is complete, a road surface model can be created by performing a two dimensional triangulation of the remaining data. This process creates a three dimensional mesh comprising triangular facets between adjacent data points. This occurs within the area defined by the extents of the data, or a specific area defined by the user.

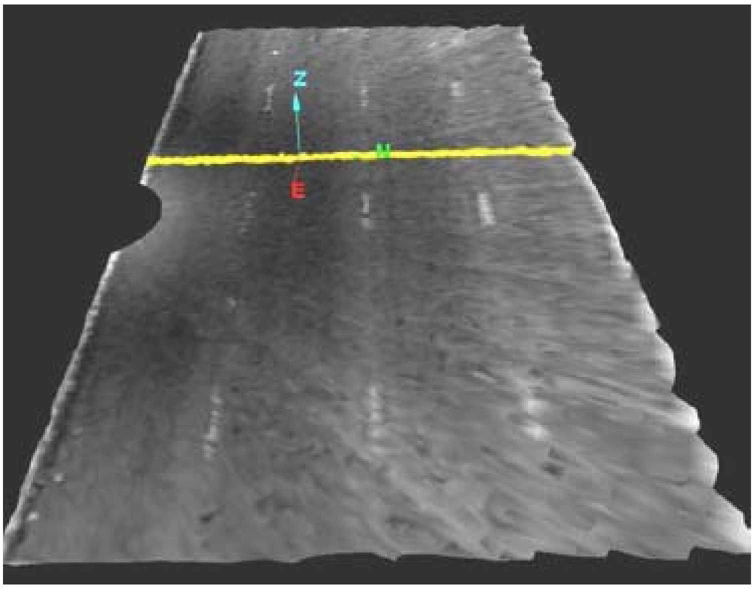


Figure 5. 3D road surface model of a busy four-lane motorway, created using the multiple scanning technique.

It should be noted that if the data is not prepared correctly, then the surface model will look visibly uneven in certain render modes. This effect is caused by the relatively high angles that can be created between the facets of a surface if the scan data has not been prepared appropriately for the creation of the surface model, i.e. where the vertical height between adjacent points is relatively high.

5. EXAMPLE COMPUTER SIMULATION AND VISIBILITY ANALYSIS USING LASER SCAN DATA

In order to simulate an incident involving a single vehicle loss of control and rollover, and to provide speed estimates for a vehicle during the loss of control, the site of an incident was scanned using the LMS-Z210 laser scanner and ISiTE software.

The incident involved a vehicle leaving the road to the left, mounting a verge and embankment, and rolling towards its right. During this movement, the vehicle travelled some distance through the air before landing on its roof, and sliding into collision with another vehicle before coming to rest. In the case of this incident the analysis focussed on determining what the initial speed of the vehicle must have been to allow it to take a known path up, and along, the embankment, and to land on the road surface at a point indicated by scrape marks.

Firstly, the marks made by the vehicle on the embankment and on the road surface were marked with road paint. This allowed these areas to be discerned within the scan data, and thus allow ‘markers’ to be placed within the surface model to assist in the development of the vehicle dynamics simulation.

Figure 6. Laser scan data of an incident site involving a vehicle rollover, example cross-section highlighted.

Example laser scan data of the incident site is shown in Figure 6, and a cross section of the data is highlighted.

This single scan data was prepared using the smoothing and highest point method (as described above) and a 3D surface model was generated, Figure 7.

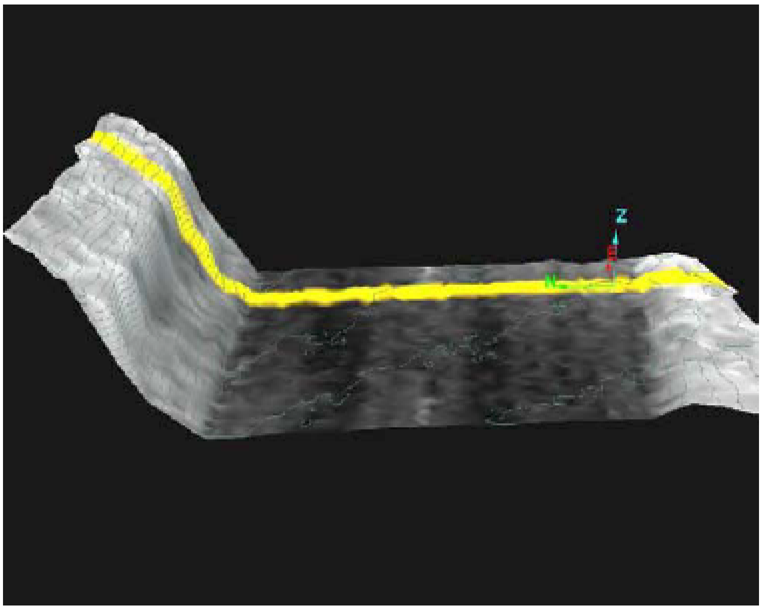


Figure 7. Section of the road surface model constructed by ISiTE, example cross-section highlighted.

The surface generated using the ISiTE software was made up of a large number of triangular facets (surfaces), thus making the model too large to import directly into computer simulation software (in this case HVE) in .dxf format. HVE (Human Vehicle Environment) is a complete 3D simulation environment providing vehicle design engineers, safety researchers and accident reconstructionists with an extremely sophisticated (but very easy to use) tool. The surface model was, therefore, firstly exported into Rhino 3D software and converted into an editable NURBS (Non uniform Rational B-Splines) surface. NURBS are industry standard tools for the representation and design of geometry. The NURBS surface format allowed the complexity of the surface model to be controlled. This allowed a greater amount of detail to be preserved on the embankment as opposed to the road surface, where less detail was required. Figure 8 shows the editable NURBS surface created in the 3D modelling software.

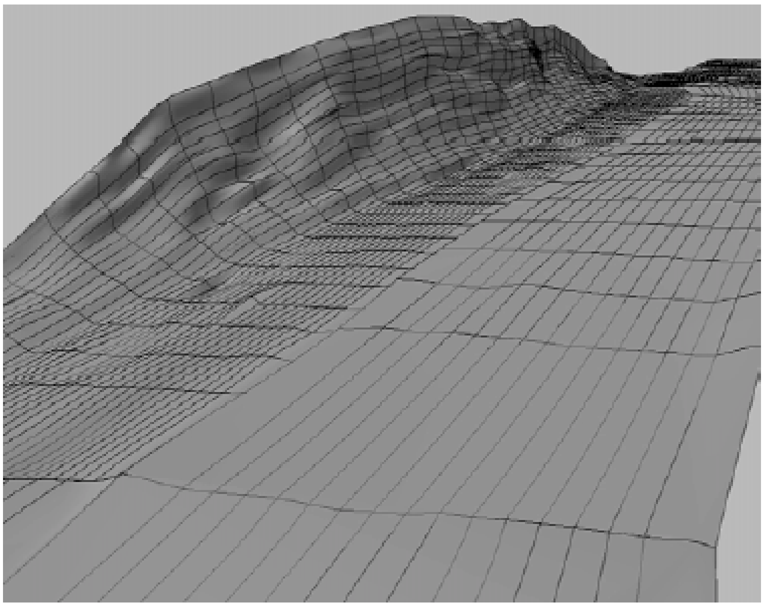


Figure 8. Editable NURBS surface created from scan data, converted in Rhino 3D.

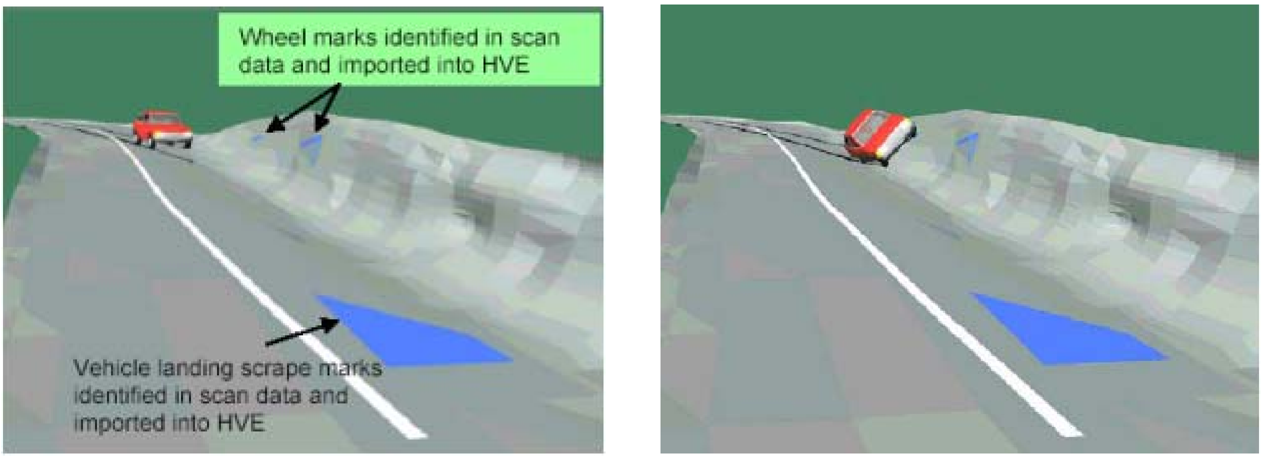
Additional features such as wheel mark locations on the embankment, and scrape mark locations on the road surface were extracted from the scan data and converted to surfaces separately in Rhino 3D. These surfaces were then imported separately into the HVE software and combined with the surface model.

Figure 9 presents frames from the HVE simulation of the example incident using the surface data generated from ISiTE.

For the enhanced visualisation of this case (analysis of driver view) the X, Y, Z and roll, pitch, yaw vehicle movements from the simulation were imported into 3D Studio Max software.

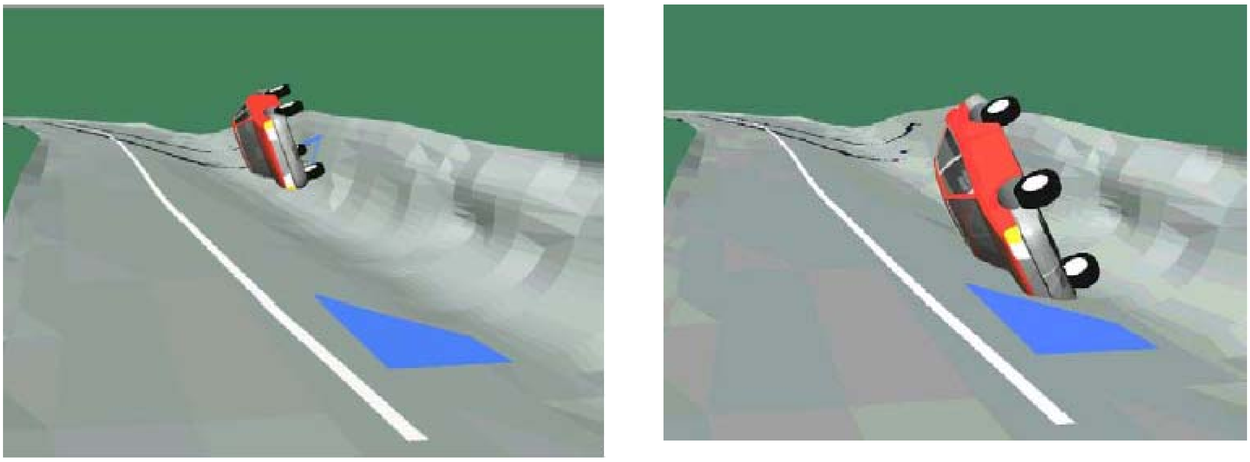
An enhanced environment model was created in 3D Studio Max using the surfaces created for computer simulation as a base. Additional surfaces were introduced into the 3D Studio Max environment model to represent the vegetation at the incident scene. The vegetation extents were created directly from laser scan data points by creating 3D surfaces from the data, and texture mapping a semi-transparent leaf texture to the surfaces, Figure 10.

This process allowed the visualisation of the involved driver's line of site through the bend immediately before the loss of control. Thus, from the visualisation the visibility of approaching vehicles around the bend could be assessed from the driver's perspective.



(a) Vehicle position before entering the left verge

(b) Vehicle position/orientation during front left wheel contact with embankment



(c) Vehicle position/orientation during rear right wheel contact with embankment

(d) Vehicle position/orientation during impact with road surface

Figure 9. (a-d) HVE vehicle dynamics simulation using road and environment model created from laser scan data.

Figure 10. Rendered image of embankment with vegetation extracted directly from laser scan data.

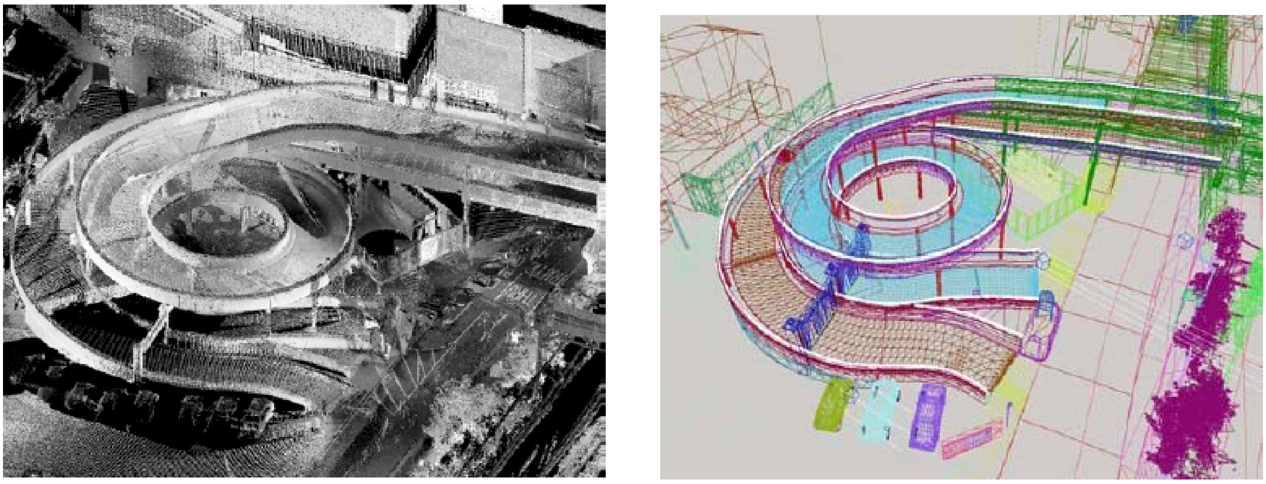
6. EXAMPLE OF SCENE ANIMATION USING LASER SCAN DATA

Whilst the following example did not involve a road traffic accident it demonstrates the techniques used in building a complex environment for incident investigation, where the issues may include witness views and the movements of involved persons or vehicles, etc.

As part of the investigation of a suspicious death TRL were instructed to construct a 3D model of a road environment around and including a section of multi-storey car park.

This model was produced as a ‘real time’ VRML model to allow:

- viewing of the model from any location to allow the presentation of witness views and CCTV camera perspectives;
- animation of different scenarios of people and vehicle movement;
- real time walk-through’s of the site during the court proceedings, thereby allowing the court to fully appreciate the incident scene.



(a) Laser scan data of incident site

(b) Wire frame mesh built from scan data

(c) Textured 3D model of incident site

(d) Real-time textured model of incident site viewed in a VRML viewer

Figure 11. Process of creating a real-time model of an incident scene using laser scan data as a survey base.

The LMS-Z210 laser scanner and ISiTE software were used to survey the incident site. The scan data was then used to build the 3D model environment in 3D Studio Max. Continuous accuracy checks were made throughout the model construction process by comparing the position of NURBS surfaces with the original scan data.

Once completed, texture maps (from photographs of the site) were applied to the surfaces of the model to provide a photorealistic appearance. Finally, the surface model was exported in VRML format to allow the real time presentation of the model.

Such real time presentation allows an operator to move around anywhere within the scene, whilst not being able to pass through solid surfaces. The full process is demonstrated in Figure 11.

7. CONCLUSION

The techniques described above are particularly suited to the generation of complex road and environment models, which would be impractical to measure with a high degree of accuracy using traditional techniques such as total station or manual measurement.

Laser scanning systems can measure vast quantities of spatial data extremely rapidly. This characteristic allows detailed road and environment geometry (including, road surfaces, verge surfaces, kerblines, buildings, street furniture and vegetation) to be captured over large areas, and provides a basis for the construction of detailed road and environment surface models.

8. REFERENCES

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Gary is Group Manager of the Highways and 3D Modelling Group within the Investigations and Risk Management Group at the Transport Research Laboratory (TRL). He is also a Principal Consultant specialising in highway maintenance, network management, liability and corporate risk management matters. Holding a postgraduate Diploma in Management Studies, Gary is a Member of the Institute of Highways and Transportation and the Chartered Management Institute. In addition, he has City and Guilds qualifications in Highway Law and Administration, Training and Development and Street Works Supervision. He is also a qualified in Quality Auditing and Highway Health and Safety.

Gary was formerly the Maintenance Policy Engineer within a County highway authority with particular responsibility for policy matters, organisational change and the Government's modernisation agenda including Best Value. Prior to that he held the post of Street Works Engineer within the same authority and was the Secretary and Treasurer of a Regional Highway Authorities & Utilities Committee.