Investigation into the potential of LiDAR to support traffic speed asset measurement and assessment

by Dean Wright

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by Dean Wright (TRL)

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Executive summary

The Highways Agency conducts routine automated surveys of trunk road pavement surface (TRACS) and structural (TSD) condition. From these surveys, the Agency is able to establish the condition of the network, prioritise reconstruction and repair work and value its road assets. However, the infrastructure of the trunk road network includes assets other than pavements - the network contains bridges, signs, gantries, lighting, embankments, drainage systems and many types of roadside furniture – none of which are assessed using current routine automated routine surveys.

Hitherto, technology for the automated routine surveys of Highways Agency trunk road assets has focused on the assessment of pavements. For example, the TRACS uses high-power laser systems focussed on the road surface, avoiding exposure of the public to the laser light. Such lasers systems provide extremely accurate (sub-mm) measurements of the pavement surface.

LIDAR (Light Detection And Ranging) uses directed laser light to identify the locations and ranges of objects in the field of view of a sensor. LIDAR is similar to RADAR, but by using shorter wavelengths and exploiting the coherency of laser light LIDAR operates at greater spatial accuracies over shorter distances. LIDAR applications include atmospheric surveying, remote sensing and obstacle detection in automated systems. Although operating with lower accuracy than the lasers used in TRACS (LIDAR systems deliver data in the ~cm accuracy range) LIDAR has potential for use in the measurement of many roadside infrastructure assets.

This report details an investigation into the potential for the use of LIDAR as a tool for the routine measurement and assessment of road infrastructure assets, and to determine how this information could be used to assist the effective management of the network. The project has comprised 3 subtasks:

Subtask 1: Establish and develop the technical capability of traffic speed LIDAR.

Subtask 2: Identify how traffic speed LIDAR data could be applied in targeted and routine surveys of the trunk road network.

Subtask 3: Development of an Implementation Roadmap.

The main objective has been to establish the potential for LIDAR technology to support existing routine surveying of Highways Agency road assets. The focus of the work is therefore to explore potential for use in routine surveys, with a long term vision of incorporating LIDAR technologies into surveys such as TRACS. To meet the requirements for routine use it would be necessary for the LIDAR method to provide data in a rapid, cost effective manner, for example employing fully automated processing techniques for interpretation of the data, and the ability to collect and process several hundred km of data each day.

To this end, the work reported herein includes:

- An assessment of the technical capabilities of the Agency’s Velodyne LIDAR system, including benchmarking against other commercially-available systems
- Investigation of a number of potential applications of Traffic Speed LIDAR
- Outline of the processes the Agency would have to undertake to implement routine Traffic Speed LIDAR surveys

Static tests of the accuracy of LIDAR show that LIDAR systems are able to measure the dimensions of objects in the view of the equipment to an accuracy of a few cm. Therefore, applications drawing on LIDAR technology should be expected to require a measurement accuracy no better than this in routine application. The work has therefore investigated how LIDAR could be used at traffic-speed in applications requiring this level of accuracy.
It is shown that the automated measurement of barrier height is possible using Traffic Speed LIDAR. A prototype algorithm is demonstrated that reliably detects barriers and estimates their height to better than ±10cm. The method is able to carry out the assessment on several km of data in only a few minutes. Although the accuracy of this "routine" method this falls outside the typical requirement for a manual survey (±3cm) it may be sufficient to identify significant problems. Also, as routine manual measurements are often only made every 100m, the more closely spaced measurements provided by the LIDAR may offset some of the absolute accuracy concerns. The use of LIDAR to measure bridge clearances is also demonstrated. Again, it should be possible to automate this process. In a much wider scale test LIDAR has been used to measure barrier clearance over long lengths, via a 200km survey of the M25. This collected all of the data in a day and employed a streamlined processing system to undertake manual analysis of the 200km of data in a few days.

It is therefore concluded that LIDAR has strong potential as a tool for routine application on the network in the measurement and assessment of assets. However, to implement such a routine tool would require the development of common systems for collecting, processing, carrying out QA, analysing and storing the LIDAR data. To maximise practicality it would also draw on the development of improved processing algorithms and suitable display systems.

Although LIDAR does not have the level of accuracy to measure road surface condition, its potential as a tool to augment surface condition surveys is demonstrated by combining high-resolution surface measurements with the relatively coarse LIDAR survey data. Surveys carried out in adjacent lanes of the same carriageway are manually aligned to deliver a hybrid 3D data set that describes the pavement surface in a level of detail typical of TRACS type surveys, but covering the whole carriageway width. It is noted that this technique could deliver major advances in condition assessment, including full-carriageway-width profiling for the modelling of vehicle handling, the assessment of ponding and 3D splash / spray modelling. The development of automated algorithms to align the data would improve the speed and practicality of the method, and assist in transferring its application to the network level.
1 Introduction

The Highways Agency conducts routine automated surveys of trunk road pavement surface (TRACS) and structural (TSD) condition. From these surveys, the Agency is able to establish the condition of the network, prioritise reconstruction and repair work and value its road assets. However, the infrastructure of the trunk road network includes assets other than pavements - the network contains bridges, signs, gantries, lighting, embankments, drainage systems and many types of roadside furniture – none of which are assessed using current automated routine surveys.

Hitherto, technology for routine automated routine surveys of Highways Agency trunk road assets has focused on the assessment of pavements. For example, the TRACS and TSD systems use high-power laser systems focussed on the road surface, avoiding exposure of the public to the laser light. Such lasers systems provide extremely accurate (sub-mm) measurements of the pavement surface.

Recent advances in LIDAR technology are challenging the current paradigm. LIDAR systems make use of low-powered laser systems that are safe to the human eye, and therefore capable of scanning the roadside infrastructure safely – in addition to the pavement surface. Although operating with lower accuracy than the lasers used in TRACS, LIDAR systems deliver data in the ~cm accuracy range – well within the accuracy specification range for many roadside infrastructure assets and as such well-suited to aid in their assessment.

This report details an investigation into the potential for the use of LIDAR as a routine tool for the measurement and assessment of road infrastructure assets, and to determine how this information could be used to assist the effective management of the network.

Note that the focus of the work is to explore potential for use in routine surveys, with a long term vision of incorporating LIDAR technologies into current surveys such as TRACS. To meet the requirements for routine use it would be necessary for the LIDAR method to provide data in a rapid cost effective manner, for example using fully automated processing and the ability to collect and process >100km of data each day.

The project has comprised 3 subtasks:

Subtask 1: Establish and develop the technical capability of traffic speed LIDAR. Work described in sections 3 and 4 falls under this subtask.

Subtask 2: Identify how traffic speed LIDAR data could be applied in targeted and routine surveys of the trunk road network. Work described in section 5 falls under this subtask.

Subtask 3: Development of an Implementation Roadmap. Work described in section 6 falls under this subtask.

The main objective of the work has been to establish the potential for LIDAR technology to support existing routine surveying of Highways Agency road assets, while at the same time investigating new areas of routine survey work in which LIDAR could be applied. To this end, the work reported herein includes:

- An assessment of the technical capabilities of the Agency’s Velodyne LIDAR system, including benchmarking against other commercially-available systems
- Investigation of a number of potential routine applications of Traffic Speed LIDAR
- Outline of the processes the Agency would have to undertake to implement routine Traffic Speed LIDAR surveys
2 What is LIDAR?

LIDAR (Light Detection And Ranging) uses directed laser light to identify the locations and ranges of objects in the field of view of a sensor. LIDAR is similar to RADAR, but by using shorter wavelengths and exploiting the coherency of laser light LIDAR operates at greater spatial accuracies over shorter distances. LIDAR applications include atmospheric surveying, remote sensing and obstacle detection in automated systems.

By combining LIDAR technology with geographical positioning systems common to contemporary pavement survey vehicles, Traffic Speed LIDAR has the potential to revolutionise roadside infrastructure assessment by generating 3-dimensional images of roads and roadside infrastructure [1, 2]. With a single pass at traffic speed, a survey vehicle has the potential to map the 3-dimensional structure of a trunk road’s assets without any need for closures or disruption to traffic. The resulting map (known as a point cloud) has the potential to be used in a number of applications, including:

- Future highways design
- Measurement of bridge clearances
- Assessment of structures
- Inspection of earthworks
- Barrier size / clearance measurements

2.1 LIDAR data

LIDAR data is typically delivered as a ‘point cloud’, which in its simplest format is a list of (x, y, z) values defining points in 3D space relative to the point of data collection (i.e. the LIDAR “head”). In addition to co-ordinate information, a point cloud may also include colour information about each point.

Typical point cloud data is shown in Figure 1. Each line represents a point. The first 3 comma-separated values in each line are the X, Y and Z co-ordinates of the point (in cm). The final 3 comma-separated values in each line are the colour information (Red, Green & Blue levels).

1319.30, -2875.32, 208.40, 107, 107, 107
1337.29, -2912.78, 243.56, 117, 117, 117
1310.47, -2692.31, 55.17, 119, 119, 119
1272.00, -3733.04, 972.49, 109, 109, 109

**Figure 1: Point Cloud data for 4 points**

A LIDAR analysis takes place by loading the point cloud into appropriate viewing software. The point cloud can be ‘clipped’ to eliminate objects that aren’t of interest¹, and then analysed using bespoke simple algorithms.

2.2 Examining the capabilities of LIDAR in the context of asset measurement and assessment

In order to fully understand the potential for LIDAR to offer benefits to roadside asset measurement, it is necessary to examine the capabilities of LIDAR technology. It is important to understand the measurement accuracy of a LIDAR system, and how that accuracy reflects upon the varying needs of roadside asset measurement.

The term ‘measurement accuracy’ here refers specifically to the LIDAR’s ability to deliver information about the size and dimensions of objects in its field of view, as well as their

¹ TRL used PointTools Pro v1.8 to manipulate and clip 3D point cloud data.
distance from the LIDAR. For different applications in roadside asset measurement it is likely that different measurement accuracies would be required.

2.2.1 Sub-mm range
Pavement surface macro-texture measurements require the collection of data in the sub-mm range. Data collected at this scale is commonly extremely dense, and allows assessment of the high speed skid resistance of the pavement surface.

2.2.2 mm – cm range
Many of the pavement condition indicators stored by the Agency’s HAPMS system make use of data collected in this range. Road profile (longitudinal and transverse) is collected accurately to a range between mm and cm, providing measures of Longitudinal Profile Variance and Rutting.

2.2.3 cm – m range
The dimensions of road furniture are commonly defined to a specification in this range. Bridge clearances are specified to the ~5cm range and barrier heights are typically required to be measured within ±3cm – see Figure 14.

2.2.4 >metre range
The TRACS requirement on the GPS accuracy of TRACS survey vehicles falls in the metre range (90% of measurements within 2m). A measurement of the physical position and therefore geometry of the road requires data collected in the ~metre range.

2.2.5 LIDAR
The fundamental ability of a LIDAR system to perform under ideal conditions can be determined by testing its ability to range and identify a series of objects under ideal conditions, i.e. static and indoors. This is investigated in section 3. Naturally we would never expect the performance at traffic speed (dynamic conditions) to be better than under ideal static conditions. However, investigating the performance of available LIDAR systems in ideal (static) conditions enables us to benchmark the expected maximum performance in more demanding dynamic conditions – sections 4 & 5.

2.3 Standalone Static LIDAR Systems
TRL had access to two LIDAR devices, a Velodyne and a Riegl, with which to test the measurement accuracy of the technology under ideal conditions.

2.3.1 Velodyne
The Velodyne HDL-64E S2 system uses a rapidly rotating (up to 900rpm) measurement head containing 64 individually-aligned laser emitters to scan a 24° vertical arc at ranges of between 1m and 100m. The system is rated to provide distance returns with an accuracy of no better than ±20mm².

2 The Velodyne specification is unclear as to precisely what ±20mm refers to.
The Velodyne data is captured in a bespoke binary format and processed into a standard point cloud using software developed at TRL. From this, measurements and calculations can be made to assess the accuracy of the data.

2.3.2 **Riegl**

The Riegl LIDAR uses a slowly-scanning head (~2.5 rpm) with a large angle of view (90° vertical arc) and is rated to measure points with a standard deviation of ±12mm. Its use within TRL is crash scene investigation, where it can be positioned at a crash scene and take a static scan over the course of several minutes.
3 Assessment of LIDAR measurement accuracy

3.1 Assessment under static conditions
A static trial was conducted to assess the performance of the Velodyne and Riegl LIDAR systems under ideal conditions. The trial had the specific objective of investigating the ability of the LIDAR to measure the locations and sizes of objects placed in its field of view. The industry standard method for carrying out a test like this is to scan a series of spherical objects of known size, then determine the position and size of each of those spheres. Spheres are used as they have a unique property that every point on the surface is equidistant from the centre. Therefore the distance of every measured point from the location of the sphere is known. This removes parallax issues that might otherwise impact results.

3.1.1 Experimental Setup
A series of polystyrene spheres of known sizes were set up in a controlled environment where the LIDAR could be positioned and used to scan the scene. The Riegl and Velodyne systems were positioned such that they were visible to each other. This made it possible to determine an offset between the scanning devices and generate a correction to merge the data sets.

Figure 4: Scale drawing of experiment set up (LIDAR Fields of View shown) including numbering system for the spheres. The Velodyne LIDAR was positioned on the far right of the diagram, in the centre. The Riegl LIDAR is shown on the small circle in the bottom right of the image.

Figure 4 and Figure 5 show the experimental setup, including both the Velodyne and Riegl LIDAR system with the spheres of differing sizes. The larger spheres (A, B and H) were 20cm in radius, the smaller spheres (C, D, E, F and G) were 10cm in radius.
3.2 Results

A simple ‘by eye’ inspection of the Velodyne and Riegl revealed some issues with the Velodyne data. The right hand image of Figure 6 shows that the Velodyne delivered whole series of points that appeared to be laterally offset from the objects being scanned. This resulted in the spheres appearing segmented and pillars appearing skewed. This contrasted with the Riegl data, in which the spheres were clearly defined and pillars were straight and smooth.

A more rigorous inspection of the performance can be achieved by attempting to determine the location of the objects in X, Y Z space. This is done by isolating the points that lie on each sphere, then taking a series of random samples of points in each to identify the physical location and size of the sphere (according to the LIDAR) and comparing this with the known size.

The equation of a sphere can be determined from any 4 points on its surface\(^3\); from the equation of the sphere its dimensions can be determined. By randomly selecting 1000 sets of 4 points on the surface of the scanned sphere it was possible to calculate a

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\(^3\) [http://paulbourke.net/geometry/spherefrom4/](http://paulbourke.net/geometry/spherefrom4/)
'mean' size and location of each sphere. This was done for each sphere in each scan. The radii calculated are tabulated in Table 1.

<table>
<thead>
<tr>
<th>Sphere</th>
<th>Riegl</th>
<th>Velodyne</th>
<th>True Dimensions</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Radius</td>
<td>X</td>
<td>Y</td>
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<tr>
<td>A (20cm)</td>
<td>20.0</td>
<td>548</td>
<td>307</td>
</tr>
<tr>
<td>B (20cm)</td>
<td>20.2</td>
<td>549</td>
<td>114</td>
</tr>
<tr>
<td>C (10cm)</td>
<td>11.2</td>
<td>488</td>
<td>369</td>
</tr>
<tr>
<td>D (10cm)</td>
<td>11.7</td>
<td>464</td>
<td>175</td>
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<tr>
<td>E (10cm)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>F (10cm)</td>
<td>12.7</td>
<td>120</td>
<td>409</td>
</tr>
<tr>
<td>G (10cm)</td>
<td>11.9</td>
<td>140</td>
<td>98</td>
</tr>
<tr>
<td>H (20cm)</td>
<td>21.1</td>
<td>30</td>
<td>287</td>
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Table 1: Dimensions and locations of the scanned spheres calculated from the LIDAR scans, compared with the known dimensions. All values in cm. Distances are measured from a (0,0) point in the corner of the room where the Riegl was located – see Figure 4.

Table 1 shows that the Riegl was more accurate in estimating the radii of the spheres. Both systems performed better at measuring the sizes of the larger spheres (as opposed to the smaller spheres). Both systems underestimated the distances of objects⁴ and slightly overestimated the sizes of the spheres.

Figures 7 and 8 show the distributions of radius measurements for sphere A and C, respectively, in the Velodyne (left) and Riegl (right) scans.

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⁴ Data was too distorted to allow a calculation to take place
⁵ Sphere was not visible
⁶ This is true of both the Riegl and Velodyne scanners. Although not immediately apparent from the numbers in Table 1, the Velodyne underestimates its distance from spheres F, G and H. This is because the position of the Velodyne in the experiment was at 300cm in the X co-ordinate and 10cm in the Y co-ordinate. Spheres F, G and H are closer to the 0 X co-ordinate than the Velodyne scanner, and so by finding each of these spheres at a higher X co-ordinate than the true value the Velodyne is underestimating their position with respect to its own location.
The histograms in Figure 7 and Figure 8 show the distribution of measured radii, centred on the true radius of the spheres being measured. The distributions in Figure 7 centre on 20cm (such is the true radius of sphere A), while distributions in Figure 8 centre on 10cm. The Riegl results show narrower distributions. Standard Deviation values for all measurements are presented in Table 2.

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<tr>
<th>Sphere</th>
<th>Velodyne</th>
<th>Riegl</th>
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<tbody>
<tr>
<td>A</td>
<td>1.59</td>
<td>1.02</td>
</tr>
<tr>
<td>B</td>
<td>1.73</td>
<td>0.91</td>
</tr>
<tr>
<td>C</td>
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<tr>
<td>D</td>
<td>1.71</td>
<td>1.07</td>
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<td>E</td>
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</tr>
<tr>
<td>F</td>
<td>1.42</td>
<td>1.15</td>
</tr>
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<td>G</td>
<td>1.49</td>
<td>1.06</td>
</tr>
<tr>
<td>H</td>
<td>1.29</td>
<td>0.98</td>
</tr>
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Table 2: Standard Deviation (cm) of sphere radius measurements

3.3 Conclusions

Generally the large spheres were measured more accurately than small ones – Table 1 shows that the size of the small spheres (C, D, E, F and G) was overestimated by up to 50% by the Velodyne and 20% by the Riegl. The size of the large sphere (A, B and H) was generally determined much better by each system. It is clear that there is slightly more noise in the data from the Velodyne than the Riegl, and a possible explanation for this overestimate is that the method used for determining the dimensions of the sphere is very unforgiving for a small and noisy data set. The small spheres necessarily are represented by a smaller data set and as such the results obtained by them are more prone to the increased noise in the Velodyne.

Both systems consistently underestimated the locations of all the spheres, i.e. each sphere was calculated to be slightly closer to the LIDAR than it really was. Though the Riegl is fairly good at measuring the locations of spheres F, G and H – which indicates some kind of systematic effect in the Riegl scanner since all these spheres were on one side of it.

As can be seen from Table 2, both LIDAR systems measure the dimensions of the spheres to accuracy with a standard deviation in the cm range. The overall is that LIDAR is capable of measuring to a ~cm accuracy, and that measurement applications drawing on LIDAR technology should be expected to require a measurement accuracy no better than this – see section 2.2.
4 Traffic Speed LIDAR systems

As shown in Section 3, LIDAR is capable of measuring the distance of objects from its optical sensors to an accuracy of a few cm. To achieve this the LIDAR “system” must remain still (although the laser itself may be rotating). To obtain measurements when the LIDAR system is under motion (e.g. installed on a vehicle) we need to know about the motion and dynamics of the platform carrying the LIDAR. This can then be used to correct for the motion when measuring assets.

The combining of LIDAR point clouds with the dynamics of the platform on which the LIDAR system is carried is a critical part of the development of Traffic Speed LIDAR application – since without this there can be no way to reference LIDAR cloud data to its environment. This can be achieved using GPS positioning to locate the moving platform in space, and the use of an inertial measurement unit (IMU) to record the platform’s dynamics (pitch, roll and yaw).

What this means is that any Traffic Speed LIDAR application must make use of inertially assisted GPS to determine the location of the vehicle, and that the ability of this inertially assisted GPS will affect the overall performance of the system.

At this stage it is important to recognise that, for routine use, we do not envisage there being a requirement to be able to conduct a survey of a location, then return for a resurvey and expect to be able to locate an object in exactly the same position in space. Though in some applications such ‘resurvey accuracy’ is of importance, it is not in the case for likely Agency applications of Traffic Speed LIDAR, in which TRACS-like surveys are the norm and ‘resurvey accuracy’ is measured with respect to the HAPMS network.

We have used two mobile LIDAR systems to investigate potential Traffic Speed applications of LIDAR - the Velodyne LIDAR system and a TopCon system.

4.1 Velodyne LIDAR on HARRIS2

The Velodyne LIDAR system is suited to Traffic Speed LIDAR survey work because its rapidly-rotating head can be used to generate a 360° 3D image of a road environment when moving at traffic speed. By installing the LIDAR head horizontally the motion of the vehicle (along the road) allows the LIDAR to generate a spiral of data as the LIDAR head spins whilst travelling down a road. The Velodyne head can spin at up to 900rpm, which means that it can complete a single revolution in as little as ~66ms. In this time, a vehicle travelling at motorway speed\(^7\) will have moved approximately 1.5m.

\[ \text{50mph is assumed. The distance travelled will be further at higher speeds.} \]
The Velodyne LIDAR device was installed on HARRIS2 in 2010 for the purposes of investigating its potential as a Traffic Speed LIDAR system. HARRIS2 is the Agency’s experimental platform for testing innovations in pavement condition assessment. It has GPS receivers, a built-in IMU and a highly-accurate Phoenix Laser Scanning system that provides mm accuracy pavement condition data. HARRIS2 is also used as a reference device for vehicles operating under the Agency’s TRACS3 contract. The Velodyne LIDAR outputs were integrated with HARRIS2’s GPS and IMU systems to meet Traffic Speed LIDAR requirements. In order to combine the systems TRL worked with Velodyne to secure an update to the LIDAR unit that ensured a GPS time marker was added to collected data. Velodyne LIDAR data could then be synchronised against the GPS and IMU data collected by HARRIS2. The integration was a complex technical task. Appendix A summarises how the combination of the GPS, IMU and LIDAR data was achieved.

The lasers in the Velodyne head are installed at a series of angles that provide a 24° viewing arc – meaning that at ground level (2m below the LIDAR head on HARRIS2) the lasers can scan a region of only 0.9m in the direction of travel. What this means is that there will be gaps in the LIDAR data on the pavement surface – see Figure 10. This is not a problem though; since the accuracy of LIDAR is in the ~cm range it cannot compete with the ~mm accuracy of dedicated laser pavement scanning systems such as the Phoenix system installed on HARRIS2, meaning that applications of Traffic Speed LIDAR are unlikely to be in direct pavement assessment.

![Figure 10: A slice of a LIDAR scan from the M25, the pavement, roadside barriers and a bridge are visible. Gaps in the point cloud appear on the pavement because of the speed of the survey vehicle.](image)

Figure 10 shows an example of a slice of LIDAR data from HARRIS2 survey using the Velodyne on the M25. During the survey HARRIS2 was driving on the outside lane of the motorway at speeds in excess of 50mph. Gaps in the data coverage appear immediately below where the vehicle was driving.

### 4.2 TopCon LIDAR vehicle

The TopCon IP-S2 mobile mapping system employs three SICK LIDAR systems that scan the ground behind the vehicle and each of the off and near sides with a small gap above the vehicle. The IP-S2 is a self-contained unit that can be seen on the roof of the vehicle in Figure 11. The unit contains the LIDAR systems, IMU, SLR cameras and a vehicle wheel-encoder attachment – it can be attached to any suitable vehicle. The system generates point clouds in full colour by using images from its cameras to artificially colour individual points.
4.3 Visualisation of traffic-speed LIDAR data from routine surveys – LIDAR Slicing

As discussed above, LIDAR data is typically visualised and analysed by taking the point cloud and plotting it in a 3D software package. This is practical for surveys of specific sites or schemes where the data size is manageable.

Routine traffic-speed LIDAR surveys would be expected to collect data over long lengths, resulting in massive data sets (for example 1km of LIDAR data collected with the Velodyne/HARRIS2 system has a size of 250MB at 80kph, more at slower speeds). A TRACS survey can cover up to 300km in a day – likely to exceed 100GB for a survey carried out in the traffic flow - a significant amount of data to process.

There is therefore a need to develop a suitable method to handle, display and process the data. We have developed the LIDAR slicing method to improve the practicality of processing LIDAR data collected at traffic-speed. The method has been developed using a similar concept to the TRACS transverse profile. In TRACS the laser measurement systems provide transverse profiles of the road surface as a series of points covering about 3.5m across the road width. These are delivered every 0.1m along the route. They are used to analyse the road shape (e.g. to obtain rut depths) and deliver parameters relative to the route (e.g. the rut depth at ym into HAPMS section abc) as well as relative to a geographical position (OSGR co-ordinate).

The LIDAR slice can be considered to be a transverse slice through the LIDAR data describing the shape of the “environment” in the 360° around the survey vehicle. Like transverse profiles, slices can then be analysed separately, with results referenced against the survey route. For example delivering the bridge clearance at ym into HAPMS section abc as well as relative to a geographical position (OSGR co-ordinate). By analysing one slice at a time as opposed to an entire survey in one go, the processing and storage requirements are reduced and the practicality is increased.

A major advantage is that one can dynamically define a co-ordinate axis within each slice that’s orthogonal to the direction of travel. We define the +Y direction as the direction of travel the +X direction as towards the offside of the vehicle, the +Z direction as up. This can significantly improve the efficiency of automated algorithms, since it means that the offside of the vehicle is always in the +X direction regardless of how the road might twist and turn.

Figure 12 shows how slices are generated – formed such that they are perpendicular to the direction of travel on the survey route. Slices can be set up to have any length, width or depth – as is appropriate to the application. Slices will be used heavily in the
remainder of this section to demonstrate new areas of analysis opened up by Traffic Speed LIDAR.

Figure 12: A point cloud (left – viewed from the top-down) is divided into sections along the survey driving line (right – 3 slices shown).

Slices can also be visualised from the point of the view of the driving line of the vehicle. Figure 13 shows a single slice of LIDAR data taken from the data set in Figure 12. In this 15m long slice the pavement is visible, as well as a part of a bridge and some trees to the left hand side of the carriageway.

When thinking about the application of LIDAR slicing, it is convenient to think of the slices as providing an ‘on board’ point of view of the LIDAR scan. From an ‘on board’ view it is possible to look down to the pavement, up to bridge decks and gantries, to the sides at barriers and along the direction of travel to see the road geometry. We make use of this implicit understanding of the positioning of objects of interest in the ‘on board’ view when developing algorithms to automatically identify and assess them.

Figure 13: A single 15m slice from the data set shown in Figure 12 – the view shown is along the road. The entrance to a bridge is visible in the centre of the image, with a canopy of low trees on the left.
5 Potential Applications of LIDAR in routine asset measurement and assessment

Applications of LIDAR are as varied as the ways in which LIDAR systems can be deployed. From airborne surveys of pollution and land surveying to coastal surveys of land erosion, LIDAR is used to quickly map a region in 3D in any situation where accurate position data can be obtained.

A LIDAR system mounted on a road-based vehicle has an advantage over airborne LIDAR in that it is much closer to highways infrastructure, and an advantage over fixed LIDAR in that it is capable of surveying large regions in a single survey. Such a LIDAR system will pass close to road barriers and signs, underneath bridges and gantries and can measure the dimensions of each from close range. A further advantage of such a system is that it is capable of operating at traffic speeds, where surveying would be carried out in a similar way to TRACS surveys. However, routine surveys at traffic speed necessitate that options often used in more scheme level application (e.g. for improving data accuracy) are impractical. In particular the use of control points (fixed points of known position marked on or alongside the road which are used to improve the data accuracy) becomes impracticable when surveying hundreds of kilometres of highways, while surveying at speeds of at least 80km/h will reduce the accuracy of data obtained as offsets in the IMU and GPS positioning systems are amplified.

Although the potential applications of using LIDAR on a vehicle-mounted platform have been explored previously, the previous work has not considered its use in the context of routine traffic speed surveys. LIDAR is capable of taking measurements that could be complimentary to existing routine (e.g. TRACS) surveys. Although existing LIDAR technology lacks the resolution to provide texture or rutting measurements, road geometry and edge condition measurements are theoretically possible. Barrier heights, bridges clearances, bridge inspections, ingress of foliage and several others all have the potential to be surveyed automatically using Traffic Speed LIDAR data.

A further, traffic-speed but not “routine” use of LIDAR surveys is also in the measurement of asset inventory such as locating and identifying roadside signage and signals. Automated surveys of this kind are already being carried out using Forward Facing Video (FFV) with pixel-tracking systems although these are not investigated as part of this research as they did not fall within our definition of routine assessment.

In the following sections we investigate whether the performance of LIDAR systems in “routine survey conditions” falls in a range suitable for application in the measurement and assessment of roadside assets.

5.1 Barrier Height

5.1.1 Viewing and manually assessing with LIDAR

The assessment of barriers is currently carried out by manual inspection. These inspections undertake measurements of the height of the barrier above the pavement level, the barrier type, any deformations in the barrier and the integrity of the barrier’s fittings.

- The specification for UK highways barriers allows ±3cm in height (see Figure 14).
- A manual measurement is made every 100m.
- The ‘height’ of the barrier is defined as the distance between the centre of the barrier and the road level.

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8 Crucially, routine operation implies the use of TRACS-like surveys, which in turn means not being able to set up control points to improve data quality, and the ability to collect 100s of km of data in a cost effective manner with optimised processing times
• There are two types of road barrier, box and TCB (tension-corrugated barrier). Box are ~20cm in size, TCB are ~30cm in size.

![Figure 14: Barriers are expected to be 610mm high above the road level, ±30mm](image)

Typically a manual inspection of road barriers consists of using a tape measure to measure by hand the height of barriers at each marker post. The height is measured with respect to the level of the pavement, which often can only be guessed at since the pavement rarely abuts the barrier directly. In practice though barrier height measurement ends up being even more ad-hoc than this. Inspectors will generally measure the height of the barrier at the first marker post and then only perform a re-measurement where the height of the barrier has visibly changed by a significant amount. A manual barrier inspection also involves checking the condition of the bolts and screws on the barrier. A lane closure is required whenever manual barrier inspections are taking place, unless the barrier is a long way from the hard shoulder or carriageway.

There is potential for the use of Traffic Speed LIDAR as a tool to measure the height of the barrier above the pavement surface. Doing so could improve the accuracy and frequency of measurements, and remove the need for closures. However, an automated system for measuring barrier heights would not be capable of inspecting the condition of the bolts and joints of the barrier.

### 5.1.2 Automatic assessment of barrier height

Because the work of this project has focussed on routine use of LIDAR at traffic-speed, we considered that LIDAR would be more practical in the assessment of barrier height if it could be applied using a method which would automatically determine the barrier height from the LIDAR data. Therefore work was carried out to develop a prototype algorithm which uses LIDAR slices to evaluate the barrier height.

### 5.1.3 Algorithm

The algorithm operates on each successive slice in the survey. Each slice is uniquely referenced in the direction of travel. For each slice, the following series of steps is carried out (see Figure 15 as a reference for the co-ordinates described here):

- Begin at the centre of the slice and work towards the nearside (−X direction) in 1m increments.
- For each 1m increment, determine the height of the road surface (mean of Z) and the variance of the points therein (Variance of Z).
- If the variance in Z is higher than a threshold, we have found a feature that isn’t just the road surface. Since we are working towards the nearside from the centre of the slice, the first non-road feature we encounter should be a barrier (or something that we can identify as not a barrier – such as overhanging trees).
Once we decide we have found a barrier, we take the $n^{th}$ percentile of $Z$ where the barrier is located.
- Record the $n^{th}$ percentile of $Z$ – mean of $Z$ from the last grid location. This provides the height of the road barrier above the pavement surface.

Figure 15: Diagrammatic representation of the geometry of a single slice of a LIDAR survey. The road + nearside barrier are shown.

5.1.4 Testing

The algorithm was tested using data provided by the TopCon system in a survey of the Large Loop of the TRL test track. The Large Loop is a ~2.5km oval on which restraint barriers have been installed on certain sections in both near and off sides.

The whole of the track was measured in one survey. A sample of survey data can be seen as a 3D plot in Figure 16. LIDAR slices were created that were 10m in longitudinal length and the barrier height algorithm applied to each slice to determine if it contained a barrier, and then provide a measurement of barrier height every metre. The physical data collection took only a few minutes. The time to process the data (extract slices and run through the algorithm) also took only minutes.

To provide reference data a manual survey was also undertaken of the TopCon LIDAR data. The data was displayed in PointTools and measurements of the bridge height were taken by identifying points on the barrier and corresponding points on the pavement surface. A measurement of barrier height as defined in Figure 14 was then recorded and used as a reference against which an automated measurement system could be tested. This manual analysis took at least a day to complete.

Figure 16: Perspective view of the LIDAR survey of part the Large Loop. The driving line, barrier and their relative positions are shown. The regular white regions on the road surface are arise from the TopCon colouring method.
Figure 17 to Figure 19 show the results for each of the sections on the test track where a barrier was present.

Figure 17: Manual (red) and Automated (blue) barrier height measurements. This section of pavement contains a constant road barrier on the nearside. The automated algorithm seems unable to detect a barrier between 180 and 260m.

Figure 18: Manual (red) and Automated (blue) barrier height measurements. There is a barrier along this entire section. The automated algorithm appears unable to detect a constant barrier height between 500 and 600m.

Figure 19: Manual (red) and Automated (blue) barrier height measurements. There is a barrier along this entire section. The automated algorithm seems to successfully detect a barrier all the way along the section.

22% of automated height measurements were within 3cm of the manual measurement, 75% of all automated measurements were within 10cm of the manual measurement. Figure 20, shows the distribution of the differences between automated and manual barrier height measurements. The automated measurements are averaged over 10m here for easy comparison with manual measurements obtained at the same chainage.
Figure 20: Distribution of differences between manual and automated barrier height measurements (averaged over 10m). 75% of automated measurements are within 10cm of the manual measurement.

Not all of the test track has a crash barrier. Figure 21 shows the results returned by the Barrier Height Algorithm in a section of the track where there is no barrier. The algorithm still returns results where there is no barrier, since it is designed to look for the first place on the nearside of the vehicle where the variance in heights values exceeds a threshold. It should be possible to identify such false positives through a number of methods. Firstly, since the lateral position of the barrier with respect to the survey vehicle should be reasonably consistent – false positives can be identified from regions where the lateral position varies quickly. Secondly, since the heights of barriers in the real world are reasonably consistent the algorithm should also find that the barrier height should not be too variable – where it is variable (see Figure 21) there are likely false positives.

Figure 21: Results of the automated algorithm in a location on the test track where there was no barrier. There is a lot of variability in the barrier height found – these are false positives.

5.1.5 Barrier heights - Conclusions

The investigation into the application of LIDAR to measuring barrier height has shown that a crude automated measurement of barrier height is possible using Traffic Speed
LIDAR data. The speed of measurement and processing is high and no manual intervention was required.

The prototype algorithm reliably detected barriers where they existed and estimated their height to about ±10cm. As noted above, the specification for UK highways barriers allows ±3cm in height. Routine manual measurements are only made every 100m, and much a more frequent assessment is possible using the LIDAR, potentially offsetting the reduction in accuracy. Hence, although these results may not be good enough to replace detailed visual inspections or identify small imperfections in the barrier, they would be capable of quickly ascertaining the potential presence of major defects.

Barriers are inspected for a variety of safety aspects other than simply height. Inspectors look for corrosion, deformation and rigidity in the ground. The nuts and bolts that connect the barrier to the post are also checked. Of these areas of inspection, it is only reasonable to expect a LIDAR scanner to automatically detect the lateral position and height of the barrier. However, a visual inspection of LIDAR data might be able to detect the presence of deformations, although we have not investigated that in this work.

5.2 Barrier Clearance

When undertaking works on or adjacent to the central reservation sufficient space must be allowed between the restraint barrier and the outer edge of the outer traffic lane (e.g. lane 3). Recently HA policy has led to the installation of increasing amounts of concrete restraint barriers, installed during major works. As a result there is now a need to update the information on the distance between the outer lane and the concrete barrier, for the purposes of confirming the traffic management requirements for works on or adjacent to the central reservation. Therefore we have investigated the potential for using LIDAR as a tool to measure the distance between the outer lane and the concrete barrier.

5.2.1 Data Collection

A LIDAR survey was carried on approximately 200km of the outer lane of the M25 using HARRIS2 with the Velodyne LIDAR. LIDAR measurements were collected by driving HARRIS2 in the outside lane of the at a speed of approximately 80kph in live traffic. The vehicle was driven in the outside lane of the motorway to ensure that traffic to the offside would not interfere with the LIDAR scans of the concrete barriers. The >200km survey data (both clockwise and anticlockwise) carriageways of the M25 was collected in a single day.

5.2.2 Analysis

The data collected by HARRIS2 was carried out after first converting the LIDAR into slices (section 4.3). A viewer was developed that allowed these to be plotted in a compressed ‘direction of travel’ viewpoint (in which the dimension in the direction of travel is suppressed). This plot provided a direction of travel view of the roadside environment, thus allowing the relative positions of the road and roadside barriers to be assessed. The LIDAR data also provides a measure of the intensity (colour), and so allows the white line to be identified. Figure 22 shows an example of the resulting data set, in which the pavement surface, concrete barrier and white line are visible.

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9 Note that the HARRIS2 survey was commissioned by Connect Plus for data collection and analysis. This project has supported the developments to HARRIS2 required to produce the analysis tool to enable assessment of the LIDAR data.
Tools were developed in the viewer to allow a manual assessor to record the distance between the outer edge of the traffic lane and the barrier by clicking on the screen and moving the mouse to measure the distance. The measured distance was then automatically stored in relation to section, chainage and OSGR coordinate. The LiDAR slice data could be scrolled forward and backward without the “view point” changing, thereby increasing the practicality of the assessment. The entire M25 was analysed in this way, with a measurement of the concrete barrier clearance being recorded at intervals of 50m. This manual analysis of the 200km took approximately 1 man-week.

5.2.3 Conclusions

An example of the results obtained in this analysis is shown in Figure 23. The portion of the M25 shown is the clockwise carriageway between junctions 15 (Heathrow) and 24 (Potters Bar). The large variability in the concrete barrier clearance over this length (ranging from ~1 – 4m) is clearly shown. Some of this variability arises from the different types of roadside infrastructure necessitating different sizes of concrete barrier clearance. For example, the present of bridges and gantries can each cause the clearance to go both up and down.

This analysis was conducted manually. However, several elements of the analysis lend themselves to automated processing. The concrete barrier clearance is defined as the horizontal distance between the outside lane white line and the base of the concrete barrier – both the white line and the concrete barrier are features that are capable of...
being automatically detected using suitable software, perhaps derived from the prototype tool developed to measure barrier height above (section 5.1).

5.3 Bridge Clearance

Similarly to the assessment of barrier height, bridge clearances must either be obtained from design drawings or manual assessment. LIDAR should be well suited to this application. Again, with a view to routine traffic-speed surveys we have developed a prototype algorithm for this application.

5.3.1 Bridge clearance algorithm

Each slice in a survey is analysed against a criteria to decide if it contains a bridge (or bridge-like object such as a gantry). Slices containing bridges are then further analysed to determine an estimate for the bridge clearance and width. For each slice in the survey, the following steps are carried out:

- Divide the slice into radial components – see Figure 24. In each radial component, make a list of all the LIDAR points therein. Figure 24 shows a ‘radial component’ of a slice of LIDAR data. Radial components are formed by isolating the LIDAR data in the XZ plane and identifying all points that lie in a given region. In Figure 24 the radial component shown is the region between the +Z (0°) axis and the θ° line. Since the (0,0) point in the XZ plane is at the location of the vehicle, we can be sure that the pavement will always lie in the range 90 < θ < 270 while the bridge will lie in a range of angles above the horizontal. These assumptions about the relative position of the bridge with respect to the survey vehicle are used in the algorithm.

- Analyse radial components ‘above’ the survey vehicle – i.e. between angles 0° – 20° and 340° – 359°. Calculate the mean Z component of all points in these radial segments. If this lies within a given set of boundaries, then assume there is a bridge. If not, skip on to the next slice.

- For slices where a bridge is found, look at every radial component and calculate the position of the nearest object to the survey vehicle. This is done by calculating the nth percentile of distances to all points in the component. Crucially
for this to work the (0,0,0) origin to which all points in the slice are referenced must lie between the bridge decking and the pavement.

- Bridge clearances can be calculated by sampling the difference between Z at the pavement level and the corresponding points located above the survey vehicle.
- Similarly bridge width can be estimated by looking at the differences in X between the two sides of the located bridge.

### 5.3.2 Results

A Topcon survey of the TRL Large Loop was used to provide a data set upon which the Bridge Clearance algorithm could be tested. The site contains one concrete over bridge. A view of a LIDAR slice containing the bridge is shown in Figure 25. The points in the figure show how the dimensions of the bridge have been estimated by taking the closest (blue) point in each segment, then the 5th (red) and 10th (yellow) percentiles of all points in each radial component.

![Figure 25: A LIDAR slice of the bridge over the TRL Large Loop. Estimates of the bridge shape are made by splitting this slice into radial components and taking either the nearest, 5th or 10th percentiles of distance from the origin.](image)

The algorithm generated measures for the bridge height and width are shown in Table 3. Reference data was collected using a laser distance meter. It can be seen that the LIDAR measurements are close to the reference. It can be seen from Figure 25 that the survey vehicle was closer to the offside of the bridge when the survey was undertaken. It may be expected that the algorithm’s estimate for the bridge height is closer to the reference for the offside height than the nearside. There is a small difference between taking the closest, 5th and 10th percentile points as the estimate for the true position of the bridge. It is not recommended that the closest point to the survey vehicle be used, since even though the closest point surveyed should be on the bridge, outliers are always possible (some of the blue points in Figure 25 are outliers).

<table>
<thead>
<tr>
<th></th>
<th>Closest Point</th>
<th>5th Percentile</th>
<th>10th Percentile</th>
<th>Manual Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>5.152</td>
<td>5.156</td>
<td>5.159</td>
<td>5.05 (nearside) – 5.16 (offside)</td>
</tr>
<tr>
<td>Width</td>
<td>15.161</td>
<td>15.215</td>
<td>15.267</td>
<td>15.7 (at the road barrier) – 15 (at the bridge deck)</td>
</tr>
</tbody>
</table>

**Table 3: Bridge dimension measurements (m).** The bridge is tapered so as to be wider at the road and higher on the offside.
5.3.3 Conclusions

The Bridge Clearance Algorithm worked well on this single bridge at the TRL Large Loop, suggesting that LIDAR would be an appropriate tool for the assessment of bridge clearances. It could be fully automated using an appropriate algorithm.

However, there is scope and requirement for further improvement before this could be used in a more general application. This would include refining the ability to extract bridges from the data and improving the algorithm to target specific parts of a bridge (in an attempt to determine a more accurate profile of its dimensions). Rather than taking a mean value across a series of radial components, it should be possible to consider only radial components lying in a range at a specified lateral position from the survey vehicle. Similarly, multiple bridge width calculations could be made by taking only radial components at particular heights on the bridge abutments. This would allow for a full profile of the bridge dimensions to be calculated. One drawback of this approach would be a reduction in the number of data points used to determine each estimate for bridge width, which in turn leaves the final result more open to the vagaries of measurement error in the LIDAR / IMU system. However, improvements in the underlying technology would lessen the impact of these errors and allow for accurate automated assessment of bridge clearances. Further work would also be needed to determine the optimum percentile to use in this algorithm, such a value would probably be dependent on the measurement accuracy of the LIDAR being used.

5.4 Measurement of whole carriageway shape

LIDAR is capable of surveying the environment in a 360 degree envelope around a survey vehicle moving at traffic speeds. This has potential for measuring roadside assets. However, the static tests discussed in section 3 have suggested that the measurement accuracy of LIDAR is not as high as that typically employed when measuring pavement surface condition. Typical measurement accuracies for LIDAR (under routine survey conditions) is the order of ±cm, whereas for surface measurements under the same survey conditions the lasers used are capable of measuring in the sub mm accuracy range.

As such, LIDAR is presently incapable of replicating the function of dedicated routine surface measurement systems like TRACS. However, TRACS surveys are only able to survey one lane at a time and there is currently no way of relating the shape data measured in adjacent traffic lanes (for example to analyse water flow). Therefore LIDAR may be able to enhance surveys such as TRACS. This could be achieved by surveying multiple adjacent lanes of the same carriageway with both a high resolution (TRACS-type) surface measurement system and a LIDAR system. Then by physically locating each pavement survey within the whole carriageway environment provided by the LIDAR it would be possible to generate a combined data set representing the overall shape of multiple lanes in the same detail that has hitherto been available for only a single lane.

5.4.1 Merging Multiple Surveys

Although TRACS surveys use inertially assisted GPS to locate the survey spatially, the accuracy of the inertially assisted GPS alone is insufficient to enable the accurate alignment of surveys of adjacent traffic lanes (at the mm level). The question that arises is - if the traffic-speed LIDAR derives its data from inertially assisted GPS (see section 4) then how can it be used to align the data from adjacent lanes? The increase in accuracy is achieved by identifying objects in the LIDAR data in the surveys and using these as markers to align the data. Assuming that the right sort of objects are used (i.e. ones that don’t move between surveys, don’t deform or change position with shifting winds and can be automatically identified), the objects can be very accurately located in multiple surveys and used as a tool to align all of the data. This concept is similar to that of using control points in a LIDAR survey, but does not require any physical laying out or
marking of the site as all the control points are effectively generated internally in the data sets.

5.4.2 Testing

A series of HARRIS2 surveys were carried out on the long straight of the TRL test track. The surveys collected LIDAR data, inertially assisted GPS and high resolution pavement surface shape data using the Pheonix PPS scanning laser. The long straight of the test track simulates a 500m long 5 lane wide motorway carriageway. Each lane of this “carriageway” was surveyed. Marker posts were laid out along the survey route every 100m and used to align each survey in space. The alignment was a manual process that provided an adjustment in 3 dimensions for each LIDAR dataset at each marker post on the survey route.

All LIDAR datasets were aligned to the lane 1 survey. A typical alignment of a dataset in lane n to a dataset in lane 1 is denoted $A_{ni}$, which consists of a series of 3D adjustments \{${x_i, y_i, z_i}$\}, where $i$ denotes the marker post that the adjustment refers to. Typically \{${x_i, y_i, z_i}$\} will differ significantly from \{${x_{i+1}, y_{i+1}, z_{i+1}}$\} because of the variability of GPS and the lateral movement of the survey vehicle. At marker post $i$, the alignment of a dataset of lane n to lane 1 will be $A_{ni}$, for any location not at a marker post the alignment must be calculated by interpolating between $A_{ni}$ at the two closest marker posts.

Because of the data collection system on HARRIS2 the PPS scanning Laser data was closely coupled spatially to the LIDAR data collected in the same survey run. Thus for each survey, the PPS laser and LIDAR data were well-aligned, and as such multiple scanning laser surveys could be manually aligned by aligning the LIDAR datasets associated with them.

![Figure 26: LIDAR scan of the TRL test track (LHS – part shown) and Scanning Laser scan (RHS) of the same](image)

Figure 26 shows LIDAR data from a single survey carried out in one lane and PPS scanning Laser data from 5 surveys (one in each lane) aligned using the method described above. In Figure 27 we can see the final result, which is a single LIDAR dataset of the roadside infrastructure augmented by 5 high-resolution scans of the pavement surface.
Figure 27: Combined version of Figure 26, the LIDAR scan of the pavement has been augmented by the combined Scanning Laser scans

Figure 28: A portion of the combined scan with the pavement coloured to show the crossfall. The crossfall shows no step changes in height as all 5 scans have been lined up using the method described here.

Figure 28 shows a different part of the test track in more detail, with the pavement coloured according to height. This colouration demonstrates full carriageway crossfall, to indicate how it might be possible to use the high resolution 3D dataset to identify whole carriageway surface defects or detect regions where ponding is a risk.

5.4.3 Conclusions

By combining high-resolution scanning Laser data with relatively coarse LIDAR survey data, it is possible to manually align several pavement condition surveys carried out in adjacent lanes of the same carriageway. GPS and IMU data can be used to convert raw LIDAR and scanning Laser data into 3D maps. Marker posts in the LIDAR scans are used to manually align each dataset. The final result is a hybrid 3D data set that describes
the pavement surface in a level of detail typical of TRACS type surveys, but covering the whole carriageway width. The surrounding infrastructure is also shown at a level of detail appropriate to the application.

In this work the processing used to align these data sets was mainly manual. Marker posts were identified manually and an adjustment in 3 dimensions for each lane determined. Currently there is no way to reliably and automatically identify the objects in the multiple LIDAR data sets. It is expected that automated alignment would be possible via the development of appropriate analysis algorithms.

There are numerous potential applications of this in the field of pavement surveying. The generation of a full-carriageway survey with pavement detail that is normally only possible in a single lane allows for the calculation of a crossfall profile across the entire carriageway. This in turn means that a full 3D picture of a carriageway can be built, which in turn allows could allow for automated routine detection of areas at risk from ponding. Multi-lane defect detection – such as multi-lane cracking – is also a possibility arising from this.
6 Implementation Roadmap

LIDAR has significant potential as a tool for road asset measurement and assessment. The technology already exists to collect the data and this work has applied current systems in a number of example applications. To make routine use of traffic speed LIDAR Surveys, the Agency would need to develop new systems for collecting, processing, carrying out QA, analysing and storing LIDAR data. It is feasible that these systems could be incorporated into existing ones, such as creating a new version of the Agency’s MSP to deal with a new bespoke RCD data file format designed specifically to hold traffic speed LIDAR data and load into management systems such as HAPMS or IAMIS\textsuperscript{10}.

6.1 Data Collection

Numerous companies are at present marketing their capability in carrying out LIDAR surveys of the road network. At present these services mainly focus on the provision of bespoke surveys of certain sites (schemes) covering (up to) several km. The intention is often to provide data from limited areas that have been set up with control points so that the data is suitable for engineering or design purposes (for example for use in scheme design).

While such surveys will undoubtedly be useful to the Agency, they are not routine or automated traffic speed surveys of the kind discussed in this report. The amount of data generated by such a survey and the difficulty of referencing that data against the network would outweigh many of the benefits that performing such surveys would bring.

The two most practical ways to generate routine LIDAR surveys of the network at traffic speed would be to either to put out a call for LIDAR survey providers to provide a routine survey capability or incorporate LIDAR technology into the TRACS contract.

With either of these options, the Agency would need to issue a detailed specification as to the measurement accuracy of the LIDAR and IMU systems used, as well as a specification for data format, transfer, positional referencing and storage.

6.2 Data quality control

The Agency will need to develop a specification for the survey equipment that traffic speed LIDAR contractors must adhere to. The Agency would also require a set of criteria against which to baseline performance and ensure data quality control. The format of this could be similar to the existing TRACS vehicle and data specifications that the TRACS contractors must follow.

Following this, the Agency could commission the creation of a bespoke data storage format that would hold LIDAR data in a format that allows interrogation, storage and calculation of appropriate condition indicators (similar to the BCD and RCD file formats used in TRACS surveys).

6.3 Data processing and analysis

The outcome of the above two items would be the provision of 3D point clouds in a common format, adhering to a minimum level of accuracy and quality. To make use of the data requires processing and analysis tools. As a minimum it would be necessary to have suitable 3D display tools for viewing the data. Many commercial software products are available for this.

However, this report has proposed a number of prototype algorithms for processing traffic speed LIDAR data. It is such semi and fully automated analysis that could make the use of the data practical in an asset management context. This could include tools to

\textsuperscript{10} The Agency has recently undertaken this process to incorporate routine TSD surveys into HAPMS
automatically extract and measure highway assets contained in the 3D dataset. The Agency would need to commission the development of such tools. A practical method of achieving this may be via carrying out research to support the development of the algorithms, and allowing commercialisation of these in commercial software products.

6.4 Data storage
TRACS data is currently loaded into the HAPMS for storage and ease of access by Agents around the country. Routinely collected LIDAR data could be treated in two different ways. Either the results of processing the LIDAR data with the MSP-equivalent program or the entire raw data sets could be kept could be stored. The former option would require little memory and it is what is currently done with TRACS surveys (i.e. raw TRACS survey data is not stored in HAPMS – only condition indicators) whereas the latter option would be much more memory intensive but carries the huge advantage of allowing Managing Agents to look at the actual point cloud scans of their infrastructure assets.
7 Conclusions and Recommendations

We have conducted a broad investigation into the use of LIDAR to measure and assess highway assets. This has included experiments to measure accuracy in both static (section 2.3) and dynamic (traffic speed – section 4) conditions. The static tests showed that LIDAR systems are able measure the dimensions of objects in the view of the equipment to an accuracy of a few cm. Therefore, routine survey applications drawing on LIDAR technology should be expected to require a measurement accuracy no better than this. We have therefore investigated how LIDAR could be used in routine traffic-speed applications requiring this level of accuracy.

The focus of the work has been to explore potential for use in routine surveys, with a long term vision of incorporating LIDAR technologies into routine surveys such as TRACS. To meet the requirements for routine use we have assumed it may be necessary for the LIDAR to provide data in a rapid cost effective manner, for example using automated processing and the ability to collect and process long lengths of data each day.

We have demonstrated a basic automated measurement of barrier height using Traffic Speed LIDAR. A prototype algorithm reliably detected barriers where they existed and estimated their height to better than ±10cm. The total processing time for the 3km site was a few minutes. Although the accuracy falls outside the typical requirement for a manual survey (±3cm) this may be sufficient to identify significant problems. As routine manual measurements are only made every 100m, the more closely spaced measurements provided by the LIDAR may offset some of the absolute accuracy concerns. We have also shown that LIDAR can be used to measure bridge clearances to a suitable level of accuracy on a test site at TRL and that, again, it should be possible to automate this process. In a much wider scale test we have demonstrated that LIDAR can be used to measure barrier clearance over long lengths, via a 200km survey of the M25. The survey collection for this took only one day and a streamlined processing system using LIDAR slices enabled the 250km dataset to be manually analysed in a few days.

It can therefore be concluded that LIDAR does have strong potential as a tool for routine application on the network in the measurement and assessment of assets. However, to implement such a routine tool would require the development of common systems for collecting, processing, carrying out QA, analysing and storing the LIDAR data. To maximise practicality it would also draw on the development of improved automated processing algorithms and suitable display systems.

Although LIDAR does not have the level of accuracy to measure road surface condition at the routine level (e.g. rutting, ride quality), it has potential to augment surface condition surveys such as TRACS by combining the high-resolution surface measurements with relatively coarse LIDAR survey data. It is possible to align surveys carried out in adjacent lanes of the same carriageway. The result is a hybrid 3D data set that describes the pavement surface in a level of detail typical of TRACS type surveys, but covering the whole carriageway width. This could deliver major advances in condition assessment, including applications in full-carriageway-width profiling for the modelling of vehicle handling, the assessment of ponding and 3D splash / spray modelling. The development of automated algorithms to align the data would improve the speed and practicality of the method, and assist in transferring its application to the network level.
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References


Appendix A  Processing Velodyne LIDAR DATA to Obtain 3D Traffic Speed LIDAR point clouds

A.1 Raw data

Velodyne LIDAR data is captured in a bespoke binary format and processed into a point cloud from which measurements and calculations can be made. A typical point cloud from the Velodyne system contains positional and colour information see Figure 1.

The point cloud is obtained using a series of banks of lasers that are positioned at known orientations within the rotating LIDAR head. Figure 29 shows the geometry of a single LIDAR laser observing a point at distance $D$ from the rotating head. The laser is mounted at an azimuthal angle $A^\circ$ and a rotational angle $R^\circ$, and at a known distance from the base of the unit. The head spins anti-clockwise (looking from the top down) and at any given moment has spun an additional $\theta^\circ$ from its initial position.

![Figure 29: Side-on and Top-down views of the Velodyne LIDAR measuring a point at distance $D$, rotational angle $R$ and azimuthal angle $A$.](image)

To use the LIDAR data the measurements must be translated into a reference frame that can be compared with other survey measurements such as those provided by the PPS, a reference frame that we refer to as the Survey Space. To obtain this information we construct the position of an observed point in the LIDAR space, translate into the HARRIS2 space, and then into the Survey space.

A.2 LIDAR Space

We first obtain the location of an observed point in a cylindrical co-ordinates $(r,\theta,z)$ in the reference frame of the LIDAR system:

$$r = D + \Delta D$$ \[1\]

$$\theta = \text{Rotational Head Position}$$ \[2\]

$$z = r\sin(A) + \text{VerticalOffset}$$ \[3\]

Such that $\Delta D$ is a laser-specific corrections to the measured distance of the measuring laser and VerticalOffset is the physical distance above the base that a laser is mounted. These values are known for each laser and supplied by Velodyne in an XML file.

We convert from a cylindrical co-ordinate system to a Cartesian system in the reference frame of the LIDAR system:

$$X = (r + Corr_x) \cos(A) \sin(\theta) - \text{HorizOffset} \times \cos(\theta)$$ \[4\]

$$Y = (r + Corr_y) \cos(A) \cos(\theta) - \text{HorizOffset} \times \sin(\theta)$$ \[5\]
\[ Z = z \]  \[ 6 \]

Corr\textsubscript{x} and Corr\textsubscript{y} are calculated from information about the laser and supplied by Velodyne. HorizOffset is a distance referring to the internal design of the Velodyne, it is supplied by the manufacturer.

### A.3 HARRIS2 Space

Given the location of the observed point in an \((X,Y,Z)\) co-ordinate system centred on the LIDAR, we perform a rotation and translation to place this point in a co-ordinate system centred on the HARRIS2 vehicle – this is the HARRIS2 Space. Figure 30 shows the HARRIS2 Space, in which a second set of Cartesian co-ordinates \((X',Y',Z')\) are centred on the vehicle – \(X\) points upwards, \(Y\) points to the left and \(Z\) points behind.\(^{11}\)

\[ Z' = Z \cos(M) - X \sin(M) \]  \[ 7 \]
\[ X' = X \cos(M) + Z \sin(M) \]  \[ 8 \]
\[ Y' = Y \]  \[ 9 \]

**Figure 30:** Side on view of the co-ordinate system of the HARRIS2 space. Note the direction of travel and the location of the LIDAR system indicated at the top and back of the vehicle.

The LIDAR system is mounted at an angle of 22.6\(^{o}\) to the horizontal – angle \(M\) in Figure 31. We perform a rotation of 22.6\(^{o}\) to the horizontal:

**Figure 31:** The Velodyne LIDAR is mounted on Harris 2 at an angle of \(M\) degrees to the horizontal.

After rotating, a translation resets the \((0, 0, 0)\) point for the \((X', Y', Z')\) co-ordinate system. Figure 32 shows the translation that is used to move the \((0, 0, 0)\) point between the co-ordinate systems. The \((0, 0, 0)\) in the \((X', Y', Z')\) co-ordinate system is at the reference point for the IMU installed in the HARRIS2 vehicle.

Data in the HARRIS2 space is referenced to a \((0, 0, 0)\) point inside the HARRIS2 vehicle. To generate a picture of the environment space around the vehicle we must make one final transformation into the Survey Space.

\(^{11}\) This is a non-standard selection for axis orientation, however it is convenient to retain this orientation
Figure 32: The (0,0,0) point for the Velodyne LIDAR is located at an offset from the inertial reference point for the Applanix system on Harris 2.

A.4 Survey Space

Given the location of a point in the HARRIS2 space (X’, Y’, Z’) we can use the known position and dynamics of the vehicle during a survey to convert to the Survey Space (X’’, Y’’, Z’’). For this work we have defined the survey space with reference to the British OSGB36 grid.

Position and dynamics information about the HARRIS2 vehicle is provided by the IMU and GPS system installed in the vehicle, which we have integrated in the vehicle so that the measurements are closely synchronised with the LIDAR measurements. The major components of the position and dynamic data are the Pitch, Roll, Yaw and OSGR grid co-ordinate. These dynamic movements are accounted for in our transformation using Tait-Byron relations\(^\text{12}\).

A.4.1 Roll

When cornering or driving on a cambered road a vehicle experiences roll. Roll is defined as an angle from the vertical at which a vehicle is leaning – see Figure 33.

\[
X' = X' \cos(\text{Roll}) - Y' \sin(\text{Roll}) \tag{10}
\]

\[
Y'' = Y' \cos(\text{Roll}) + X'' \sin(\text{Roll}) \tag{11}
\]

A.4.2 Pitch

A vehicle experiences Pitch when traversing slopes, or when braking / accelerating. Pitch is defined as a deviation in the vehicle’s orientation from the horizontal – see Figure 34.

\(^{12}\) http://en.wikipedia.org/wiki/Euler_angles
Pitch is accounted for by adjusting the co-ordinate system as follows:

\[ X' = X' \cos(Pitch) - Z' \sin(Pitch) \]  
\[ Z' = Z' \cos(Pitch) + X' \sin(Pitch) \]

A.4.3 Yaw & Position

The vehicle yaw equates to its bearing, i.e. its instantaneous direction of travel. The yaw is defined as an angle relative to north – see Figure 35.

\[ Y' = -Y' \cos(Yaw) - Z' \sin(Yaw) \]  
\[ Z' = -Z' \cos(Yaw) + Y' \sin(Yaw) \]

Once this is done, the final part of the transformation is to simply add the position data from the GPS to deliver a globally-referenced position for the point we originally measured in Figure 29. The co-ordinate system used is the OSGB36, for which an Easting (E), Northing (N) and Altitude (A) value is reported from the HARRIS2 IMU. The final result is:

\[ \text{Easting} = Y'' + E \]  
\[ \text{Northing} = Z'' + N \]  
\[ \text{Altitude} = X'' + A \]

A.5 3D point clouds

The process described here allows a set of data obtained from the LIDAR (the Velodyne system used for this application) to be visualised as a 3D map of the environment around a moving survey route. The original LIDAR data collected in the LIDAR space contains information that cannot be related to the environment in which it was collected,
which significantly reduces its usefulness. The process of converting it into the survey space provides crucial spatial information – see Figure 36.

**Figure 36: LIDAR space (left) and Survey space (right) of the same point clouds**

In Figure 36 the LIDAR space point cloud consists of a mist of points centred on a very small region. This is because the cloud is effectively compressed into the reference frame of the static LIDAR system. The Survey space point cloud contains geometry, and as such a picture of the surveyed environment (pavement and trees) emerges.
Glossary of terms and abbreviations

LIDAR – Light Detection And Ranging
TRACS – Traffic Speed Condition Survey
TSD – Traffic Speed Deflectograph
HARRIS – Highways Agency Roads Research and Information System
HAPMS – Highways Agency Pavement Management System
FFV – Forward Facing Video
MSP – Machine Survey Pre-Processor
BCD – Base Condition Data
RCD – Raw Condition Data
IMU – Inertial Measurement Unit