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Use of Traffic Speed Lidar in Road Asset Assessment

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Executive Summary

The Highways Agency conducts routine automated surveys of trunk road pavement surface condition under the TRACS survey, and of structural condition under the TRASS survey. These surveys assist the Agency in establishing the condition of the network, prioritising reconstruction and repair work and valuing its road assets. However, the network includes assets other than pavements – such as bridges, signs, gantries, lighting, vehicle restraint systems, embankments and many types of roadside furniture – none of which are assessed using current automated routine surveys.

LIDAR (Light Detection and Ranging), which uses laser sensors to measure distances from the sensor head, has the potential to deliver measurements of objects much further from the survey vehicle than TRACS surveys. Although the accuracy of LIDAR sensors is lower than TRACS sensors, it is well within the accuracy required for measuring many roadside infrastructure assets.

This report describes an investigation into the use of LIDAR for the measurement and assessment of road assets. The work, which builds on previous research carried out for the Agency, focusses on the automation of asset assessment, describing the development and application of algorithms for the location and measurement of roadside barriers, bridges and gantries. The algorithms draw upon a method called LIDAR slicing to allow the large LIDAR data set to be broken down into manageable lengths whilst still containing the information required for automated analysis.

An algorithm to assess barriers is shown to automatically identify the presence of barriers (either steel or concrete) and estimate their heights. Testing using data collected on the M25 shows it to be capable of identifying the heights of 80% of barriers to an accuracy of ±5cm. There is a reasonably low level of noise in the data, but errors occur where bridges or vegetation lie between the survey vehicle and the barrier. An algorithm to locate and assess bridges has also been developed and tested on structures (bridges, foot bridges and gantries) on a section of the M25. It is shown to identify 25 of the 26 structures. Furthermore, the algorithm correctly discerns the 8 road bridges from the 26 structures. Automated bridge heights show good agreement with those obtained from manual assessment. It is suggested that the algorithms could be applied on the network, but it would be preferable to fine-tune their using network tests before implementation. Further work could also consider how the data could be used to assist the road operator in managing the asset.

With the size of the HA’s network and its many thousands of asset inventory items there would be significant advantage in time, cost and objectivity if the use of automation could be expanded. This work has shown that LIDAR could offer the potential to automate the identification and measurement of these assets. However, the work has been limited to two distinct types of asset, representative of the types of asset that would be most straightforward to extract from LIDAR data. There is potential to expand the automated application to other assets, although this would require the development of further algorithms. The required LIDAR data could potentially be provided through the addition of LIDAR to existing TRACS surveys. However, before considering expansion of the LIDAR methodology there is a need to consider how such data would fit into the Agency’s current Asset Management practice, in terms of the need for the data, the required coverage and accuracy and the required frequency of updates. This would assist in establishing a case for further development and implementation.
1 Introduction

The Highways Agency has conducted routine automated surveys of trunk road pavement surface condition since 2000 under the TRACS survey, and more recently (since 2011) of structural condition under the TRASS survey. 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, vehicle restraint systems, 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 survey vehicles use laser systems focussed on the road surface to measure surface shape, 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 beginning to challenge the current paradigm. Although operating with lower accuracy than the lasers used in TRACS (LIDAR systems deliver data in the ~cm accuracy range), LIDAR can deliver measurements that are well within the accuracy specification range for many roadside infrastructure assets and as such is likely to be well-suited to aid in their assessment. In additional, LIDAR systems make use of lower-powered laser systems that are safe to the human eye, and therefore capable of scanning the roadside infrastructure without risk to the road user, in addition to measuring the pavement surface.

This report details an investigation into the use of LIDAR as a routine tool for the measurement and assessment of road infrastructure assets. The work builds on previous research carried out for the Agency into this application [1]. This report focusses on the automation of asset assessment, describing the development and application of proposed algorithms for detecting and determining the locations and dimensions of roadside barriers (Section 4), bridges and gantries (Section 5).
2 LIDAR

2.1 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 utilises a similar time-of-travel principle to radar. But instead of measuring the travel time of radio pulses from a transmitter to a target and back to a receiver, it uses pulsed laser light. The shorter wavelengths and coherency of laser light allows LIDAR to achieve much better spatial accuracies over shorter distances than possible with radar. LIDAR applications include atmospheric surveying, remote sensing and obstacle detection in automated systems.

By combining LIDAR technology with geographical positioning systems common to pavement survey vehicles, Traffic-Speed LIDAR has been shown to have the potential to revolutionise roadside infrastructure assessment by generating three-dimensional images of roads and roadside infrastructure [2, 3]. With a single pass at traffic speed, a survey vehicle is able to map the three-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

2.1.1 HARRIS2

TRL maintains and operates the HARRIS2 (Highways Agency Road Research Information System 2) survey vehicle, which is a traffic-speed survey vehicle developed by TRL for the Highways Agency (Figure 1). HARRIS2 is currently used as a reference device for the network-level surveys of pavement condition carried out on the Strategic Road Network, and also as a platform for developing and testing new approaches to pavement assessment.

For the “traditional” measurement of pavement condition (shape) HARRIS2 is fitted with a Phoenix Scientific Pavement-Profile System (PPS), which is a high resolution transverse profile laser system capable of collecting over 1000 transverse points across an approximately 4.2m survey width. HARRIS2 is also equipped with an Applanix POSLV GPS and Inertial Measurement Unit (IMU) that records the movements of the vehicle in space (yaw, pitch, roll) as well as its position using GPS.

HARRIS2 is also fitted with a Velodyne HDL-64E-S2 LIDAR system (Figure 1 and Figure 2). The LIDAR is fitted to the rear of the vehicle, affording it an unrestricted 360° view of the surrounding area. By combining data from the Velodyne and Applanix systems, it is possible to carry out LIDAR surveys at traffic speed, and combine the GPS, IMU and LIDAR data to construct point clouds of the road and roadside environment.
2.1.2 Velodyne LIDAR

The Velodyne HDL-64E S2 system uses a rapidly rotating (up to 1200rpm) measurement head containing 64 individually-aligned 905nm (near infra-red) lasers. The laser pulses are of 5ns in duration and the data rate for each laser is about $2 \times 10^3$ samples per second. The system is estimated to provide distance returns with an accuracy of approximately ±20mm. When mounted with a vertical rotation axis the lasers in the unit cover a vertical angle from 2 degrees above horizontal to 24.3 degrees below at ranges of between 1m and 100m in a 360° envelope.

On HARRIS2 the unit is mounted with the axis tilted at 68 degrees from the vertical, therefore the ground immediately below the sensor and the surrounds are covered. The Velodyne system is suited to traffic speed LIDAR survey work because the rapidly-rotating head allows it to generate a 360° “3D image” of a road environment. This forms a spiral of data as the LIDAR head spins and the vehicle is moving at traffic speeds.

Previous work at TRL [1] has established the accuracy of a Velodyne LIDAR both statically and when operating at traffic speed. Distance accuracy of the Velodyne is specified as ±20mm, though previous static laboratory trials at TRL demonstrated a poorer performance than this and wide scatter. The accuracy that is ultimately achievable with the Velodyne LIDAR at traffic speeds will therefore depend on this. When mounted on HARRIS2, the angular resolution, range and the accuracy achieved by Velodyne is further impacted by the movement of the vehicle, particularly roll and lateral translations. This is corrected for by making use of data from the Applanix system, but errors in measurement by the Applanix and differences in timing between the two systems can still lead to additional errors being introduced.
2.1.3 Processing LIDAR data - LIDAR Slicing

LIDAR data is typically visualised and analysed by taking the survey data and plotting the point cloud in a 3D software package that allows for user-manipulation of the data. This is a practical analysis method 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, and a LIDAR survey carried out over this distance could generate around 100GB of data – a significant amount to process.

There is therefore a need to develop a suitable method to handle, display and process LIDAR data collected routinely at traffic speed. A method called LIDAR slicing was developed in previous research for the Agency [1] to improve the practicality of processing LIDAR data collected at traffic-speed. The method is based on a similar concept to the measurement of transverse profile, and is like methods used by other groups to identify the locations of roadside curbs [3]. To measure transverse profile a laser measurement measures the shape across the road surface as a series of points covering about 3.5m across the road width. These transverse profiles are delivered every 0.1m along the survey route. Each transverse profile is then processed after the survey to interpret the road shape, and hence obtain rut depths. These are delivered relative to the route (e.g. the rut depth at a given location into a pavement management system such as HAPMS) as well as relative to a geographical position (e.g. OSGB36 co-ordinate).

The LIDAR slice is defined as a transverse portion of a LIDAR data set that describes the shape of the “environment” in a 360° envelope around the survey vehicle. Like transverse profiles, slices can then be analysed separately, with results referenced against the survey route as well as relative to a geographical position (OSGB36 co-ordinate). By analysing one slice at a time, as opposed to an entire survey, the processing and storage requirements are reduced and the practicality of the method is increased.

Figure 3: A point cloud (left – viewed from the top-down) is divided into sections along the survey driving line (right – 3 slices shown). The image has been artificially coloured to emphasise the differences in elevation.

Figure 3 shows how LIDAR 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. A major advantage of using slices is that separate co-ordinate axes, orthogonal to the direction of travel, can
be dynamically defined within each slice. The +Y direction is defined as the direction of travel, the +X direction towards the offside of the vehicle and the +Z direction vertically upwards.

Slices can also be visualised from the point of the view of the driving line of the vehicle. Figure 4 shows a single slice of LIDAR data taken from the data set in Figure 3, viewed in the +Y direction. 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.

Figure 4: A single 15m LIDAR slice from the data set shown in Figure 3 – 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. The same artificial colouring as used in Figure 3 is used here.

When looking at 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. Indeed the view of the roadside environment provided in Figure 4 appears to be from on-board a vehicle. 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 will make use of this implicit understanding of the positioning of objects of interest in the on-board view when developing algorithms in Sections 4 and 5.
3  Collection of Test and Reference Data

3.1  Collection of data

As noted in section 1, the work described in this report has focussed on the development of LiDAR as tool for the measurement and assessment of road infrastructure assets. In particular the work focusses on the automation of asset assessment, developing and applying algorithms for detecting and determining the locations and dimensions of roadside barriers, bridges and gantries. In order to provide both a test and reference dataset for the further development of the asset assessment algorithms, a LiDAR survey using HARRIS2 was carried out on the M25.

LiDAR (including Inertial and Applanix (GPS) data) and forward-facing images were collected in the outside lane of the M25 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 in the central reservation. All the data was collected in a single day, under dry conditions with an Agency-provided crash cushion to ensure safety for road users and TRL staff.

Two sections of this survey, from Junction 1b to 3 (J1b-3) and from junction 9 to 11 (J9-11) in the clockwise (CW) direction, have been used for testing and development of barrier and bridge measurement algorithms. The J9-11 section is equipped almost entirely with a central concrete step-barrier mounted with twin-armed lighting columns. The J1b-3 section has significant lengths of steel box-beam barrier and corrugated beam barrier. Both sections include a large number of overhead sign-gantries and a substantial number of road bridges and some footbridges.

3.2  Analysis to deliver a reference dataset

The LiDAR data collected by HARRIS2 was divided into slices (see Section 2.1.3). A viewer was developed that allowed the slices to be plotted in a compressed ‘direction of travel’ viewpoint (in which the dimension in the direction of travel – the Y co-ordinate – 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 (see Figure 5). The LiDAR data also provided a measure of the intensity (RGB levels), and so allowed white lines to be identified.

![Figure 5: LIDAR slice focussed on the pavement and adjacent concrete barrier. The Y co-ordinate has been supressed, meaning that the slice lacks depth in the direction of travel.](image-url)
Tools were developed in the viewer to allow a manual assessor to record distances, by clicking on the screen and moving the mouse. Measured distances were automatically stored in relation to section, chainage and OS co-ordinate. The LIDAR slice data could be scrolled forward and backward without the “view point” changing, thereby increasing the practicality of the assessment. Barrier distances and heights, as well as the locations and clearances of bridges and gantries, were measured manually using this technique. The height of the central barrier was manually estimated by locating the top of the barrier and measuring the vertical distance between it and the pavement. These results were used in section 4 to baseline the performance of the automated barrier algorithm.

Using a technique similar to this, a manual assessment of the locations, sizes and types of bridges and gantries could also be carried out. The dimensions of the bridges were marked out using the same tools that were used to determine the heights of barriers. Forward-facing images that were collected during the LIDAR survey were then used to determine the nature of each bridge, and categorise each as a road bridge, foot bridge or gantry. The results of these manual analyses are used in section 5.
4 Barriers

4.1 Types of barrier

There are several different types of barriers that are commonplace on the UK’s trunk road network. On the length of the M25 selected for algorithm development and testing, J9-11 contained mainly concrete barriers (Figure 7). A mixture of barrier types were present on the J1b-3 site, including steel tensioned-corrugated and box-beam barriers (Figure 6). In addition, there were some concrete barriers on the J1b-3 site.

Figure 6: Two types of steel barrier, Box-beam (left) and corrugated (right)

Figure 7: Example of a concrete barrier

4.2 Algorithm Overview

The objective in developing the barrier algorithm was to develop an automated method of identifying the locations of barriers, and their dimensions from LIDAR data collected in a traffic speed survey. Ideally the algorithm would be capable of delivering measurements on several different types of roadside barriers.

The test data sets used as inputs into the algorithm are the slices of LIDAR data described in Section 2.1.3. Each slice contained 10m of LIDAR data in the longitudinal direction. An example of a 10m slice is shown in Figure 8. There are approximately 200,000 individual LIDAR points contained in each slice.

The rotational speed of the LIDAR head and the forward driving speed determine the longitudinal spacing along the road of each LIDAR scan. As the forward speed increases gaps begin to appear between successive scans. In the M25 survey there are significant
gaps between the scans which extend laterally as far as the expected location of the barrier. These can be seen clearly in Figure 8 as dark areas on the surface of the road.

Figure 8: Visualisation of a single 10m long slice of data from the M25. The road is clearly visible, along with the barrier and a gantry running over the carriageway. The colouring is artificial and designed to aid in the visualisation of the heights of objects in the image.

Initial development of the barrier algorithm was carried out as part of previous work [1], which delivered a prototype algorithm in the form of Matlab scripts. Matlab is ideally suited to processing large quantities of array data. A summary of the prototype barrier algorithm (before any further development) follows:

- Load each 10m slice and sub-divide it further to 1m sub-slices
- For each 1m sub-slice, firstly check for the presence of a bridge or gantry (Section 5). If there is no bridge or gantry found...
  - Work outward from the centreline of the survey vehicle to obtain lateral sections. Each lateral section is a self-contained chunk of point cloud data covering a 1m portion of LIDAR data in the transverse direction – see section 4.2.1 for further details.
  - Search for a change in the variance of the z-co-ordinate (height) of adjacent lateral sections greater than a specified threshold change. Where this is found, assume a barrier has been found.
  - Calculate the barrier height as the difference in vertical height between this and the adjacent lateral sections. The barrier height was taken as the mean of the z co-ordinates in the adjacent lateral section (assumed to be the road) and the 95th percentile of the z co-ordinates in the lateral section identified as containing a barrier.

4.2.1 Lidar Lateral Sections

Lateral Sections of LIDAR data were created by further subdividing the portions of LIDAR data that had been sliced (and then sub-sliced) longitudinally. The slices are subdivided in the transverse direction into chunks 1m in width to produce Lateral Sections. A single Lateral Section of LIDAR data therefore contains all such data in a 1m by 1m square in the x / y plane.
There is no fixed number of Lateral Sections that can be made from each 1m sub-slice, it is possible to work outwards in the offside or nearside directions from the survey vehicle generating Lateral Sections as long as data is available. The first Lateral Section created from a sub-slice will contain all data lying between 0m and 1m in the transverse direction from the centre point of the vehicle, the second lateral Section will contain data between 1m and 2m – and so on until there is no more LIDAR data available.

What this means, is that in general all of the LIDAR points incident on a barrier face will lie within one Lateral Section (or possibly across two adjoining ones). Therefore by using Lateral Sections as a way of breaking up LIDAR data, it is possible to quickly isolate portions of the point cloud that are of interest.

4.3 Testing of the prototype algorithm

Before doing further developments to the algorithm, tests were carried out to baseline its original performance. The behaviour of the barrier algorithm in its initial form, when applied to the LIDAR data collected on the J9-11 site data, is shown in Figure 9. The results show the height of the road (blue), height of the barrier (red) and lateral position of the barrier (purple), all in metres. The algorithm reports a very wide distribution of the apparent barrier location, which suggests a large number of erroneous barrier detections. There is so much noise in the lateral location of the barrier that it is difficult to discern the true barrier height, although it appears likely that it is around 1m for most of the site. The road height has been measured as being at approximately -0.7 m (below the zero height of the Inertial Measurement Unit on HARRIS2), but is again extremely scattered. There are additional points above and below the limits of this chart, representing even wider scatter in results.

A close inspection of the data was carried out to determine the reasons for the behaviour of the algorithm and to suggest potential ways of improving its performance. This was done by viewing slices in both 2D and 3D using software tools and by close observation of the operation of the algorithms on sections of the data containing specific features. It was determined that many of the spurious data points occurred when the algorithm failed to detect the barrier, but carried on searching until a lighting column, a vehicle in the opposite carriageway, vegetation or cutting slope was found, which was then
reported as the barrier. This resulted in both the calculated barrier height and road height being wrong. Therefore a way to improve the lateral identification of barrier position was sought.

A second problem was that the accuracy with which the LIDAR system measures heights reduces with lateral distance, since the points are further from the measurement head. This makes sense as the measurement accuracy of the LIDAR naturally decreases with increasing time of flight of the laser in the system. The potential knock-on effect of this is that there will be decreased measurement accuracy for features far from the survey vehicle, i.e. measurements made of the near side barrier from a survey vehicle in lane 3 will be less accurate than those of the same made from lane 1.

Thirdly, the faces of concrete barriers slope such that it was quite common that the face of the barrier lies across two lateral sections. This possibility is mentioned in section 4.2.1 and is clearly visible in Figure 5 and Figure 7 (where the barriers are clearly sloped). This results in the variance difference (which is used to detect the barrier) failing to exceed the detection threshold.

Finally, lighting luminaires, support arms and columns and road-signs in the central reserve could also render the barrier detection ineffective, since their presence disrupts the calculation of variance in z co-ordinates.

### 4.4 Algorithm Development

The following methods of reducing the problems identified above were proposed and developed into the algorithm:

- Reducing the width of lateral sections to improve lateral resolution and detection selectivity. The lateral section interval was found to be optimal at 0.5m (however this is without carrying out any filtering – see section 4.6). In addition comparing lateral sections two intervals apart reduced the chances of missing a barrier.
- Introducing a new criterion to apply when looking for a bridge (see Section 5).
- Detecting barriers by comparing height differences between lateral sections rather than comparing height variance. The variance is too sensitive to single extreme outliers, and a better solution was found by comparing the mean (or median) height of the data in one lateral section against the 95th percentile height of the appropriate lateral section.
- Modifying the threshold at which the location of a barrier is identified in accordance with the above change.
- A more precise lateral position of the barrier can be determined by taking the mode of the x-co-ordinate points in the lateral section where the barrier was identified.
- Introducing a minimum number of points to define a valid lateral section. If less than 10, the section is ignored.

### 4.5 Testing of developments

Figure 10 shows the result of applying the amendments above to the J9-11 survey data, all the measurements appear to be greatly improved. The top of the barrier is now reasonably clearly defined, although sometimes is appears that points on the face are
still being detected in lieu of points on the top of the barrier, as shown by the spurious low barrier heights reported.

![Figure 10: M25 CW J9-J11 barrier data using the updated algorithm](image)

The road height is now much more clearly defined, with very few spurious outliers. There are still a small number of erroneous “noise” points above the barrier, which may be caused by the presence of lighting columns. A periodic raising of the height of the barrier for short lengths in the vicinity of bridge piers and gantry legs is apparent in the data. Examination of the forward images from the survey has confirmed that this correctly reflects the way the barriers have been constructed close the bridges on this site. The lateral position of the barrier is shown as an almost continuous curve with few spurious outlying points.

An additional dataset of bridge and gantry heights is also shown in Figure 10, which lie in a band mainly between 5m and 7m. A small number of points above this level are likely to be due to a failure to completely eliminate lighting equipment. These points are discussed in more detail in Section 5.

Figure 11 shows the results of applying the improved algorithm to the J1b-3 site. This section contains significant lengths of both corrugated steel beam barrier and steel box-beam barrier. There appears to be significant noise towards the end of the site, but it is suspected this is due to the presence of vegetation.
4.6 Data Filtering

Although the improvements to the barrier algorithm appeared to reduce the noise in the data considerably, variability is still present, in particular in the reported barrier height. Therefore the application of filtering was investigated in order to reduce noise. By applying basic knowledge about the nature of roadside barriers on the network, assumptions can be made about the results and therefore outliers easily removed.

4.6.1 Noise in the data

Figure 12 shows the results of the barrier algorithm for the J1b-3 site. Here the focus is on the height measurement, and hence the scale is reduced over that shown in the above figures. Two outputs are shown, the blue line shows the results of the algorithm using 1m lateral sections, the red line shows the same for 0.25m lateral sections.

An initial examination of Figure 12 shows that there are large spikes located along the whole length of the data. It can also be seen that there is a large variation in the calculated barrier height between approximately 2km and 7km. This is due to the effect of the concrete barrier that slopes outwards slightly on the algorithm (discussed in Section 4.4). As the algorithm searches laterally it is possible for it to find the bottom of the barrier before it finds the top. This is especially true when using a small lateral section spacing, which explains the increase in noise between the 1m and 0.25m spacing in Figure 12. This can be mitigated by making use of a larger lateral section spacing, though by doing this we risk losing the improvements in accuracy that were achieved in Section 4.4.
Figure 12: Results of the barrier height algorithm for the J1b-3 site. Results using both a 1m and 0.25m lateral section spacing are shown.

In the region from approximately 8km onwards there are large areas of noise. In this part of the survey there was a grassy central reservation which is likely to cause erroneous barrier height measurement as the algorithm is responding to the grass itself rather than to the barrier on the other side of it. This can be seen in Figure 13 where the position of the barrier is clearly obscured by the presence of the grass.

Figure 13: Image of the grassy central reservation (right) and how the LIDAR slice of this part of the road appears in the manual analysis tool (left)

4.6.2 Filter application

A simple spike removal filter can be used to remove any points whose values differ greatly from the mean value of points in the surrounding length. Such a filter was applied over 5m moving lengths using a difference threshold of 0.4m to remove the large spikes. After removing spikes, a moving average method was used to smooth out remaining noise. A moving average is taken over a 20m wavelength. The average is calculated by taken the mean of values of points lying between and including the 70th and 95th percentile in that range. This results in a smoothed value that always sits close
to the top of the noise band in Figure 12. The resulting cleaned barrier algorithm output is shown compared to the original algorithm in Figure 14. Significant improvement is shown over the original.

Figure 14: Original data output from barrier height algorithm compared to the cleaned & filtered data. There is a significant reduction in noise.

4.7 Testing against manual reference

A manual analysis of the J1b-3 site was carried out in accordance with the method laid out in section 3.2. Figure 15 compares the modified algorithm and filtered data set to the manual reference. This shows encouraging results for all but the grassy section of the survey located between 8km and 10km.

Figure 15: Filtered algorithm and manual reference data for the J1b-3 survey.
The two apparent spikes in the barrier height at ~8km in Figure 15 are real jumps in the height of the barrier. These are places where the barrier height goes up just before bridges over the main carriageway.

Figure 16 shows a plot of the differences between the automated and manual barrier height methodologies. The distribution is slightly skewed towards a positive difference, meaning that the algorithm mostly over-estimated the reference barrier height. However there is a long negative tail in the distribution, indicating that there are still a large number of heights that were underestimated.

Manual inspection of barriers is expected to accurately record their heights to ±3cm accuracy. In Figure 16 the 80th percentile lies at 3.1cm and the 20th percentile lies at -3.5cm, meaning that approximately 60% of barrier heights were measured with an accuracy matching that which is expected from manual, walked inspections. 80% of all automated measurements lay within ±5cm of manual measurements.

4.8 Summary

Following the identification of the limitations of the barrier algorithm proposed in the previous research, this research has identified and developed a number of improvements. Overall, the following changes to the barrier height algorithm are proposed:

- Reduce erroneous barrier identification by excluding bridges and gantries from the analysis. Identify bridges and gantries using an alternative methodology (see Section 5).
- Vary the size of lateral sections. Sections that are 1m in size result in more noise, whereas section that are 0.25m in size result in more false positives when identifying concrete barriers. The solution lies in 1) using small (0.25m) lateral
sections when there is positive knowledge that no concrete barriers are present and 2) using larger (1m) lateral sections when there is no such positive knowledge, and applying a post-processing filter to remove noise.

- Reject lateral sections that contain too few points. Fewer than 10 points appears to be a reasonable cut-off.
- Determine the locations of barriers by looking at the differences in mean z co-ordinate height between lateral sections. This is better than using the variance of the z co-ordinate as the variance is much more sensitive to outlying individual values.
- Lateral position of the barrier can be determined by using the mode of the x-co-ordinate in the lateral section where a barrier is found. This replaces the use of the mean x co-ordinate.
- Adopt a post-processing filter that removes spikes and smooths the results over a moving average of data lying between the 70th and 95th percentiles

Comparison of the final output against manual analysis was favourable (Figure 15). This demonstrates that using this algorithm, a traffic speed LIDAR system is capable of identifying the locations of roadside barriers and assessing their heights to a reasonable degree of accuracy. 80% of all barriers in the test data set were automatically measured to within ±5cm of the manual reference, 60% of all barriers were automatically measured to within ±3cm of the reference – the accuracy required of manual on-site barrier assessments.
5 Bridges and Gantries

The UK trunk road network is crossed by several types of bridges and gantries of varying sizes, shapes, constructions and – most importantly – clearances. The clearance that a bridge running over a highway affords the traffic running on that highway is one of the most important things that engineers must keep in mind when carrying out maintenance. When maintaining a pavement that runs underneath a bridge, the clearance under that bridge must be accounted for when laying a new surface. To this end, it is important that the Agency has up-to-date and accurate information about the locations and clearances of bridges and gantries on the network.

LIDAR naturally lends itself to the identification and assessment of bridges and gantries. LIDAR point clouds include all the roadside assets and environment around and above the survey vehicle. Depending on the exact mounting angles and field of view of the LIDAR system, it will commonly be capable of viewing the abutments upon entry and exit, as well as the underside of the bridge decking. Information about the location of the pavement and the bridge decking will allow a calculation of the bridge clearance.

5.1 Initial Development

Previous work [1] introduced a prototype algorithm for detecting the locations of bridges from LIDAR data. The method works by operating on LIDAR slices (Section 2.1.3) and taking advantage of what the ‘on board’ view from the survey vehicle reveals about the relative location of parts of the bridge. For example, the bridge decking is always above the vehicle while the road surface is always below the vehicle. The prototype algorithm assessed each LIDAR slice in a survey in turn. Firstly the algorithm checked to see if there was likely to be a bridge-like feature present, then tried to determine the dimensions of the feature, and then categorising it as either a bridge or a gantry. The prototype algorithm [1] used a complicated system of radial components to identify potential bridges. In this work the approach was revisited and it was determined that it would be appropriate to take a new approach using a simpler but more effective method. In summary, the new approach:

- Checks each slice in the survey in turn; consider one slice at a time.
- Considers the z and x co-ordinates of the points in the slice. If >5% of points in the slice have a z co-ordinate >4m above and the vehicle and an x co-ordinate lying within 2m of either size of the vehicle, then assume that this slice contains a bridge. This relies on the idea that the LIDAR will only ever record a significant number points above the survey vehicle when it passes under a bridge.
- If a bridge is detected then do not try to apply the barrier height algorithm to this slice. This is because the presence of a bridge will disrupt the smooth operation of that algorithm. This reduces the number of errors in the barrier height algorithm.
- Determine the height of the bridge by isolating points in the slice within a ±20° arc in the vertical above the centre of the survey vehicle (bridge points), and points within ±20° about the vertical below the centre of the survey vehicle (road points). The bridge height is then estimated as the difference between the 5th percentile of the z co-ordinates of the bridge points and the 95th percentile of the z co-ordinates of the road points. By using percentiles, it is more likely that the
algorithm will under-estimate the bridge height than over-estimate it. This is desirable from a safety point of view.

5.2 Testing of initial development

The above enhancements to the algorithm were made and tests were carried out to determine their impact on the performance. A comparison was made between the results of the algorithm and the results of the manual analysis outlined in Section 3.2.2.

Applying the bridge algorithm to the J1b-3 survey results in the output shown in Figure 17. The location and heights of "bridges" reported by the algorithm are shown as a series of crosses, with the true locations of road bridges, foot bridges and gantries shown as circles of different colours. The initial results show a lot of apparently spurious outputs from the algorithm, i.e. a large number of false positives.

An inspection of Figure 17 shows that there are a number of distinct false positives. The three types of false positives are:

1. There are a large number of detections likely to have been caused by the presence of lighting columns, bracket arms and luminaires. These occupy the zone above a certain height.

2. Large clusters of points where real objects are present. This is caused by the fact that the LIDAR survey is being analysed as a series of slices, whereas in fact large bridges are usually single continuous objects. Therefore rather than reporting multiple instances of the same bridge, the algorithm should ideally be reporting a single bridge.

3. A few other erroneous points caused by special cases.

It was considered that each of these could be mitigated by a change to the algorithm.
5.3 Further Algorithm Development

To acquire a more accurate output, the issues identified in Figure 17 were addressed by altering the bridge detection algorithm in the following way:

- Increase the proportion of overhead points needed to detect a bridge from 5% to 7%. This helps to reduce the detection of lighting brackets and luminaires. Any further increase above 7% resulted in reduced reliability in detecting bridges, so 7% should be considered a maximum.

- Lighting columns always fell above a particular height, so these were removed by ignoring anything above a certain height threshold. For this a threshold of 9m was deemed appropriate.

- In order to group together the points which actually belong to the same object, successive points were grouped together as long as they were spaced less that 2m apart longitudinally. The mean longitudinal location and height of these points was reported as a single point.

- It is assumed that all objects of interest are large enough to be visible in multiple LIDAR slices. Therefore data points that appeared isolated within a single slice were removed as false positives.

Categorisation of bridges as footbridges, road bridges or gantries is possible by estimating their width. Width is estimated by counting the number of successive LIDAR slices containing a bridge. Since each slice was 1m in length, the length in bridge in metres is estimated to be equal to the number of consecutive slices containing the bridge. Manual inspection of the bridges and gantries along the survey routes showed that typically road bridges were greater than 8m wide, whereas foot bridges and gantries were commonly less than 8m wide.

5.4 Testing of developments

A comparison between the updated bridge algorithm and the manual analysis is shown in Figure 18. Here there is a much improved performance, with many fewer false positives and the bridges clearly categorised as either road bridges or ‘other’. In the 10km long section shown, there are 26 structures identified in the manual analysis. Of these, 8 are road bridges – all of which are correctly identified by the automated algorithm. Of the remaining 18 structures, 17 are identified and correctly classified as ‘other’ (i.e. not a road bridge).

In addition to categorising the types of bridges, the heights of the bridges are also well-estimated by the automated algorithm. Figure 19 shows the correlation between the automated bridge height and the heights calculated from manual assessment. There is good correlation between the two ($R^2 = 0.86$).
Figure 18: Comparison of manual assessed bridge & gantry heights against automated detection and categorisation. Note that the automated categorisation is only capable of discerning between road bridges and ‘others’.

Figure 19: Correlation between automated height detection and manually assessed height.

Figure 20 shows the differences between the automated and manual bridge and gantry height measurements for each of the 26 structures. The mean difference between the measurements is approximately 0.2m, with the automated measurement generally over-estimating the clearance.
Figure 20: Differences between Automated and Manual structure heights (m). The differences are mostly positive, indicating that the automated analysis is generally over-estimating the structure heights. The mean difference is ~0.2m.

5.5 Summary

The tests on the updated algorithm show significant improvement in performance. However, though the method shows promise, there is still potential for further development. For example it should be possible to distinguish between foot bridges and gantries by looking at the density of bridge points, since gantries are generally constructed from steel beams and therefore punctuated by many more gaps than bridges. In addition, a better estimate of the width of the bridges could be made by considering the $x$ and $y$ co-ordinate distributions of the bridge points, rather than crudely aggregating the slices where bridge points are identified. Lastly, the algorithm appears to be generally over-estimating the clearance afforded by structures. It would be preferable that the clearances of structures are underestimated rather than overestimated; therefore further adjustments to the sensitivity of the algorithm to change this would be desirable.

It was noted in Figure 17 that a source of noise in the results was the lighting columns that line the carriageway. Clearly the algorithm is picking up the lighting columns, and so it should be possible to identify then. From this it might be possible to calculate the spacing between them, their heights and even if they are leaning unacceptably.

Finally, the method presented in previous work and here has always focussed on the clearance of the bridge in the lane being surveyed. The LIDAR mounted on the survey vehicle surveys the entire width of the carriageway (where it isn’t obscured by passing traffic). It should be possible to identify different groups of bridge points at different lateral positions, and from that estimate the clearance under the bridge in all lanes.
6 Conclusions

Although LIDAR surveys are becoming more common for measurement of assets in a number of areas, the large datasets provided are typically analysed manually to identify and assess assets. Automation of the analysis process, both in asset identification and measurement is less well developed. This work has drawn on the initial developments of previous research to attempt to automate the identification and measurement of two common assets – barriers and bridges (including gantries). This has the long term aim of assisting in the development of LIDAR as a routine tool for the measurement and assessment of road infrastructure assets.

Due to the large quantity of data delivered in network level LIDAR surveys, it is necessary to break the dataset down into a form that can be applied for automated analysis. The work described in this report has continued to apply the concept of LIDAR slicing developed in the previous work. LIDAR slicing has successfully allowed the very large LIDAR data set to be broken down into manageable lengths whilst still containing the information required for the automation process.

Following a review of the capability of the barrier algorithms proposed in the previous research, the research has identified and developed a number of improvements to the algorithms, which have then been tested using data collected on the M25. The results of the comparison with reference data on the M25 appear very promising. The noise and random (spike) errors identified in the outputs of the previous algorithms have been virtually eliminated. The algorithm also appears to be capable of dealing with both concrete and steel barriers. It is therefore highly likely that the algorithm could be applied on the network to LIDAR slices data extracted from Traffic Speed LIDAR surveys. However, although the work has suggested that the heights of 80% of barrier could be automatically assessed to within ±5cm a manual reference, the method has not been fully tested at the network scale, and it would be preferable to examine and fine-tune the performance over several hundred km of the network before any routine implementation of the method. Further work could also consider how the data could be used to assist the road operator in managing the asset, for example determining if the method could be used to support ongoing checks of compliance of barriers to the required standards and hence highlighting requirements for maintenance.

The work has also applied the concept of LIDAR slicing in algorithms to identify and measure bridge clearances. Although initial tests of the algorithm proposed in the previous work showed a high level of noise and false positive reporting of features, the developments carried out in this work have delivered a significant reduction in this noise and a reasonable level of confidence in the ability of the algorithms to both identify structures and estimate the clearance. The algorithm also appears to robustly distinguish bridges from other structures. However, it is again recommended that the method be fine-tuned over a longer length of the network. The method could also be expanded to measure the clearance at several points across the structure (e.g. in each lane), which would expand its capability and usefulness in characterising structures assets.

With the size of the HA’s network and its many thousands of asset inventory items there would be significant advantage in time, cost and objectivity if the use of automation could be expanded. This work has shown that LIDAR could offer the potential to automate the identification and measurement of these assets. However, the work has been limited to two distinct types of asset, which are representative of the types of asset
that could be most straightforward to extract from LIDAR data. There is potential to expand the automated application to assets such as signs, bollards, VMS, lighting etc., although this would require the development of appropriate algorithms. The required LIDAR data could potentially be provided through the addition of LIDAR to existing network surveys such as TRACS. However, before considering expansion of the LIDAR methodology there is a need to consider how such data would fit into the Agency’s current Asset Management practice, in terms of the need for the data, the required coverage and accuracy and the required frequency of updates. This would assist in establishing a case for further development and implementation.
A.1 References

[1] “Investigation into the potential use of LIDAR to support traffic speed asset measurement and assessment”, HA Client Project Report CPR1385, D. Wright (August 2012)
