New pattern recognition methods and the detection of edge deterioration

by P Watson and A Wright (TRL Limited)

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Executive Summary

New pattern recognition methods and the detection of edge deterioration by P Watson and A Wright

Edge deterioration is becoming a widespread problem in the UK. It has been estimated that the cost of repairing failed edges is in excess of £1,500 million for UK roads. Edge deterioration occurs mainly on unkerbed roads. Its primary cause is vehicle over-run onto the verge, causing overriding and stepping at the road edge. However other factors, such as lack of edge support, inadequate drainage, and encroachment of trees and other vegetation also contribute to this deterioration.

In the UK edge deterioration is typically assessed by inspectors, who carry out visual inspections on foot. In these inspections the deterioration of the road edge and adjacent verge is assessed by visual observation, and the rutting in the verge is either estimated, or measured using a straight edge and wedge. Defects are located by their distance from the start of each road Section surveyed, and this distance is measured with a hand pushed surveying wheel. The disadvantages of manual inspections lie in the fact that they are time consuming, hazardous, subjective and disruptive to traffic. It is clear that a faster, safer and more objective survey would offer a desirable alternative to these manual surveys. However, such facilities are not provided by current traffic-speed surveys.

This project has the objective of investigating experimentally whether deterioration of the road edge can be automatically identified using traffic-speed techniques. The first stage was to demonstrate what the data requirements would be to enable the deterioration to be automatically identified. A practical investigation was therefore carried out to collect images and measure the transverse profile of the road edge and determine whether this data could be manually analysed to a level that compared with surveys carried out on site. This investigation showed that there is sufficient information contained within colour image and transverse profile data collected at the road edge to identify and quantify road edge deterioration.

Equipment installed on the Highways Agency’s HARRIS vehicle was then utilised to obtain good quality image data and high resolution transverse profile data over the road edge, in surveys carried out at approximately 10km/h. We are grateful to the HA for their agreement to use of the HARRIS vehicle for this purpose. The HARRIS scanning laser transverse profile measurement system provided transverse profile over the road edge with little detrimental effect resulting from the challenging conditions presented at the road edge (edge stepping, rough profiles etc). The image system was also able to provide good quality images, under ideal conditions. However the lack of artificial illumination lead to a significant proportion of the images being of either poor quality, or insufficiently illuminated.

An approach was adopted to utilise image and transverse profile processing algorithms to identify the road edge and the edge of the verge, with further algorithms being applied to combine these “intermediate” datasets to identify edge defects. The image processing algorithms to identify the road have been based on the assessment of changes in the colour distribution across the image. The same approach has been applied to identify the edge of the verge. Stepping at the road edge has been identified by quantifying step edges in the transverse profile data. The work has also sought to identify “inventory” features such as kerbs, surfaced verges and white lines. Information on the presence of these features is then used to remove lengths that are more likely to give rise to false positive reports of edge deterioration. Combination of the image and profile datasets has also been used to characterise potholes at the road edge.

Following the programme of algorithm development and testing on local datasets, more extensive tests of algorithm performance were undertaken on a number of sites located on the local road network. The performance was assessed against the results of manual analysis of the image and profile data. The assessment demonstrated a high level of performance in the algorithms on many of the test lengths. However, there were examples of localised areas of poor performance. The use of
algorithms to remove edge features that could adversely affect the detection of edge deterioration (e.g. kerbs) contributed to the higher levels of performance.

The identification of kerbs was particularly successful, which is a direct result of combining the image and profile analyses when detecting kerbs. Unfortunately, the detection of flush kerbing was not so successful, because the low level of stepping at flush kerbs cannot be used to enhance the detection of the kerb in the image data. The identification of surfaced verges was also successful, with the majority of surfaced verges reported in the manual reference data also reported by the automatic analysis. The final edge feature, white lines at the road edge, was not well identified, and a large number of false positive detections were reported. The presence of unevenly lit images was a key reason for this poor level of performance.

Following the automatic removal of lengths containing poor images, kerbs and surfaced verges, the remaining lengths have been analysed with respect to the reporting of edge defects. General agreement was found between the automatic and manual reporting of overriding (at two levels of severity), with a low number of false positive reports. Again the accuracy was affected by poor image illumination. Similar behaviour has been observed in the identification of potholes. However, the identification of both of these defects relies not only on the correct measurement of the shape of the road edge, but also the scheme that is employed for interpreting this intermediate data. It is reported that this is not yet sufficiently developed to provide accurate assessment of the severity of the overriding or pothole edge defects and methods to improve this are suggested.

It is concluded that the image and profile processing algorithms demonstrate considerable potential for use in the automatic detection of edge deterioration. The intermediate measurements (e.g. road edge positions, step heights) appear sensible and reasonably accurate. The methodologies to interpret this intermediate data to obtain defect severities are also relatively successful. It is recommended that any further development of these approaches should be carried out using larger samples of data, representative of the road network, as most aspects of the edge deterioration algorithms to produce intermediate measurements appear to have been developed as far as they can be whilst working with small samples of data. However, this would require the development of a data collection system suitable for the collection of large datasets on local roads.
1 Introduction

Edge deterioration is becoming a widespread problem in the UK. It was reported by Luck (1991) that the estimated cost of repairing failed edges at that time was in excess of £1,500 million for UK roads. Edge deterioration occurs mainly on unkerbed roads, and although vehicle over-run onto the verge is the prime cause of the deterioration, other factors, such as lack of edge support, inadequate drainage, and encroachment of trees and other vegetation also contribute to this form of deterioration. The principal occurrence of edge deterioration on unkerbed roads is supported by the National Road Maintenance Condition Survey, which has reported that, on English rural classified and unclassified roads, an average of about 12m in every 100m of road exhibits edge deterioration (NRMCS, 1996). Most of these roads are unkerbed.

To provide information on edge deterioration for the UK, inspectors carry out visual inspections on foot. In these inspections the deterioration of the road edge and adjacent verge is assessed by visual observation, and the rutting in the verge is either estimated, or measured using a straight edge and wedge. Defects are located by their distance from the start of each road Section surveyed, and this distance is measured with a hand pushed surveying wheel. The disadvantages of manual inspections lie in the fact that they are time consuming, hazardous, subjective and disruptive to traffic. It is clear that a faster, safer and more objective survey would offer a desirable alternative to these manual surveys. However, such facilities are not provided by current traffic-speed surveys (Young, 1992).

The main project aim is to investigate experimentally if deterioration of the road edge can be automatically identified and quantified using image and profile data collected using traffic-speed techniques.

2 Establishing Requirements

2.1 Monitoring Edge Deterioration

On typical unkerbed roads deterioration of the road can take the form of:

- Overriding of the verge. This concerns the strip of verge adjacent to the nearside edge of the road. The overriding can occur with or without deformation or potholing of the verge. Narrow roads are most likely to suffer from this defect, which, when combined with inadequate subsoil drainage, can compound and accelerate deterioration of the edge of the road.

- Fretting and potholing of the edge.

- Longitudinal and transverse deformation of the road surface within the vicinity of the edge (more likely to occur on wider roads).

- Longitudinal or transverse cracks within the vicinity of the edge, erosion of the edge,

To meet the requirements of Pavement Management Systems, such as UKPMS, equipment capable of automatically monitoring edge deterioration should therefore be able to collect data showing the visual appearance of the road edge and the adjacent strip of verge. The equipment should also be able to collect data on the longitudinal and transverse deformation of the road surface in the vicinity of the road edge and any deformation in the strip of verge adjacent to the edge. The data should be located by its distance from the start of the road section being surveyed. Ideally it should be possible to survey at traffic-speed.

Consideration of typical road survey equipment showed that a system that delivered detailed images of the road/verge interface, combined with a measure of the shape of this interface should provide sufficient information to identify edge deterioration. However, it was not certain that edge deterioration could be quantified using the image and shape data alone. Therefore, before commencing a programme of research into methods to automatically identify edge deterioration, an investigation was carried out to determine whether it would be feasible to undertake any sort of...
“remote” assessment of edge condition using image and profile measurements. Should this investigation demonstrate the feasibility of this approach then work would commence on the development of automated techniques.

2.2 Basic Data Collection Techniques

A basic data collection system was constructed to test the above hypothesis – is it possible to utilise image and profile data to measure edge deterioration? Images were provided by a digital frame camera (Kodak DC120) mounted on the side of a survey vehicle. Images were collected covering a rectangular area of length 1m along the road and 0.75m width across the road. The area covered by the image was chosen so that cracks of width 1mm or more could be readily seen in the images. Illumination was provided using flash lighting, angled at 30 degrees to the road surface. This equipment is illustrated in Figure 1. During image collection on the road sites the vehicle was driven along the site and stopped every metre travelled to record an image of the road edge and verge.

The Trevor Deakin Flatmate was used to measure transverse profile (shown in Figure 1). This equipment provides an individual profile consisting of a hundred readings of vertical displacement that span the width of the beam. The measurements do not provide an absolute profile of the surface (i.e. relative to the “true” horizontal), but one relative to the heights of each end of the mounting beam. The Flatmate was used to collect the transverse profile of the verge adjacent edge of road every 0.5m. The lateral position of the edge of the road within the profile was noted for each transverse profile measurement so that, before the analysis was carried out, the road edge could be marked on the profile.

2.3 Surveys and Analysis

Trials were undertaken on two unclassified rural roads, each 100m long. The first survey length was on Carter’s Hill in Billingbear (Berkshire). The second survey length was on Orchard Road in Hurst (Berkshire). Wokingham District Council maintains both roads. A survey was carried out by a CHART inspector on each of the sites to assess their condition and provide reference data for comparison with the results of the analysis of the profile and image data collected on the sites.

An independent assessor carried out a manual analysis of the image and profile data (in the office) to identify the defects. The analysis was carried out a metre as a time along the survey length, each metre length being referred to as a segment. The process of identifying the defects consisted of viewing each image whilst simultaneously examining the corresponding profile to determine the severity of the overriding in the verge. An example profile is shown in Figure 2. A linear trend line (through the profile points on the road surface) was superimposed on all the profiles to assist the observer in the assessment of overriding. For each segment the condition of the edge of the road and...
the verge was assessed as none, slight, serious or severe. The gradings reflected the treatments required to repair the edge in question defined in the CHART inspectors’ handbook (CHART, 1986).

![Figure 2: Example of basic transverse profile measurement at the road edge](image)

Figure 2: Example of basic transverse profile measurement at the road edge

![Figure 3: Comparison between CHART inspections and manual analysis in terms of undeteriorated lengths](image)

Figure 3: Comparison between CHART inspections and manual analysis in terms of undeteriorated lengths

Comparison between the CHART survey and the manual analysis of the image and profile data is shown in Figure 3, Figure 4 and Figure 5, which show the results of the CHART inspection and the results of the manual analysis of the images and profiles, for reports of no deterioration, severity 1 deterioration and severity 2 deterioration respectively. It can be seen that there is remarkable agreement between the CHART survey and the manual analysis of the image and profile data in the identification of 10m lengths containing severity 2 deterioration. However, the CHART inspection generally identified fewer segments containing severity 1 deterioration than the manual analysis of images and profiles. Comparison of the CHART inspector’s notes and the images showed that the higher number of segments in the manual analysis arises from minor cracking observed in the images that was not recorded by the CHART inspector. This is not surprising as assessment of visual deterioration, whether it be during a road inspection, or in the office observing images of the road, contains an element of subjectivity. For undeteriorated lengths the correlation between the results of the CHART inspection and the manual analysis of the images and profiles was also very good when the data was compared on a segment by segment basis. The slight disagreements are probably due to the subjectivity in the assessment.
Figure 4: Comparison between CHART inspections and manual analysis for severity 1 deterioration

The overall performance on the surveyed lengths is that both approaches identify no segments exhibiting severity 3 deterioration. The proportion of segments exhibiting severity 2 deterioration is 14% from CHART inspections and 13% from manual analysis of images and profiles. For severity 1 deterioration the corresponding proportions are 26% and 32% respectively. For un-deteriorated segments the corresponding proportions are 60% and 55% respectively.

Figure 5: Comparison between CHART inspections and manual analysis for severity 2 deterioration

2.4 Summary

The goal of this initial study was to determine whether information collected with image and profile measurement equipment could be analysed to produce results similar to those obtained using a manual inspection. The study showed that, for data collected on two road sites containing edge deterioration, there is strong agreement between the two survey methods. The success of this comparison enables us to draw two basic conclusions.
That there is sufficient information contained within image and profile data collected over the road edge to reliably identify edge deterioration using manual analysis. Therefore there is potential for the development of automated analysis techniques.

The results of manual analysis of image and profile data can be used as a proxy for site surveys. This should reduce the burden on the collection of reference data for development of automated methods of identifying edge deterioration.

3 Equipment and Surveys

3.1 Equipment

It was shown above that there is sufficient information to identify edge deterioration using image and transverse profile data recorded at the road edge. However, the practical achievement of fully automated measurement of edge deterioration relies on a combination of equipment to provide the image and transverse profile data at traffic speeds, and suitable data processing methods. Although this work aimed to develop the processing methods, it was not the goal of this work to develop equipment to collect the measurements at traffic-speed. Nevertheless, the work has required the construction of systems to provide the image and profile data required for algorithm development. It was realised early in the project that the equipment used for the above demonstration of the comparison between the manual analysis of data and site surveys would be impractical for the collection of sufficient data for the development of robust algorithms.

The first development in the collection of image data was to install a colour digital frame camera on the Highways Agency’s HARRIS survey vehicle. A digital (Nikon Coolpix) camera was mounted in the nearside wheeltrack, so that the camera framed a rectangular area of ground behind HARRIS. This system was arranged to that it would be correctly located for images of the road/edge interface if the nearside wheels of HARRIS were positioned against the edge of the road surface. This reduced the problem of the survey vehicle blocking traffic on the other side of the road during surveying. A photograph of the image collection apparatus is shown in Figure 6. Images were illuminated with two flash guns, reducing evenly distributing the light across the image. This system enabled improved location referencing for the surveys over that achieved in the above work, because the HARRIS Position Integration Unit (PIU) system could be used to log the chainage position of each image. Although the collection of images using HARRIS provided an increase in image quality over that provided using the original system, the image collection was still slow speed (stop-start), achieving a survey rate of around 1 km/h. Furthermore, the collection of transverse profile data was very slow, at a rate of around 40 transverse profiles per hour (0.002 km/h).

Figure 6: Image collection on the HARRIS vehicle – system 1

In the later stages of this project it was possible to utilise, with the permission of the Highways Agency, equipment that enabled the simultaneous measurement of transverse profile and the
collection of road edge image data. An upgrade to the image collection system was provided through a colour linescan camera mounted onto the rear of HARRIS. The camera faces downwards from a location on the nearside rear corner of the vehicle, such that images are collected over a width of about 2 metres, with 1m of this width extending to the nearside of the vehicle. Unfortunately, the linescan image system lacks artificial illumination of the road surface, and hence relies on the ambient light available at the time of the survey. This meant that the survey vehicle has to travel at a reasonably low speed in order to allow adequate exposure for the images. Furthermore, the resulting images were sensitive to the presence of shadows and to direct sunlight. A compromise of exposure time, gain, and survey speed was established to minimise this problem, but this had to be determined on a site by site basis. Nevertheless, it was still recognised that a proportion of the images taken from surveys would be of low quality, due to variations in brightness.

A further major advancement was made in the measurement of transverse profile with installation of the PPS-2002 Laser Scanner System on HARRIS. This system, which measures transverse profiles over a width of 4m using a scanning laser, enables detailed transverse profiles to be collected over the road/verge interface at speeds of up to 80 km/h. For this project the PPS-2002 was set up to store one scan every 50 mm. However, due to the limitations of the image collection system the survey speed was still limited to 10 km/h. Nevertheless, this was still a significant improvement over the stop-start system, and separate transverse profile surveys were no longer required.

![Image collection system on the HARRIS vehicle – System 2.](image)

Red arrow shows colour image camera. Blue arrow shows scanning laser transverse profile measurement system

### 3.2 Data

For algorithm development and testing data was obtained from test sites exhibiting a wide range of features related to edge deterioration. These included:

- Supported Edges (kerbed and surfaced verges).
- Rutted verges.
- Cracking.
- Patching/haunching and overbanding.
- Mud/Debris on the road edge.
- Potholes.
- Overhanging vegetation/tree lined roads.
- Open (clear) ‘ideal’ verges.
- Shadows and sunshine (tree lined/buildings with gaps/fence posts etc).
Sites were identified both on the TRL test track and on the local road network that exhibited one or more of these features. Table 1 summarises the network sites, and the defects and other features present on each site.

Selected lengths of images and profile from these sites were used in the development of image processing and transverse profile analysis algorithms for the detection of edge deterioration. When the algorithms had reached a status suitable for performance assessment the image and transverse profile data from all of the sites was processed and the results compared with the reference.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Site</th>
<th>Length (m)</th>
<th>Features</th>
<th>Comments on Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>run 1</td>
<td>Binfield Road Wokingham</td>
<td>1685</td>
<td>Overriding, driveway entrances, kerbs, drains/covers.</td>
<td>Images quite dark. Road busy.</td>
</tr>
<tr>
<td>run 2</td>
<td>Hungerford Road East</td>
<td>2090</td>
<td>Potholes, cracking, overriding, patches, shadows</td>
<td>Light and Shadow in images</td>
</tr>
<tr>
<td>run 3</td>
<td>Hungerford Road East</td>
<td>970</td>
<td>Potholes, cracking, overriding, patches.</td>
<td>Carried out a repeat survey of portion of site with lower gain settings.</td>
</tr>
<tr>
<td>run 4</td>
<td>Hungerford Road West</td>
<td>1015</td>
<td>Potholes, cracking, overriding, patches.</td>
<td>Road in shadow - gains raised</td>
</tr>
<tr>
<td>run 5</td>
<td>East from Shurlock Row</td>
<td>1200</td>
<td>Potholes, cracking, overriding, patches.</td>
<td>Bright Sunlight so gains lowered.</td>
</tr>
<tr>
<td>run 6</td>
<td>Smewens Farm Road North Pt1</td>
<td>340</td>
<td>Kerbs</td>
<td>All kerbed, Images appeared dark.</td>
</tr>
<tr>
<td>run 7</td>
<td>Smewens Farm Road North Pt2</td>
<td>1235</td>
<td>Potholes, cracking, overriding, mud and debris on road.</td>
<td>Narrow road, difficult to negotiate.</td>
</tr>
<tr>
<td>run 8</td>
<td>Ripley Lane South Pt1</td>
<td>1785</td>
<td>Overriding, kerbs, closed in vegetation.</td>
<td>Survey terminated due to unexpected laser shutdown</td>
</tr>
<tr>
<td>run 9</td>
<td>Ripley Lane South Pt2</td>
<td>1725</td>
<td>Overriding, kerbs, closed in vegetation</td>
<td>Continuation of above survey</td>
</tr>
<tr>
<td>run 10</td>
<td>Masons Bridge Rd North Pt1</td>
<td>175</td>
<td>Overriding, cracking, potholes, white lines, shadows.</td>
<td>Images too bright</td>
</tr>
<tr>
<td>run 11</td>
<td>Masons Bridge Rd North Pt2</td>
<td>285</td>
<td>Overriding, cracking, potholes, white lines.</td>
<td>Survey terminated due to laser exposure risk, images bright.</td>
</tr>
<tr>
<td>run 12</td>
<td>Masons Bridge Rd North Pt3</td>
<td>1235</td>
<td>Overriding, cracking, potholes, white lines, kerbs, driveway entrances, side road entrances, parked cars, drains/covers.</td>
<td>Continuation of above survey. Images either bright or very dark when in shadow.</td>
</tr>
<tr>
<td></td>
<td>Total: 14340</td>
<td></td>
<td>All of desired features covered</td>
<td>Total includes 970m repeated survey and 800m with non-optimal gain settings</td>
</tr>
</tbody>
</table>

Table 1: Summary of sites, and the surveys carried out
3.2.1 Reference data

Reference data for both development and testing of algorithms was obtained from the test sites via manual analysis of the data collected on the sites listed in Table 1. It was assumed that this would provide a robust reference dataset, given the results of the investigation described in section 2. Software was used to display the consecutive road edge images tiled together as a vertical strip. As many of the survey images were poorly lit (see Section 3.1), a normalisation algorithm was applied in the display software to brighten the images and hence enable manual analysis of dark images. The transverse profile data measured at the same location at the images was also displayed for the analysis, superimposed onto the images. This presented the image and profile data in a way that enabled assessment using both pieces of information.

The manual analysis was carried out by overlaying the image data with a 200mm grid in software. Grid squares containing visible defects were labelled by the assessor. The features that were identified from the combined data are described in Table 2. For comparison with the results of automated analysis the reference data was interpreted to enable the reporting of defects over 10m lengths, as described in section 5.2.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor Images</td>
<td>1 – Too dark</td>
</tr>
<tr>
<td></td>
<td>2 – Too bright</td>
</tr>
<tr>
<td></td>
<td>3 – Very dark and very bright patches.</td>
</tr>
<tr>
<td>Kerbing</td>
<td>1 – Kerbstone, flush with kerb surface</td>
</tr>
<tr>
<td></td>
<td>2 – Raised kerbstone.</td>
</tr>
<tr>
<td>Surfaced Verge</td>
<td>1 – Bound/hard surface</td>
</tr>
<tr>
<td></td>
<td>2 – Unbound/loose surface</td>
</tr>
<tr>
<td>Overriding</td>
<td>1 – Shallow, over 200mm wide, possibly not evident in profile data.</td>
</tr>
<tr>
<td></td>
<td>2 – Deep, over 200mm side, clearly visible in image and distinct step at road edge.</td>
</tr>
<tr>
<td>Edge Erosion</td>
<td>1 – Edge Erosion</td>
</tr>
<tr>
<td>Cracking</td>
<td>1 – Cracking</td>
</tr>
<tr>
<td></td>
<td>2 – Sealed Patch</td>
</tr>
<tr>
<td></td>
<td>3 – Unsealed Patch</td>
</tr>
<tr>
<td></td>
<td>4 – Pothole</td>
</tr>
<tr>
<td></td>
<td>5 – Drains/Manhole covers</td>
</tr>
</tbody>
</table>

Table 2: Manual analysis grid system for marking defects.
4 Development of Algorithms

The objective of the algorithm development is to provide a method to use image or transverse profile data (or a combination of these) to automatically identify features associated with edge deterioration. The defects to be identified from the image and transverse profile data were summarised in Section 2. This list of defects was reviewed, and images and transverse profile data collected over the defects examined (manually) to determine what approach should be taken in the algorithm development. This lead to the following proposals:

- An image of the road edge will contain sufficient information to identify deterioration that occurs near the road edge, such as overriding, edge potholes and edge cracking. However, the verge presents a large amount of noise, and contains features that would prevent the reliable identification of the deterioration due to false positive reporting. There is therefore a requirement to identify the location of the edge of the road surface within an image in order to segment the image into the road and verge. Following the segmentation algorithms could be applied to the remaining “road” segment to identify defects in the road and the “verge” segment to identify defects in the verge.

- Defects in the road include cracking and potholes. Previous work has been carried out on the detection of cracking for routine surveys of the Highways Agency network (Pynn et al 1999), and therefore this defect would not be targeted in this work (although it is noted that detection of the road edge would enable crack detection systems to re-classify cracking as edge cracking). However, further work would be required for the identification of potholes. Detection of this “3-dimensional” defect would benefit from the assessment of both image and transverse profile data.

- There is partial information in the image to identify overriding of the verge. For this defect there is a requirement to identify a further “verge edge” located to the nearside of the road/verge interface that would define any region of verge erosion in order to measure overriding. However, there is not sufficient information to assess severity, due to the 2 dimensional nature of the images. This could be further enhanced through the use of transverse profile measurement.

- Examination of images shows that the road edge is a cluttered region of the road containing features such as kerbs and white lines that may affect defect detection. There would be benefit in detecting these features.

These observations instigated a programme of algorithm development, aimed at the accurate identification of the road and verge edge in image and transverse profile data, the identification of edge features such as kerbs and white lines, and the detection of potholes of the road edge. The following sections describe these algorithms.

4.1 Image Processing

4.1.1 Identifying the road and verge edges using image processing

Initial investigations were carried out using established techniques such as Canny (1986) (modified for use with colour images), and other methods (Carron and Lambert, 1994, Garcia et al., 1999, Wesolkowski and Jernigan, 1999) to identify the road edge in colour images. However, it was found that the edge outputs from these methods were not ideal for the accurate location of the road edge, as they did not actually separate and classify the road and verge segments of the image. Existing segmentation methods were also investigated, both colour (Deng et al., 1999) and texture (Setchell et al., 1999) based. But these techniques could not provide any significant improvement over edge detection, as they enabled segmentation of the image into distinct regions but problems still remained with regard to locating the correct road/verge boundary.
Although the investigation of potential methods of segmenting the images of the road surface did not deliver a suitable method, it was determined that a more simple thresholding of the Hue, Saturation and Intensity representation of the image could aid in segmenting the road part of the image from the rest of the image in a promising manner. However, the precise threshold values varied for each image and therefore the thresholds would need to be calculated from the image. Hence the thresholds would be “dynamic”, and depend on the region of each image that covered the road surface.

This method of dynamic thresholding was pursued in order to locate the road/verge boundary. The method that was developed depends on the fact that the road/verge edge is nominally vertical in the centre or right hand side of each image and that the road surface is definitely present within the right side of the image. The road edge identification algorithm calculates the position of the road/verge boundary in stages.

The first stage is the creation of a Hue, Saturation and Intensity image from the original RGB image collected on the survey site.

\[
\begin{align*}
\text{Hue} &= H_{x,y} = \begin{cases} 
255 \cdot \frac{60(G_{x,y} - B_{x,y})}{\text{Diff}_{x,y}} & : \text{Max}_{x,y} = R_{x,y}, \text{Diff}_{x,y} \neq 0 \\
255 \cdot \frac{120 + 60(B_{x,y} - R_{x,y})}{\text{Diff}_{x,y}} & : \text{Max}_{x,y} = G_{x,y}, \text{Diff}_{x,y} \neq 0 \\
255 \cdot \frac{240 + 60(R_{x,y} - G_{x,y})}{\text{Diff}_{x,y}} & : \text{Max}_{x,y} = B_{x,y}, \text{Diff}_{x,y} \neq 0 \\
\text{undefined} & : \text{Diff}_{x,y} = 0 
\end{cases} \\
\text{Saturation} &= S_{x,y} = \begin{cases} 
255(1 - \frac{\text{Diff}_{x,y}}{\text{Max}_{x,y}}) & : \text{Max}_{x,y} > 0 \\
0 & : \text{Max}_{x,y} = 0 
\end{cases} \\
\text{Intensity} &= I_{x,y} = \frac{1}{3} \cdot (R_{x,y} + G_{x,y} + B_{x,y})
\end{align*}
\]

Using:

\[
\begin{align*}
\text{Max}_{x,y} &= \max\{R_{x,y}, G_{x,y}, B_{x,y}\} \\
\text{Min}_{x,y} &= \min\{R_{x,y}, G_{x,y}, B_{x,y}\} \\
\text{Diff}_{x,y} &= \text{Max}_{x,y} - \text{Min}_{x,y}
\end{align*}
\]

A sampling box, described by a rectangular region D that is almost certain to lie completely on the road surface is then defined, as shown in Figure 8 where Dx1 and Dx2, Dy1 and Dy2 are chosen so that D typically lies within the rightmost 20% of the image. The mean hue, \( \overline{D\hat{H}} \), and saturation, \( \overline{D\hat{S}} \), and variances for the hue, \( D\sigma_2(H) \), and the saturation, \( D\sigma_2(S) \), values within the box are also calculated.
The mean hue, $\bar{H}$, and saturation, $\bar{S}$, values for the region within the box are calculated, as shown in equations 4 and 5:

$$
\bar{H} = \frac{\sum_{x=Dx1}^{Dx2} \sum_{y=Dy1}^{Dy2} H_{x,y}}{(Dx2 - Dx1) \cdot (Dy2 - Dy1)} \\
$$

[4]

$$
\bar{S} = \frac{\sum_{x=Dx1}^{Dx2} \sum_{y=Dy1}^{Dy2} S_{x,y}}{(Dx2 - Dx1) \cdot (Dy2 - Dy1)} \\
$$

[5]

The variances for the hue, $D\sigma^2(H)$, and the saturation, $D\sigma^2(S)$, values within the box are also calculated:

$$
D\sigma^2(H) = \frac{\sum_{x=Dx1}^{Dx2} \sum_{y=Dy1}^{Dy2} (H_{x,y} - \bar{H})^2}{(Dx2 - Dx1) \cdot (Dy2 - Dy1)} \\
$$

[6]

$$
D\sigma^2(S) = \frac{\sum_{x=Dx1}^{Dx2} \sum_{y=Dy1}^{Dy2} (S_{x,y} - \bar{S})^2}{(Dx2 - Dx1) \cdot (Dy2 - Dy1)} \\
$$

[7]

An intermediate image is now produced containing pixels having values that are related to how close the hue and saturation values of each pixel in the HSI image were to the values of the statistics of the sampling box. We term the intermediate image, $P$, an “HSI closeness” image, consisting of three channels $P_h$, $P_s$ and $P_l$, obtained using equations 8, 9 and 10 respectively.

$$
P_{h_{x,y}} = \begin{cases} 
255 \left(1 - \lambda \cdot \frac{\delta}{D\sigma^2(H)}\right) & : \left(1 - \lambda \cdot \frac{\delta}{D\sigma^2(H)}\right) \geq 0 \\
0 & : \left(1 - \lambda \cdot \frac{\delta}{D\sigma^2(H)}\right) < 0 
\end{cases} \\
$$

[8]
\[ P_{s,x,y} = \begin{cases} 
255 \cdot \left( 1 - \lambda \left( \frac{S_{x,y} - D \hat{S}}{D \sigma^2(S)} \right) \right), & \frac{1 - \lambda \left( \frac{S_{x,y} - D \hat{S}}{D \sigma^2(H)} \right)}{D \sigma^2(H)} \geq 0 \\
0, & \frac{1 - \lambda \left( \frac{S_{x,y} - D \hat{S}}{D \sigma^2(S)} \right)}{D \sigma^2(S)} < 0 
\end{cases} \]  

\[ P_{i,x,y} = \begin{cases} 
255, & I_{x,y} > W \\
I_{x,y}, & I_{x,y} \leq W 
\end{cases} \]

\[ \delta = \min \left( \left| H_{x,y} - D \overline{H} \right|, \left| H_{x,y} + 256 - D \overline{H} \right|, \left| D \overline{H} + 256 - H_{x,y} \right| \right) \]

where \( \lambda \) is a scalar multiple of the higher of the two variance (hue or saturation) values. \( \lambda \) governs the cut-off level for values far from the sampled mean values (due to the second part of conditional equations 8 and 9) and also governs the resolution/spread of the closeness values for low differences from the mean (high closeness values), \( \delta \) can be considered to give the distance of the hue value of the pixel from the mean hue of the sampling region \( \overline{H} \), allowing for the cyclic nature of hue within the scale 0 to 255. \( W \) is a simple threshold applied to obtain the “intensity” image, \( P_I \), which is reserved for later use in filtering white line regions of the image.

An example image (P) is shown in Figure 9. For this image green/yellow pixels represent regions that are close in saturation/hue and saturation to the sampled region and red pixels represent regions that are less similar to the sampled region, being similar only in the hue channel. Darker pixels and black areas represent regions that are removed in colour properties from the sampled area.

Unfortunately, the intermediate image still does not provide a simple clean segmentation, as it contains noise elements from isolated road-like regions of high values on the verge, and regions of low road closeness values within the road, as can be seen in Figure 9. We locate the most likely location of the road edge by defining a vertical “line” within the verge, parallel to the road edge direction and made up of \( T_{\text{Total}} \) square cells of several pixels equally spaced in the longitudinal (y) direction. Starting at the far left of the image each column of points is shifted in the x direction traversing the image across the road edge, and moving over increasing road edge closeness values. The mean of the values contained within the cell is compared with a threshold value to locate prospective edge points. When the threshold is exceeded the iteration stops and that point is stored as a possible edge point. The threshold is then increased and the edge points iterate further in the x direction until the cell values exceed this new, higher threshold. This is repeated until a number of road edges, each located further towards, on, or past the road edge is obtained. By using two sets of threshold values, the method is able to locate prospective edges, or contours, for both the road/verge interface and the verge/overriding interface, as shown in Figure 10.

It remains to select the correct edge line. Although often no one line completely follows the road edge with no deviation, there is usually a clustering of these closeness lines at most positions along the
actual road edge. At each edge point location a density value, $D$, is defined, according to Equation 12, where $C$ is the number of line points (each with position $E_{i,t}$) that are coincident, $I$ is the row of edge points being evaluated, $T$ is the threshold level of the current line point (where a particular threshold level indexes a particular edge line), and $t$ indexes the threshold levels from the minimum level $t_{\text{min}}$ to the current threshold $T$ in order to iterate over all edge line positions to the left of the current line position.

$$D_{I,T} = \begin{cases} 0 & : E_{I,T} = E_{I,T-1} \\ \sum_{t=t_{\text{min}}}^{T} C \left( E_{I,T} - E_{I,t} \right) & : E_{I,T} \neq E_{I,T-1} \end{cases}$$  \[12\]

We then obtain a second set of points describing where these densities ($D$) are a local maximum, as shown by the dots in Figure 11. These high density points are then joined up and down the image to their nearest neighbours to segment the image into smaller areas. This is illustrated with (Figure 11) and without (Figure 12) the contour lines.

It is assumed that some of the segment boundary lines joining the dots will lie on the true road edge, and some on the overriding to vegetated verge edge (where present). With these segments defined an algorithm is applied to calculate the mean red and green closeness values for each of the segment areas. This produces the image of Figure 13. This has simplified the task of determining the appropriate road and verge edge boundaries. An algorithm is applied to select which of the high density points and joining segment boundaries lie on the road edge. This begins by selecting the rightmost points and edges for the road edge (green) and the leftmost points and edges for the verge edge (white) in Figure 14.
Next the verge edge points are moved to the right (jumping to the next located edge point) until a significant difference in the mean segment closeness values are seen from those found in the verge region at the left of the image. A similar process is followed to move the road edge to the left whilst the segment mean values remain similar to those seen in the road region. The criteria for determining whether the values are significantly different from the road or verge are calculated from the road and verge values at the far left and right of the image, and the difference between these. In the example Figure 15, the hue closeness values (red) are fairly similar across the image and so do not contribute much to the edge placement, this is dealt with by the calculations. The road and verge edges are shown on the original image in Figure 16.
4.1.2 Identifying kerbs

The above image processing algorithms were developed to identify road and verge edges for roads where edge deterioration is likely to occur. As edge deterioration is primarily observed on unsupported road edges work was carried out on the detection of kerbs, so that images containing these features could be removed from the analysis. This delivers two benefits. Firstly, the presence of kerbs could introduce errors into the image processing, so it is desirable to remove them. Secondly, a report of the presence of kerbs would be of use to engineers in maintenance planning.

The straight geometric shapes and edges that kerb elements theoretically present in an image suggest that edge detection could be used here to identify these features. However, on minor roads kerbs often display no straight edges as a result of varying degrees of coverage - by mud, vegetation and other verge debris, as shown in Figure 17 - and can vary widely in material, texture and colour. A simple kerb detection method was developed that uses the intensity channel of the image and relies on the fact that kerb features are nominally aligned vertically on the image, parallel to the road edge. To detect the kerbs the intensity information is summed for each column of pixels in the image and stored as a column-sum histogram. A fixed-width operator is moved along this histogram to locate ‘humps’ indicating columns of brighter image pixels that often result from kerb elements within the image. Analysis of the information obtained regarding the position and width of any ‘humps’ detected by the operator enables the image to be labelled as kerbed. Figure 17 illustrates these stages in the application of the kerb detection method.
4.1.3 Surfaced Verges

On examining the images it was noted that, in addition to the adverse effects of kerbs on the edge detection, the edge detection was also affected by the presence of a “verge” segment which is actually surfaced, or where there is no clearly defined “verge” segment present. This can be due to a side road, property entrance, footway or simply driving the survey vehicle too far from the verge. Clearly an automated inspection system needs to be able to identify these features so that they do not affect the reported deterioration. Work was carried out to develop methods to identify the lengths containing these features so that they could be removed from the analysis.

The identification technique developed to identify what were defined as “surfaced verges” is based on a simple threshold for the mean closeness values of the large “verge” segment on the left of the image. If this part of the image is a distinctly different colour to the sampled road surface then it will have low red and green values in the closeness image. However, if it is of a similar colour then it will have high closeness values. Figure 18 shows two contrasting examples. Figure 18 (a) is a closeness image of a grass verge, with region of overriding and a heavily cracked road surface. Figure 18 (b) is a kerbed road with a surfaced verge (i.e. a footway). Edge location has been totally unsuccessful in this case, which is often the result when there is a uniform surface over the image, and hence could lead to false positive reports of edge deterioration if not filtered using the surfaced verge detection. However, the high red and green values in Figure 18 (b) lie above the surface verge threshold, hence enabling us to identify this as an image containing a surfaced verge.

Figure 17: (Left) Image containing a partly obscured kerb, (Right) illustration of method to detect kerb features - Histogram of column intensities (top), threshold (middle), kerb detection (bottom)

Figure 18: Appropriate response for detecting surfaced verges. a) response to ordinary grass verge with some overriding, b) response to surfaced verge (road and kerb).
4.1.4 White Lines
As for kerbs and surfaced verges, during the development of the image processing algorithms it was found that the presence of white lines can have a detrimental affect on performance in the detection of edge defects such as potholes and edge cracking. It was therefore necessary to develop techniques to remove areas of the images that contained white lines. This was achieved through thresholding of the image to segment the verge, road and white line regions. This is shown in Figure 19, which shows an image where all points to the left of the identified road edge have been set to white. Also, any points with an intensity value greater than or of 254 are set to white. However, the simple removal of points having an intensity value Pi of 255 does not completely remove the presence of white lines, as white lines that have suffered deterioration will probably be broken up and appear darker than a recently laid white line. Therefore, to remove residual white line features, the blanked-out regions of white road paint are “grown” and joined wherever elements are close enough to assume that they are broken segments of the same area or line of road paint. The patches of white pixels are grown and joined using row and column iterative processing within an image. If two white areas are separated by a number of pixels less than a predetermined length along a row or column of pixels then that length of that row or column is set to white.

![Figure 19: Processing stages in white line removal.](Note: masked white region to right of image arises from uneven illumination on this image)

4.1.5 Image Quality
It was noted in Section 3.1 that the image collection system did not use artificial lighting and was therefore subject to the effects of shadow and sunlight. A particular effect of this was that significant lengths of the test data contained images that were dark or appeared to have poor quality. So that these images did not have a detrimental affect on the development process, methods were developed for the identification of these poor/dark images. The average intensity value calculated from the whole image was used to determine whether an image should be classified as ‘dark’. The average intensity is compared to a threshold intensity level (determined from experiment) below which the image processing is more likely to be unreliable.

A second automatic measurement of image quality aims to identify ‘poor’ images, which are not necessarily dark but contain features which make the identification of the road surface part of the image using colour information less reliable. It was found that the variation in colour sampled from the road area of the image could indicate a poor image, if the colour properties of the road were
unusual. This can occur where patchy shadow and sunlight are present within the image or where there is low quality ‘noisy’ colour information. However, this can also be the case if an image contains more than one surface type, road markings within particular parts of the image. It could also be due to colour differences between parts of the road surface material (i.e. aggregate and binder) though this has not been seen to cause reduced confidence in the images for the sites tested.

The variation in colour sampled from the road part of the image can be indicated by inspecting the ‘closeness’ values of the segmented region of the image that lies against the right (offside) edge of the image. The closeness values for the Hue and Saturation colour parameters are compared to a threshold, if either value is below the threshold then that part road surface region is shown to be different in colour to that of the sampled road region, and the image quality is recorded as ‘poor’.

4.2 Processing of Transverse Profile Data

4.2.1 Identifying the Road Edge using Transverse Profile Data

The use transverse profile to identify the road edge is limited to detecting edges where stepping at the road edge is present, as identifying the edge of the road in transverse profile data where no stepping is present is not feasible.

Methods to identify step edges in the transverse profile data were developed based on the application of a moving average filter across each transverse profile to establish the confidence to which each point within the transverse profile could be labelled as a step edge. This filter calculates a step height value for each point along each transverse profile. Moving along each transverse profile right to left, each transverse profile is examined to see where the step height first exceeds a certain magnitude up or down. This is stored as the transverse profile road edge. Each transverse profile is analysed again to determine where the first large step upwards occurs moving from the right to the left. This is stored as a possible raised kerb location. Note that if the transverse profile contains no step that exceeds the predefined magnitude then there is no transverse profile edge position associated with that transverse profile. The profile data for a sample image is shown in Figure 20 with its associated transverse profile data superimposed.

![Figure 20: Road edge image with transverse profile data superimposed.](image)

Note that further step edge detection operators (the method of evaluating the step height at a particular position in the profile) were developed and assessed, including a derivative of the Canny (1986) technique. This technique is similar to the above method that uses the average of the points to either side of the current position, with the key difference that the points are weighted according to their proximity to the evaluation position, according to a particular function (typically a Gaussian) designed to greater emphasise the difference between true profile steps and ‘noise’. However, it was established that this method offered little or no increase in performance. Further, it was still necessary to use the above averaging method once the step position had been established, in order to better estimate the step height.
4.2.2 Identifying kerbs

As for the image processing, it is desirable to have information on the presence of kerbs when assessing transverse profile data at the road edge. A kerb step detection algorithm was developed to identify kerbs within the transverse profile. It was found that this information could be particularly useful when used in combination with the data to confirm the presence of a kerb.

The algorithm to detect kerbs assesses the transverse profile to detect large upward steps. In this assessment the step height is compared against a kerb step height threshold. The search is carried out from the offside to the nearside of the transverse profile until the first step height exceeding the threshold is encountered. Note that this assessment is exclusive of the detection of the road edge. Therefore we could obtain locations for the road edge and the kerb (if present) that are not coincident.

The points describing the location of the kerb locations, and associated steps heights are averaged over all of the transverse profiles corresponding to each 1m image, generating a single kerb step height and transverse location for each image. The kerb location obtained in this way can then be evaluated against the kerb location obtained via image processing (section 4.1.2) and used in the combined assessment scheme (section 4.3) to determine whether a kerb is actually present. This approach makes the assumption that the kerb lateral location (relative to the survey vehicle driving line) and height will change little within a 1m length.

4.3 Combining the Image and Profile Data

4.3.1 Obtaining a combined image and profile road edge

The image and transverse profile processing algorithms deliver a possible location for the road edge using two different methods. The image based system is expected to place the edge line on the visible boundary between road surface material and un-surfaced verge. The profile road edge is likely to be coincident with the presence of stepping at the road edge.

To segment the images into road and verge regions a combined edge is defined. This ‘combined edge’ takes the transverse position of either the image or profile detected road edge, according to which position is furthest to the offside. Where no profile steps exist on the road surface or at its edge, the combined edge takes the value of the image derived edge position. However, any deviation of the combined edge from the image derived road edge indicates the identification of a step within the transverse profile that lies within the part of the image assessed as containing the road surface. This can be taken as an indicator of pothole, severe fretting or settlement/subsidence, as discussed below.

4.3.2 Identifying potholes

Initial attempts to identify potholes were based on accurate tracing of the road edge in the images, based on the assumption that the sudden change in the shape of the edge at a pothole could be used to automatically identify these features. However it was found that many edge potholes do not actually intersect the edge line of the road surface. Holes often lie adjacent to the road edge often with a narrow bridge of intact surface between the hole and the edge. Potholes were, therefore, frequently missed. Also, it was found that the general reporting of the edge by the image processing algorithms was unpredictable (often inaccurate) if attempts were made to achieve reliable tracing of the offside edge of potholes as part of the road edge.

Therefore we considered the use of the transverse profile road edge for pothole detection. It was found that the step edges present at the location of potholes and overriding could be used to obtain a line tracing the path of the step edge along the road at the location of the pothole. Furthermore, where a pothole is present we typically find that the image road edge falls to the nearside of the profile road edge because the base of the pothole still appears more like the road than the verge. Figure 21 illustrates the approach. Where the distance between the image and profile road edges exceeds a defined threshold, and a step is present, we report the presence of a pothole.
5 Identifying Defects

5.1 Using the outputs to identify defects

The algorithms described in Section 4 may be applied to the image and transverse profile data to identify specific features such as the location of the road edge, the location of the verge edge, kerbs edge stepping and white lines. Suitable interpretation of this information is required to quantify the condition of the road edge. Rules were developed to combine and use measurements derived from the edge locations, and other information extracted from the images and transverse profiles, to obtain a single value for each defect, reported over a known reporting length (typically 10 m). These are described in the following sections.

5.1.1 Image quality

| Dark Images % | Percentage of images within the 10m reporting length with an average intensity (brightness) below a certain threshold. Threshold is user definable within the software. |
| Poor Images % | Percentage of images within the 10m reporting length where a low confidence is held in the accuracy of either of the mean colour parameters sampled from the road surface. Low confidence is determined when a colour parameter falls below a particular threshold. |

5.1.2 Kerbing

The image processing algorithms report the transverse position of the kerb for each image (where detected/present). The transverse profile kerb detection algorithm reports the average transverse position and size of kerb sized steps adjacent to the road surface. The presence of raised kerbs is then determined as the percentage of the length where a kerb has been found by both the image and profile methods, and the transverse position of the kerb located by both of the methods agrees. The result is reported as:

Kerbed % Percentage of the images (each 1m) within the 10m reporting length that are kerbed.

5.1.3 Surfaced Verge

The surfaced verge is assessed by analysing how close the pixels in the nearside segment of the image are to the mean values calculated by the image based edge location algorithms in the offside segment.
which is assumed to be a road surface). The verge is considered to be surfaced if the mean pixel colour values are close enough to the road sampled colour values. This is reported as:

**Surfaced Verge %**

The percentage of images within the 10m reporting length that contain a surfaced verge.

### 5.1.4 Overriding

The following values are calculated for each 10m:

- **Length Mild**
  
  The total length over which the width between the location of the road edge obtained in the image and the location of the verge edge obtained in the image exceeds a predefined threshold.

- **Length Severe**
  
  The sum of the length over which the predefined threshold for mild overriding has been exceeded AND the edge step determined from the transverse profile data is above a certain size downwards from the road to the verge AND this step location and the location of the (image located) road edge are close to each other.

### 5.1.5 White Lines

The average white line width and transverse location is calculated over each 1m image of image data. The transverse location is then compared to the lateral position of any kerb step edge found, to prevent light coloured raised kerbstones from being identified as white lines. The white lines are reported as the lengths within the 10m reporting length where white lines are present with normal, thin/eroded and wide widths.

### 5.1.6 Potholes

**Length %**

The length within each 10m reporting length where the combined road edge is located further to the offside (into the road) than the image detected road edge by more that a particular threshold AND the step height associated with the (image located) road edge is greater than a certain threshold AND indicates a step downwards from offside to nearside.

### 5.2 Comparing automatic and manual analyses.

Because the automatic and manual processing cannot report exactly the same parameters, a process was also required to interpret the results of the manual analyses, as described in the following paragraphs.

#### 5.2.1 Image quality

Reported as the percentage of the reporting length that contains dark or poor images.

#### 5.2.2 Kerbing

The percentage of the reporting length containing kerbed road edge reported by the automatic processing can be compared to the percentage of the length containing a raised kerb in the manual assessment.

The manual assessment also contains an assessment of the length containing flush kerbs. However, unless accompanied by a surfaced verge, these do not present overriding of the edge. The percentage of the length containing this type of kerbing was assessed to determine whether it had been counted as kerbing in the automatic output, or coincided with any of the other edge deterioration parameters.
5.2.3 **Surfaced Verge**

The percentage of the reporting length identified in the manual analysis to contain hard paved verges (side roads, footways) or loose surfaced verges (gravel driveways).

5.2.4 **Overriding**

Reported as the percentage of the reporting length containing mild overriding and severe overriding.

5.2.5 **White Lines**

The approximate start and end positions of images containing white road edge lines or side junction markings were noted in the manual assessment. For analysis this data reported as the percentages of the reporting length which contained white lines, narrow or broken white lines or a significant area of the surface identified as containing white markings.

5.2.6 **Potholes**

Reported as the area of potholes present within the 10m reporting length. Note that the automatic output for the extent of potholes is likely to be triggered by severe fretting, edge subsidence and any defect producing a transverse step downwards within the road surface, and is reported as a percentage of the reporting length affected. Therefore it is more difficult to directly compare these two outputs.

6 **Performance**

This section compares the results of the automatic and manual assessments of the test sites listed in section 3. In general, the results are presented in the form of a plot of particular output values against chainage along the survey site(s). To present the results for all of the sites the entire length of data for all of the survey runs will be shown in each plot, with each survey plotted consecutively as shown in Figure 22. The accumulated chainage through the survey sites is shown on the horizontal axis.

![Figure 22: Survey runs making up the test dataset for this section, labelled by number (Table 1).](image)

For clarity the reporting lengths (initially output over 10m lengths, as described in section 5) have been aggregated over 100m in this section. This reflects how the parameters might be used at a network level, and allows the overall trend of the automatic analysis to be compared with the manual analysis over the length of surveys. Differences in ‘equivalent’ parameters from the automatic and manual results are further explored by examining localised results to assess the success of the algorithms.

6.1 **Image quality**

The two image quality parameters are plotted against the manual report of poor images in Figure 23. All parameters are reported as a percentage of the reporting length. It is apparent that the automatic indication of poor or dark images generally agreed with the manual assessment. There is therefore
evidence that the automatic identification of poor and dark images could be used to enhance the performance of the edge deterioration algorithms by filtering poor data from the analysis. The application of the automatic identification of poor images will be discussed in the following sections. However, it can be seen that there were significant lengths within the dataset containing images rated as poor by the automatic algorithms. Removal of these lengths removed a significant proportion of the dataset.

6.2 Kerbs

The manual and automatic identification of raised kerbs, reported as a percentage of each 100m length, is shown in Figure 24. It can be seen that there is significant agreement between the lengths of kerbing that have been located automatically and those reported in the manual analysis. However, some lengths have been missed. It is also evident that where the automatic algorithms have located a section of kerbing accurately, the values for the percentage of the length that are kerbed are lower than manual reference. This is because continuous lengths of kerbing are only detected intermittently (fragmented) by the automatic processing.

A closer investigation of the data was carried out to determine why some lengths of kerbed road were not detected. Within the interval 500m-1600m, it was found that only intermittent kerbing existed across entrance driveways. Whilst these kerbstones were often not completely flush with the road, the
small step edge found in the profile had fallen below the automatic algorithm threshold for raised kerb
detection. These kerbs had been therefore been included within the manual analysis but the automatic
analysis had missed them, due to its higher sensitivity to the detection of raised kerbs resulting from
the use of the transverse profile data. It was found that the length between 11700m and 12100m also
contained lengths of flush kerb across road entrances. Figure 25 shows the type of flush kerbing over
this length that was missed by the automatic method. The errors between 6800m-7200m primarily
arise from poor image quality in this length, combined with kerbstone colour and brightness being
similar to that of the road, resulting in the kerbs not being detected by the image based method.

![Figure 25: Flush/Dropped kerb across driveway entrance](image)

Nevertheless, the detection of kerbing using a combination of profile and image data has generally
worked well. The failure to detect kerbs flush with the road suggests that it may be appropriate to
additionally report where kerbs have been detected from the image data only (i.e. where no step has
been identified in the transverse profile data), in order to indicate where flush kerbing may be present.
However it has been found that this output will produce false positives due to white lines and similar
features.

6.3 Surfaced verge

The automatic detection of surfaced verges (footway, side road, where the image only contains the
road surface) is shown in Figure 26, along with lengths identified in the manual assessment.

![Figure 26: Surfaced verge (footway, side road, fully surfaced image) detection, automatic and manual.](image)

It can be seen that the automatic reporting of surfaced verges agrees very well with the manual
reporting of bound surfaced verges. Some of the automatic responses have occurred where the manual
assessment has marked a loose surfaced verge. The large peak within the automatic analysis that
occurs at the start of the data is coincident with a section containing very dark and poor quality images, which have caused the false positive detection of surfaced verges. Nevertheless, overall the detection of hard surfaced verges of various forms has worked well, although examination of the data has shown that verges with loose or dry mud or stony surfacing can be sometimes be falsely reported as a surfaced verge.

It is noted that the identification of surfaced verges aims to enable the “switching off” of the detection of edge deterioration along these lengths. This is because the image based road edge location algorithms are inaccurate where the verge is surfaced. The presence of a surfaced verge indicates a supported road edge, or no road edge within the data (e.g. at a junction to the nearside). The agreement between the manual and automatic reporting of surfaced verges is reassuring, in terms of the effect it could have on improving the accuracy of the detection of edge deterioration – in particular with respect to reducing false positives. However, if it is desirable to identify surface deterioration adjacent to a kerbed edge and paved verge, as may be encountered in built up areas, a different approach would be required. It would necessary to establish methods for correctly segmenting the road surface where paved verges and kerbing exist.

6.4 Overriding

The assessment of overriding found that the results were severely affected by the presence of poor images, and the inclusion of lengths identified as supported (e.g. containing a raised kerb or a surfaced verge). Therefore lengths where the image quality was automatically identified as poor have been set to zero for this assessment. Furthermore, lengths over which kerbing was automatically identified over greater than 3% of the length, and surfaced verges were reported over greater than 10% of the length, have also been removed (set to zero). Clearly this reduces the overall length reported in the automatic analysis, but reflects the intended use of surfaced verge and kerb identification for the reduction of false positives. The results are shown in Figure 27, it can be seen that, following the automatic removal of “suspect” lengths, a dataset is obtained where the shape often follows the reference, and the number of false positives is low.

![Overriding graph](image.png)

**Figure 27**: Automatic overriding outputs, set to zero for kerbed, surfaced verge sections and poor image sections.

A further examination of the results was undertaken through examination of the image and profile data to see how the overriding algorithm performed at a localised level, as discussed below. The discussion presents example screen-shots to illustrate our observations. These show the placement of the road and verge edge lines, the separation of which determines the presence of a region of overriding.
Key for following figures:

White line = verge edge
Green line = road edge from image
Blue line = road step edge from profile
Orange line = combined edge
Red line = transverse profile
Blue numbers = Edge step, +ve is a downwards step road to verge

Dark red bar on left signifies poor images detected.

Figure 28 shows a badly patched road surface with a region at the edge that is felt to be an overridden area of the verge. However, it could be an area where a rutted verge has been filled with bitumen (patch repair) or an area at the road edge that is damp. It is difficult to be certain. Consideration of the profile data shows no rutting or edge stepping at the join with the lighter surface, it resembles a patch repair of a rutted verge. Assuming the dark area is actually overriding then it can be seen that the algorithm has correctly segmented this area as a region of overriding using the image processing information. However, the step edge of the road has been consistently placed against the grass verge part of the image. This means that we will obtain a report of mild overriding.

![Figure 28: Successful detection of road and verge edges where no downwards road edge step is found. Road surface is very patchy and ‘overriding’ region could equally be a haunch repair - there is uncertainty over the exact nature of the dark area.](image)

Figure 29 illustrates the effect of shadow. The contrasting brightness has affected the colour information within the image, such that the verge edge is not well located. The road edge (orange as it is incorporated into the combined edge here) has been better located, but it may have been assisted in this by the placement of the bright patches of the image. It was found that very bright images, where the intensity reached the maximum level, and caused loss of colour information for areas of the image, also prevented the road edge from being well located.

In summary, we have found that the method for the automatic detection of overriding can deliver results in good agreement with the reference data, but is subject to the reporting of false positive lengths of overriding, and the missing of true overriding. However, image quality is a major factor in the accuracy of the algorithms, and we have shown that the use of the automatic poor image detection
enables most of these lengths to be removed – at the expense of the removal of some correctly identified lengths of overriding.

![Figure 29: Effect of survey vehicle shadow in bright light on images, has resulted in poor verge edge location in this case.](image)

### 6.5 White line markings

While not really an edge defect, the identification of white lines is desirable for a number of reasons. Such markings can affect the measurement of edge deterioration. Also, knowledge of their presence would be of interest as an inventory tool. Example images, demonstrating white line detection, can be seen in Figure 30, which also shows some small additional elements of the road surface masked incorrectly as white lines. Here the algorithms have been successful. However, it was found that where an image is too bright and unevenly lit (involving areas of sunlight and shadow), false positive identification of white lines could occur. The use of three width categories for automatically detected lines was therefore useful, because indications of wide white lines can often be taken to indicate that false identification has occurred.

Figure 31 compares the percentages of the reporting length that were reported to contain normal width, narrow or broken, and wide white lines with the reference data (which simply reported the presence, or not, of white lines). Here lengths automatically identified to contain poor images have been set to zero, to reduce false positives. Although these is some agreement between the automatic reporting of “normal” lines, and manual reporting of white lines, it is apparent that the level of performance has not been high on the sites surveyed. Examination of the images has shown that the poor performance primarily arises from uneven illumination in the images, and therefore the algorithm would benefit from an improvement in image quality, particularly in image lighting.
Figure 30: Examples of successful removal of the verge and masking of white lines (where they exist) from the image prior to crack detection.

Figure 31: White line detection, various width levels against manual analysis, lengths containing poor images set to zero.

6.6 Potholes

The reported detection of potholes is shown in Figure 32 and Figure 33. In Figure 32 the results shown represent those obtained for all images collected. The results obtained in Figure 33 follow the removal of invalid data due to poor images, kerbing and surfaced verges. The performance could be
described as “mixed”. It appears that omitting results using the image quality indicator has removed some correct pothole detection. This reflects the fact that, although the images were dark, the algorithms often continued to work correctly on these images. Lengths where potholes were automatically detected were further investigated by looking at the image and profile data, as discussed below.

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Figure 32: Pothole detection, automatic and manual response.
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Figure 33: Pothole detection, automatic and manual response with invalid lengths removed according to image quality, detection of kerbing or surfaced verges.
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Examination of a number of images found that, even though there was correct placement of all of the edge lines, small pothole defect did not contribute to the reported number of potholes because the stepping at the pothole edge did not exceed the minimum step threshold for potholes. This indicated that the thresholds used to trigger potholes should be revised.

Several examples were also found where the profile edge was reported to the offside of the image road edge, hence resulting in the reporting of a pothole, but no pothole was reported in the manual analysis. On closer inspection it was found that this typically occurred where a significant step or slope existed within the profile data. Figure 34 shows an example where this occurred at a depression at the road edge. This is visible as a step within the superimposed profiles on the image. Also, where the profile edge lies within the road there is a longitudinal crack. Such features may be reported as potholes. This is an interesting observation, as this is clearly a defect, but not necessarily a “pothole”. This highlights the difficulty in making comparisons between manual and automated techniques, and suggests that it may be appropriate to redefine the definition of “potholes” for automatic analyses.

A further example of difficulty in classification is severe overriding (Figure 35). This is likely to develop into potholes at the road edge. However, examples were found where overriding was present with step heights falling below the pothole threshold, and hence we did not obtain a pothole. Some of
these examples were reported as potholes in the manual analysis. Examples of the opposite behaviour were also observed – where severe overriding was reported as potholes. This indicates that, although we appear capable of detecting deterioration, the accurate classification of the deterioration is not so good.

Figure 34: Location of profile edge along edge of depression in surface, could result in false positive pothole detection.

Figure 35: Profile edge has traced pothole, but so has image detected edge. Would be classified as severe overriding.

False positive pothole detection was also observed in the presence of drains, as shown in Figure 36. Here the profile step edge detector can intermittently locate a step edge between the drain grills (as may be expected). This will lead to the false detection of a pothole. It is seen that the image derived road edge (green) has sometimes been placed on the drain edge, where this occurs overriding will be (falsely) detected, and not a pothole.

Figure 36: False positive pothole detection at drains.

In summary, the use of combined image and profile analysis for the detection of potholes has proved inconclusive. The statistical comparison of the results of the automated and manual analysis did not show good agreement. However, in depth examination has shown that the false reporting of potholes was often associated with the presence of deterioration, but the assessment methods were not sensitive enough to make the distinction between the defect types. Some of this poor reporting can be
associated with the thresholds used within the software to decide on the presence of potholes and overriding. Assessment of the data, and experimentation, suggests that alterations of the thresholds could include increasing the pothole width threshold to reduce the amount of false positive detection, and reducing the minimum width for reporting overriding to increase the true reporting of overriding. However, it would be best to determine the appropriate parameters for network level application once a significantly larger dataset representative of the network becomes available.

7 Conclusions

This project has demonstrated that there is sufficient information contained within colour image and transverse profile data collected at the road edge to identify and quantify road edge deterioration. This has formed the basis of a programme of research to develop automated methods to identify road edge deterioration.

Because systems do not currently exist for the traffic-speed collection of the detailed transverse profile and colour image data required to identify edge deterioration, we have utilised equipment installed on the Highways Agency’s HARRIS vehicle to obtain good quality image data and high resolution transverse profile data, from surveys carried out at approximately 10km/h. Trials have shown that the image and transverse profile data can be successfully collected, and that it is feasible to achieve good locational alignment between the datasets. The HARRIS scanning laser transverse profile measurement system was capable of measuring transverse profile over the road edge with little detrimental effect resulting from the challenging conditions presented at the road edge (edge stepping, rough profiles etc). The image system was also able to provide good quality images, under ideal conditions. However the lack of artificial illumination lead to a significant proportion of the images being of either poor quality, or insufficiently illuminated. However, it is felt that enhancements to this system to provide illumination and enable increased survey speeds would be easily achievable, given suitable investment in equipment.

An approach was adopted that uses image and transverse profile processing algorithms to identify the road edge and the edge of the verge, with further algorithms being applied to combine these “intermediate” datasets to identify edge defects. The image processing algorithms to identify the road edge have been based on the assessment of changes in the colour distribution across the image. The same approach has been applied to identify the edge of the verge. Stepping at the road edge has been identified by quantifying step edges in the transverse profile data. We have also sought to identify “inventory” features such as kerbs, surfaced verges and white lines, because information on the presence of such features can be used to remove lengths that are more likely to give rise to false positive reports of edge deterioration. The identification of these inventory features has relied on a combination of image and transverse profile processing techniques. Combination of the datasets has also been used to characterise potholes at the road edge.

Following the programme of algorithm development and testing on local datasets, more extensive tests of algorithm performance have been undertaken on a number of sites located on the local road network. The performance has been assessed in relation to the agreement with the results of manual analysis of the image and profile data. The assessment has demonstrated a high level of performance in the algorithms on many of the test lengths, with localised areas of poor performance. The use of algorithms to remove edge features that could adversely affect the detection of edge deterioration (e.g. kerbs) contributed to these high levels of performance.

The identification of kerbs is particularly successful, which is a direct result of combining the image and profile analyses when detecting kerbs. Unfortunately, the detection of flush kerbing is not so successful, because the low level of stepping at flush kerbs cannot be used to enhance the detection of the kerb in the image data. The identification of surfaced verges is also successful, with the majority of surfaced verges reported in the manual reference data also reported by the automatic analysis. The final edge feature, white lines at the road edge, was not well identified, and a large number of false positive detections were reported. The presence of unevenly lit images was a key reason for this poor level of performance.
Following the automatic removal of lengths containing poor images, kerbs and surfaced verges, the remaining lengths were analysed with respect to the reporting of edge defects. General agreement has been found between the automatic and manual reporting of overriding (at two levels of severity), with a low number of false positive reports. Again the accuracy was affected by poor image illumination, but could also be confused by edge patches and poor surface condition as well as damp road edge surfaces. Similar conclusions can be drawn for the identification of potholes. However, the identification of both of these defects relies not only on the correct measurement of the shape of the road edge, but also the scheme that is employed for interpreting this intermediate data. Many examples were seen that were “incorrectly reported”, but were actually associated with the presence of deterioration. However, the automated classification was incorrect. It is therefore felt that there is a need to develop the methods employed for the assessment of the severity of the overriding or pothole edge defects. Methods to improve this have been suggested. This includes the application of further filtering using logic based on the expected behaviour of the features (such as filling in very short gaps in a long length of kerbing).

It can be concluded that the image and profile processing algorithms developed in this project have demonstrated considerable potential for use in the automatic detection of edge deterioration. The intermediate measurements (e.g. road edge positions, step heights) appear sensible and reasonably accurate. The methodologies to interpret this intermediate data to obtain defect severities have also been relatively successful, but further work on classification and evaluation of severity is required. However, any further development should be carried out using larger samples of data, representative of the road network, as most aspects of the edge deterioration algorithms to produce intermediate measurements appear to have been developed as far as they can be whilst working with small samples of data. This would require the development of a data collection system suitable for the collection of large datasets on local roads. The images collected with such a system would benefit from artificial lighting to improve image quality and provide more accurate colour response.

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