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# CONSTRUCTING DETAILED ROAD SURFACES FOR VEHICLE DYNAMICS SIMULATION USING 3D LASER SCANNING TECHNIQUES

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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, crime scene preservation, and transport related infrastructure investigations. One such application of this technology is the detailed measurement of road surface, verge and/or kerb line geometry.

Laser scan data has been used to generate detailed road surface models, in the form of a dense three dimensional mesh, for vehicle dynamics simulations where the precise geometry of the road surface is important to the simulation, or where detailed road geometric information is difficult, or impractical, to measure using other means.

The paper describes the methods used to generate detailed road surface models from laser scan data. Examples are provided in which road surface models have been created from data captured in heavily trafficked road environments, and in which laser scan data has been used to construct a complex 3D surface for a vehicle dynamics simulation.

The use of laser scanning systems at incident sites will invariably involve the measurement of areas surrounding the road such as topography, buildings, vegetation etc. This information can be used to enhance visualisations by allowing detailed models of the environment surrounding the road to be constructed.

## 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 (eg, 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 May 2003 the system will be 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 will 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 to HVE via a .dxf format geometry file.

## 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.

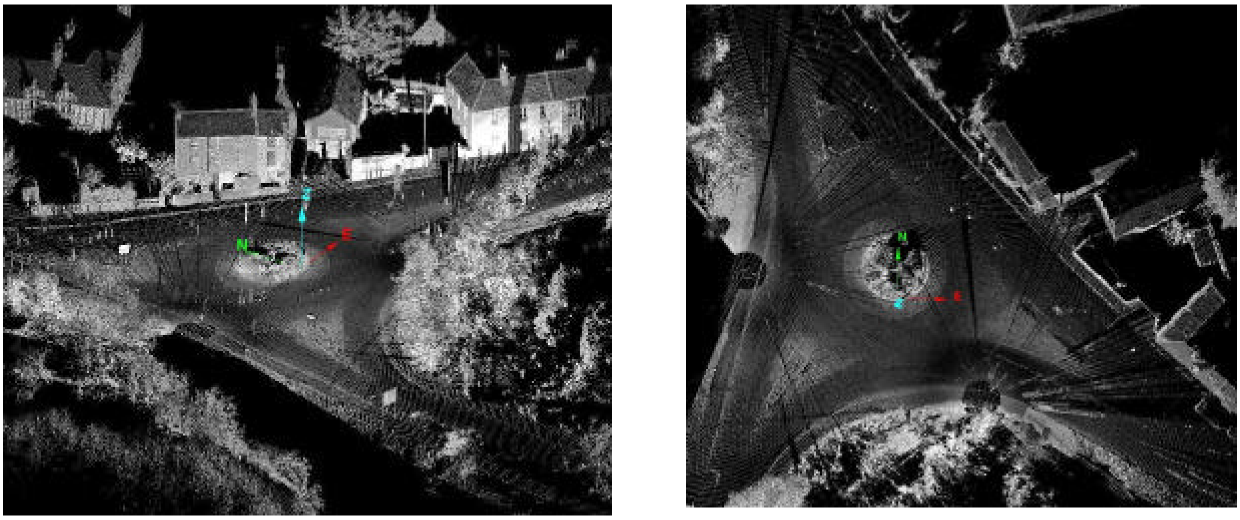
**Figure 1** RIEGL LMS-Z210 laser scanner, and the ISiTE 3D analysis software

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.

Laser scanning systems thus provide a rapid mechanism for the collection of detailed spatial information from any medium or large-scale subject or environment, such as a major incident site, a road traffic accident scene/site, or an area of infrastructure (Figure 2).

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 0.9ìm, or 'photo IR'). Thus, the emitted laser pulse is directed through a precise angular pattern in the '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 instantly visualised and manipulated.

Laser scanning systems scan a defined volume of space, and calculate X, Y and Z co-ordinates for points which represent the surfaces of features and/or objects within the field of scan and in line-of-sight of the scanner.



**(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 I-SiTE software

The numbers of individual point data collected for any one scan will vary with respect to the extent of the scanned area and the pre-defined resolution of the scan. The individual laser scans recorded by the system would typically be composed of hundreds of thousands of data points, and are presented in what is essentially a precisely defined cloud of three dimensional data points.

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. To achieve detailed coverage of key areas at an incident scene several laser scans may, therefore, be required.

Each scan produces a three-dimensional model which includes every static surface and object within line-of-sight. The resolution of the scan data can be set to match user requirements, with a maximum resolution, in the case of the LMS-Z210 scanner, of 13 measurements per degree, both horizontally and vertically. At this intensity the scanner measures 169 points per 1 X 1 degree window around the scanner.

From the distance and angular information recorded by laser scanning systems for each measured point, a distinct X, Y and Z co-ordinate is calculated within the analysis software. 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. When the scan data is coloured in this way the data presentation and analysis, are greatly improved, with easier object discernment and identification.

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. For example, Figure 2 presents data from two scans registered together. Once scans are registered, measurements can be taken from any point in one scan to any point in any other scan.

Once individual scans are registered together they share a common co-ordinate system. This co-ordinate system will be that of one of the scans to which the others have been registered.

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 .dxf format. An example of such data is provided in Figure 3.

Given the large volume of data captured by laser scanning systems it is possible to use the data points measured on buildings, vehicles, street furniture and vegetation, in addition to the data captured for the road infrastructure, to construct detailed 3D environment models. Whilst this paper discusses the use of laser scanning for the generation of 3D road/environment surfaces for vehicle dynamics simulations, it is recognised that the potential for these techniques in computer visualisation and animation are extensive.

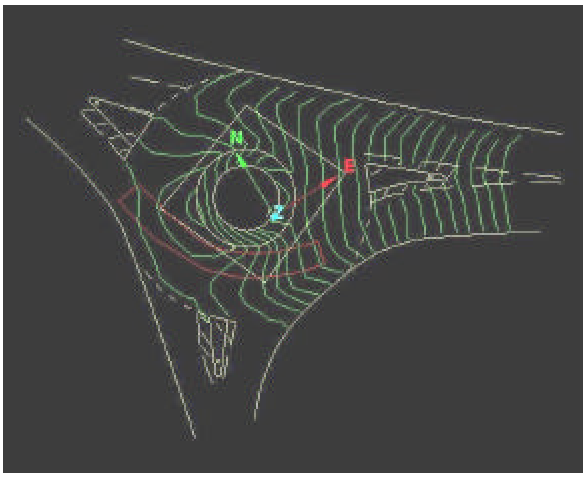



**Figure 3** CAD plan of a road environment with line marking and road contour detail

TRL's work in this area has also involved developing methods for the rapid modelling of 3D environments from laser scan data for visualisation and animation. This work has involved the modelling of environments at a number of major incident and crime scenes in the UK.

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.

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

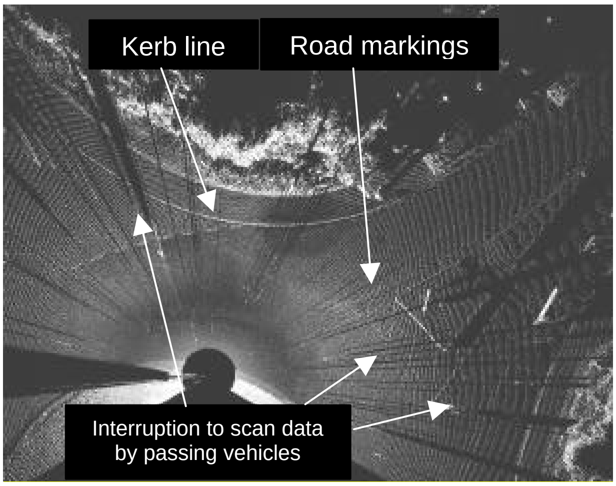



**Figure 4** Plan view of 'raw' laser scan data at a highly trafficked roundabout junction

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 to sub centimetre levels.

## On-Site use of Laser Scanning

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.

- The 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.

- The 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.

- The scanning intensity. Higher intensity captures more detailed information, but increases scanning times and data storage requirements.

- The 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.

- The 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.

- The 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.

## Constructing 3D Surfaces Using LMS-Z210 Data and ISiTE Software

Once laser scan data has been acquired from a site, the data can be analysed using ISiTE software to generate 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 generated the surface 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. 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).

<u>Point cloud thickness</u>

As discussed, laser scanning systems can record very large amounts of data. This data is at its most intense in areas close to the position of the scanner, such that areas of high data density are limited to areas within around 20 metres of the scanner (at ‘high’ scanning intensity 81 points are recorded per 1 degree by 1 degree window around the scanner). In areas of high data intensity the point cloud defining the surface of a road will have a certain thickness, i.e. the elevation of the individual scan points making up the road surface varies, this variation being caused by the measurement accuracy of the scanning system. Our experience is that this thickness is up to 5 cm for single scans, and around less than 1 to 1.5 cm for a set of point data averaged from multiple scans (10 or more).

Regardless of the thickness of the point cloud, the cross sectional shape of the cloud has been observed to closely match road surface vertical geometry.

Both relatively thick point clouds, such as those generated by the single scan technique, and the thinner more precisely defined cloud, such as those generated through multiple scanning, can be used to generate surface models, as long as the limitations of the data that are being used are recognised and accounted for.

Single scanning technique

In the case of the single scanning technique both the smoothing and thinning of data by highest or lowest elevation values take advantage of functionality within the ISiTE software. In preparing the laser scan data for the creation of a surface model, the 'smoothing' function reduces the thickness of the point cloud by correcting each data point with respect to the surrounding data points by way of an inverse distance averaging routine. Secondly, the 'thinning' of data by the lowest or highest points involves the splitting up of the laser scan data into cells (or volumes), and the detection of the lowest or highest points in each cell. The size of these cells can be defined by the user, and a size of 10 to 25cm is commonly adopted.

This technique ensures that the points from which the surface mesh is created are from the same 'height' in the point cloud (top or bottom). Thus, the effect of the data scatter caused by the measurement accuracy of the laser scanner instrument is significantly reduced.

It is important to note, however, that this technique can only be successful where there is sufficient data within each cell to allow a true low or high point to be selected, hence the importance of creating such surfaces in high data intensity areas.

Using TRL's standard laser scanning methods with the scanner mounted at a height of around 2.0 metres above the road surface and 2.0 metres back from the road surface edge, it has been found that sufficient data intensity is measured for radius of around 20m. However, data intensity can drop off rapidly at crest locations. Greater radii of high data intensity can be captured by increasing the elevation of the scanner, or by using higher scanning intensity levels. However in the course of our work we have found practical and time constraints limit the application of these approaches.

Multiple scanning technique

In the case of the multiple scanning technique the thickness of the point cloud is reduced by a process of data averaging using the data set provided by each of the repeated scans. The technique involves the combination and averaging of a number of scans taken at the same location.

This process produces a set of averaged point data which significantly improves the accuracy of this data, such that the combination of 10 laser scans can increase the measurement precision to around +/- 10mm. Thus, the point data representing the road surface is thinner (in terms of cross section) than a point cloud generated from a single scan. The averaged data set obtained from multiple scanning also requires thinning, preferably by highest or lowest elevation values.

The multiple scanning process also has the benefit of automatically removing transient points within the scan data, such as those caused by the passage of vehicles through the area being scanned (Figures 5 and 6).

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.

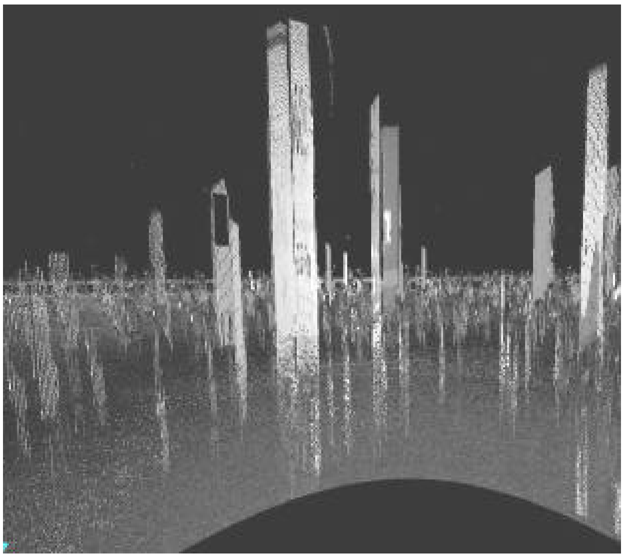


**Figure 5** Interruption to laser scan data from vehicles travelling through the scan window during data capture in a motorway environment

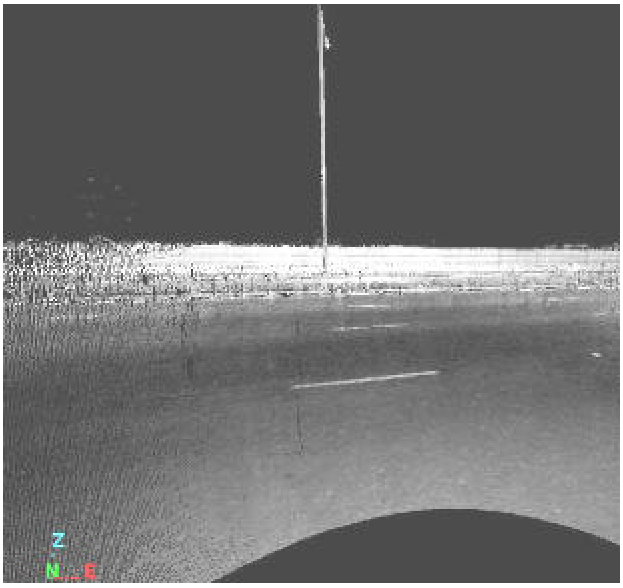


**Figure 6** View of scan data from the 'scanner eye' perspective after the removal of transient data caused by vehicles

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.

Figure 7 presents the road surface model constructed from the data shown in Figures 5 and 6.

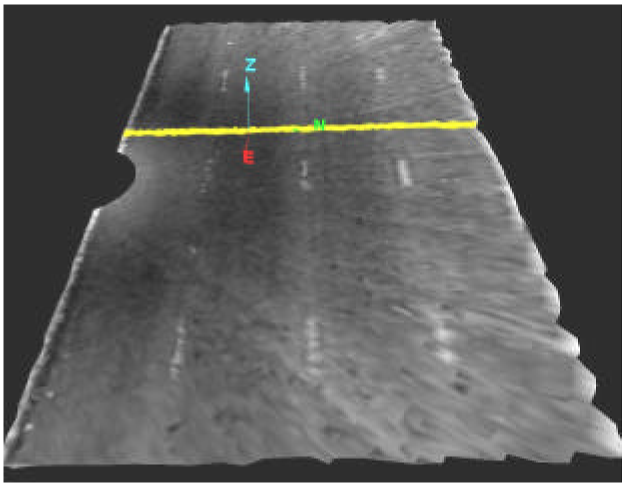


**Figure 7** 3D road surface model of a busy four lane motorway, created using the multiple scanning technique

## Example HVE Analysis Using a Surface Model Constructed from 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 the 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 HVE simulation.

The laser scan data of the incident site is shown in Figure 8, and a cross section of the data is highlighted in yellow.

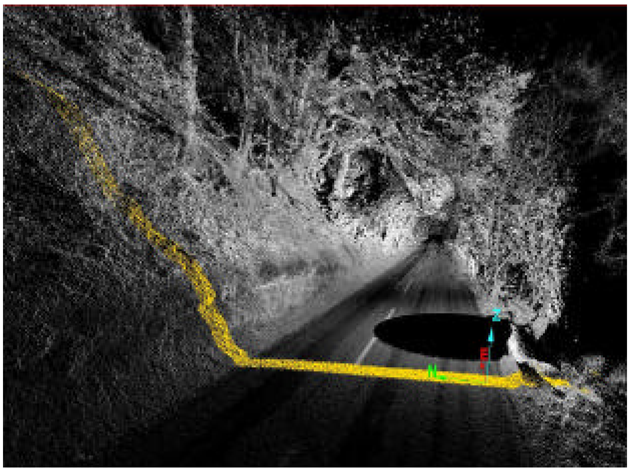


**Figure 8** Laser scan data of an incident site involving a vehicle rollover, example cross section highlighted in yellow

This single scan data was prepared using the smoothing and highest point method (as described above) and a 3D surface model was generated, Figure 9.

The 3D surface model generated by ISiTE was then exported as a .dxf file, and imported into HVE. Additional features such as the wheel mark locations on the embankment, and scrape mark locations on the road surface were surfaced separately in ISiTE and exported as separate .dxf files.

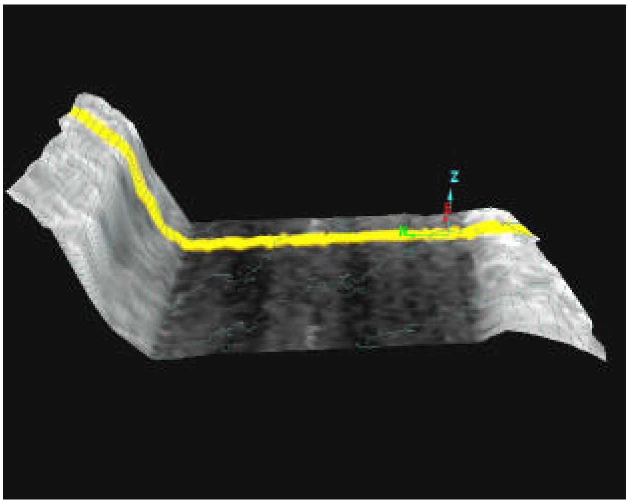


**Figure 9** Section of the road surface model constructed by ISiTE, example cross section highlighted in yellow

These files were then imported separately into HVE and combined in the Environment Editor.

Figure 10 presents frames from the HVE simulation of the example incident using the surface data generated from ISiTE.

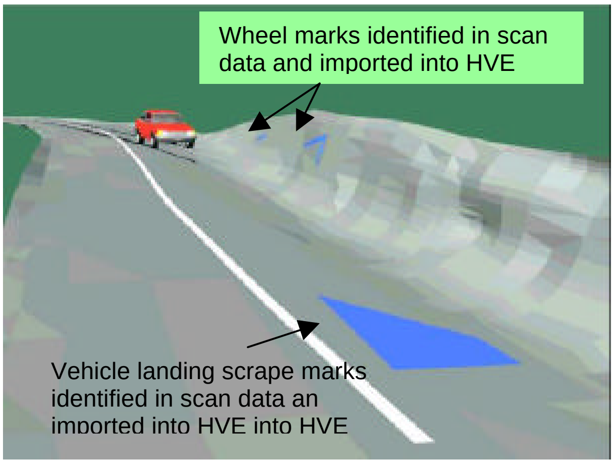
## Summary

Over the past few years TRL Limited has been investigating the potential applications for laser scanning systems in incident investigation.

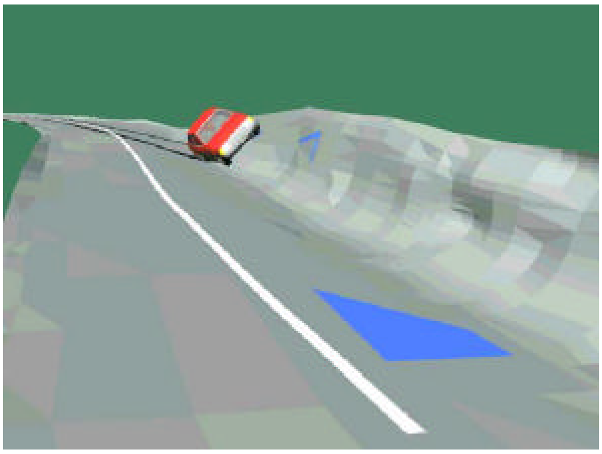
This paper discusses the use of laser scanning systems and analysis software to generate 3D road surface models of road traffic incident locations for use in the simulation of vehicle dynamics.

This technique is 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.

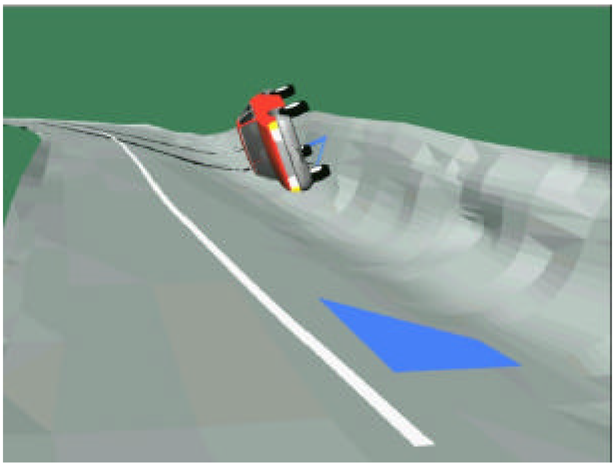
Laser scanning systems can measure vast quantities of spatial data extremely rapidly. This



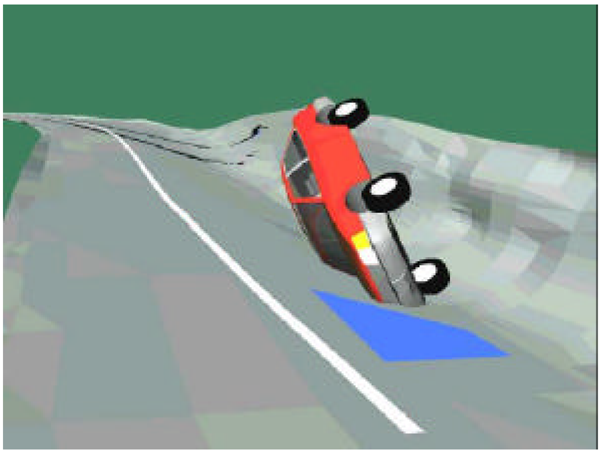

**(a)** Vehicle position before entering the left verge



**(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 10** HVE vehicle dynamics simulation using road and environment model created from laser scan data

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.

The volume of data captured during laser scanning, and the presentation of this data within analysis software (where the brightness of individual points is determined by the intensity of the reflected laser signal from that point) allows the data to be viewed as a 'point cloud' model, in which features such as road markings, changes in road surfaces, vegetation etc can be discerned within the data cloud.

This characteristic allows specific features from an incident site, such as tyre marks, scrape marks etc to be incorporated into a 3D road and environment model of the type used within simulation software such as HVE.

The elements of a 3D road / environment model can be constructed directly from laser scan data using the ISiTE analysis software. This software allows individual surface elements to be exported in a HVE compatible import format.

The ISiTE software has been used to develop two techniques for the generation of 3D road and environment surfaces. These techniques involve the construction of surfaces from single laser scans, or multiple scans taken from the same location.

The single scan technique is suitable for surface generation where there is little or no interruption to the data through the passage of vehicles and/or pedestrians, and relies on a high density of data points. In this case the data must be prepared so as to reduce the intensity of data, and to produce a much thinner point cloud than the raw data measured by the scanner. The technique for achieving this within the ISiTE software is described above.

The multiple scanning technique is suited to locations where a high volume of vehicle or pedestrian traffic causes interruption to the collection of laser scan data. By taking multiple scans from the same location data can be combined and transient points (formed by vehicles etc passing through the scan) can be removed. The remaining points can then be averaged to improve the accuracy of each point. This averaged data cloud can then be thinned and used to generate 3D surfaces in the same way as single scan data.

These techniques provide methods for the detailed 3D modelling of complex, difficult to access and/or highly trafficked roads that cannot be closed for measurement. The resulting 3D surface models can be exported to a CAD format which can then be utilised within computer simulation software such as HVE.

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