Abstract

Pancam is an inspection system for in-service monitoring of wear and damage to pantographs on electric locomotives. Damage and wear of pantographs can cause damage to the locomotive and overhead wiring with subsequent interruption of service. Pancam uses CCD cameras to capture side and top views of the pantographs of locomotives in normal service. The side view is analysed for wear and damage to the carbon current collectors while the top view is analysed for damage to the horns on the pantograph. Analysis results are reported to railway staff through a database with a thin-client Web interface. This paper presents an overview of the Pancam system and discusses some of the analysis techniques. Performance results are also presented.

1. Introduction

Most electric locomotives use a pantograph to transmit electric power from an overhead wire to the locomotive. Commonly, the pantographs incorporate a carbon block that contacts the wire, to reduce wear on the overhead wire. The carbon block, however, can be significantly damaged by electrical arcing and impact from damaged overhead wiring support structures. In addition, the horns of the pantograph can become deformed or broken due to accidental damage. If damage to the carbon block or horns is not detected and repaired, the overhead wire and/or the pantograph itself can be severely damaged with a consequent loss of service.

To detect pantograph damage, railways commonly conduct regular manual inspections. Such inspections require the locomotive to be taken to a service depot. The overhead wire must be electrically isolated before inspectors access the top of the train to inspect the pantographs. Clearly, the associated labour costs and loss of service time of the locomotive are undesirable features of this inspection method and an automatic monitoring technique is desirable.

One approach to automatic monitoring of carbon block damage is to incorporate pressurised tubes [2, 3] or optical fibres [1] in the block so that wear or damage to the carbon block will rupture the tube or optical fibres and can then be detected. Unfortunately, these modifications add significant cost to the systems, so passive monitoring by automated visual inspection is a preferred solution.

Kin [5] describes an automated visual inspection solution that employs multiple cameras to capture the profiles of the carbon blocks, and laser stripes to precisely locate the pantograph in 3-D space. The analysis extracts profiles of the carbon blocks from the images, transforms them into 3-D space and measures the wear on the carbon block. The system is deployed at a train washing station where the trains are not in service. The speed of the train is limited to 12km/h during inspection.

The pantograph inspection system described below is called Pancam. It uses a single camera to inspect the carbon blocks for wear and damage. A second camera provides for inspection of the pantograph horns. The analysis techniques are rapid and effective, involving only 2-dimensional processing. Pancam is capable of analysing pantographs of locomotives that are in active service and travelling up to 80km/h.

In the following sections we present an overview of Pancam and discuss the design goals for the system. We then discuss techniques for 2-dimensional analysis of pantograph images, and the methods used to report inspection results. Finally we present performance results based on trials with coal trains in QR Limited’s rail network.

2. System overview

Pancam uses two 2-megapixel digital cameras, one to capture the side-view profile of the pantograph and one to capture the top-view. The side view is used to
detect wear and damage to the carbon blocks while the
top view is used to monitor damage to the horns.

Optical sensors are used to detect the presence of a
pantograph in the field of view of each camera. An
additional sensor detects the presence of the
locomotive. This is helpful to prevent false triggers
caused by birds and insects that often fly in the semi-
controlled environment in which Pancam has been
installed.

Lighting is provided by high intensity discharge
lamps. Bright illumination is required to allow the
short exposure times necessary to capture useful
images of in-service locomotives travelling at up to 80
km/h. Two lamps directly illuminate the pantograph,
enabling the top view camera to inspect the pantograph
structure. Two more lamps illuminate a white back
board that is used by the side view camera to obtain a
silhouette of the pantograph.

Pancam is deployed in a semi-controlled
environment where daylight is at times much brighter
than artificial illumination. The Pancam software
adjusts the camera gain and exposure to accommodate
diurnal variations in illumination. Exposure times are
restricted to ensure that in-service trains can be
correctly imaged day and night.

Specific design goals for Pancam are as follows:

1. Monitoring of in-service locomotives.
2. Rapid acquisition of inspection data.
3. Timely reporting.
4. Robust to changing environment.
5. Employ standard computer and
   communications infrastructure.
6. Operate on demand 24x7.

Pancam monitors pantographs of locomotives in
QR Limited’s coal transport network. Trains in this
network typically contain five locomotives in pairs or
triples with wagons between the locomotive sets.
When these trains are travelling at 80km/h, the time
between the acquisition of images of one pantograph
and the next may be as short as 360ms. However, the
time between trains is typically no less than 10
minutes. Pancam rapidly acquires the inspection
images and queues them for analysis in a separate
image processing thread. This allows Pancam to use
the time between trains for analysis. The total
processing time for each image may not exceed 1
minute, since there are two images (side and top view)
for each pantograph. In practice, the image processing
must take much less than 60 seconds in order to leave time for other tasks such as recording images and reporting results.

3. Analysis of side view images

Side view images show the pantograph silhouetted against a white back board. The back board is brightly lit compared to the illumination of the pantograph itself so that the pantograph appears silhouetted against the back board. A typical image is shown in figure 1 (a).

There are two distinct types of pantograph in use on QR Limited’s network. The first, shown in figure 1, has a Y-shaped pantograph arm. The other, shown in figure 2, has a T-shaped pantograph arm. The first analysis task is to identify the type of pantograph as the different pantographs require different parameters for the analysis of wear and damage to the carbon blocks. Pancam uses the template matching capabilities of Halcon [6], a commercial machine vision library, to identify the pantograph type. The location of the pantograph within the image is also determined by the template matching, and this information is used to determine the expected locations of the carbon blocks within the image as shown in figure 1 (c).

Once the pantograph has been identified, Pancam segments the silhouette image to obtain a binary image of the pantograph (figure 1 (b)). A simple threshold segmentation is suitable, but the threshold must be automatically adjusted because Pancam needs to accommodate diurnal illumination variations. A novel threshold selection algorithm is used, based upon the image histogram. The goal of the threshold selection algorithm is to find a threshold value in the centre of a wide low valley in the histogram. The valley lies between two uneven peaks representing the back board and the pantograph. We define a hypothesised valley by the minimum and maximum pixel values representing the limits of the valley. We define the height of the valley as the maximum histogram bin count in the pixel value range of the valley, and the width of the valley is defined as the difference between the minimum and maximum pixel values. The score assigned to a hypothesised valley is the width divided by the squared height. The valley with the maximum score is found by an incremental search procedure starting with the local minima of the histogram and growing the valleys to the left or right depending on which direction has the lowest histogram bin counts. The centre of the highest scoring valley is used as the threshold value to segment the back board from the pantograph. This technique has proved to be very reliable and is sufficiently robust to uneven lighting of the back board (figure 1 (b)).

After segmentation of the silhouette, morphological image processing [7] is used to identify damage and wear of the carbon blocks. Firstly, morphological opening is used to remove the overhead wires and other similar artefacts from the binary image. A linear structural element, parallel to the top surface of the carbon block, eliminates the overhead wires.

Notches and steps which could catch the overhead wire are then identified by applying morphological closing with a large circular structural element to the top edge of the carbon block silhouette. The closing operation fills in the notches and steps, so the difference with the original segmented silhouette reveals the notches and steps as small regions. After eliminating insignificant regions, a coloured outline is displayed around the notches and steps in the display image which is histogram equalised for visual
presentation to maintenance staff (figures 1(c), 2(b) and 3(b)).

In addition, the segmented carbon block silhouette is analysed for wear. Rather than attempt to separate the carbon block from its carrier, the combined depth of the carbon block and the carrier is measured. The algorithm uses morphological opening with a vertical linear structural element equal in length to the minimum acceptable combined depth of the carbon block and carrier. This morphological operator removes sections of the silhouette where there is excessive wear, so once again the difference with the original silhouette reveals the worn sections and a coloured outline is displayed around these sections in the output image (figure 4).

The minimum acceptable depth depends not only upon the type of pantograph but also upon its distance from the camera, because the depth is expressed in image coordinates. Since the camera is in front of the pantograph, slightly below and to one side, the pantograph moves through the image from side to side as it approaches the camera. A reasonable estimate of the location of the pantograph is obtained by determining the image column coordinate where the overhead wire contacts the pantograph (figure 1(c)), since the overhead wire normally remains in the same vertical plane. Pancam uses the column coordinate of the wire contact point to calculate a scaling factor for the measurement of carbon block depth. The relationship is determined from sample images where a particular pantograph was photographed at different positions.

The carbon block analysis is performed for both near and far carbon blocks for Y-shaped pantographs, as both carbon blocks are clearly visible in the image (figures 1, 3, 4). In contrast, only the near carbon block is visible for T-shaped pantographs due to visual obstruction of the far carbon block by the pantograph support structure (figure 2).
4. Analysis of top view images

Top view images show the pantograph with an uncontrolled background which typically includes the track surrounds and a portion of the roof of the locomotive or a following wagon. In addition to the changing image content, there are diurnal variations in illumination which further modify the background. With such an uncontrolled background, traditional segmentation techniques do not provide a reliable solution. Halcon's template matching capability is used to analyse these images.

The first analysis step is to identify the type of pantograph based on the shape of the pantograph arm, because the two types of pantographs use different horn designs. Figure 5 shows a typical top view image for a Y-shaped pantograph while figure 6 presents an example of a top view image for a T-shaped pantograph. The horns of the Y-shaped pantograph form a single unit that is shaped like a Y or a V, whereas the horns of the T-shaped pantograph consist of three separate curved components.

The template matching used to identify the type of pantograph also identifies its location in the image. Based upon the position and size of the pantograph in the image, the expected locations of the horns can be calculated. For Y-shaped pantographs, template matching is used to check that the horns are present and have not been seriously damaged. This requires matching a pattern representing the shape of the left or right horn as appropriate. The template matching is constrained to search only that portion of the image where the horn is expected to be found. For T-shaped pantographs, a similar procedure is used except that the three horn components are individually checked. First, the main horn component is checked by template matching and then the location of that component is used to predict the location of the two smaller horn components which are checked by matching with their own patterns.

5. Reporting

Pancam reports the results of analysis through a variety of media. Analysis results are highlighted by drawing on a display image which is saved to disk along with the original image for future reference. Conditions that require attention can be notified to maintenance staff by e-mail, SMS and through a database with a web monitoring interface.

Pancam sends email to designated e-mail addresses to report conditions that require attention. The e-mail messages include a textual description of the condition. The relevant input and display images are included as attachments. Where required, an abbreviated e-mail message can be sent to an SMS gateway to notify maintenance staff via SMS.

In addition to the above reporting mechanisms, Pancam reports all analysis results to a Microsoft SQL database. A PHP web interface is provided to enable maintenance staff to query this database with search parameters such as locomotive ID, inspection site, date range and inspection results. Using these queries, staff can examine the history of a particular locomotive and check the status of damage reports. In addition, a specific PHP web interface is provided for the exclusive use of Rollingstock Defect Coordinators (RDCs) who hold primary responsibility for monitoring results from Pancam and other trackside systems. This interface provides regular updates that rapidly notify the RDCs of damage and wear.

<table>
<thead>
<tr>
<th></th>
<th>Day</th>
<th>Night</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missed</td>
<td>344</td>
<td>56</td>
<td>400</td>
</tr>
<tr>
<td>OK</td>
<td>678</td>
<td>944</td>
<td>1593</td>
</tr>
<tr>
<td>Damaged</td>
<td>57</td>
<td>10</td>
<td>67</td>
</tr>
<tr>
<td>Total</td>
<td>1079</td>
<td>1010</td>
<td>2089</td>
</tr>
</tbody>
</table>

Table 1. Top view analysis results
conditions and allow them to respond in a timely manner.

6. System performance

Pancam’s analysis and reporting has been biased towards false positives rather than false negatives because failure to detect damage can be catastrophic. A human RDC makes the final judgment on the damage reported by the system, filtering out the false positives at a small cost of their time.

During a trial period, Pancam captured and analysed 6005 images from one installation site. Of these, some 1930 images were invalid images captured because of incorrect triggering due to birds and insects. There were 4075 valid images for analysis.

Table 1 shows the results of analysis of top view images. ‘Missed’ denotes images in which the pantograph was either not present or in an unsuitable position for analysis. Most of the top view images were analysed as OK, reflecting the fact that horn damage is rare, although it causes severe problems when it does occur. In this particular period, there were no incidents of horn damage and the damage analysis results are false positives, often caused by background shadows that can render the horns invisible. Additional infrastructure may be added in future to reduce these false positives if it is considered cost effective.

Table 2 shows the analysis results for the side view images. Again “missed” denotes images in which the pantograph was either not present or in an unsuitable position for analysis. “Damaged” includes conditions ranging from chips which only require attention at the next service to large steps in the carbon requiring the immediate replacement of the pantograph. False positives were low at approximately 10% of the “damaged” pans and were usually caused by unusual lighting conditions or light discolourations of the carbon block (e.g. bird faeces on the face of the block).

7. Discussion

Pancam has been designed for in-service inspection of electric locomotives. The analysis techniques for detecting wear and damage are simple and rapid. They include Halcon’s template matching, a novel adaptive segmentation algorithm and well-known morphological techniques. Unlike other similar work [5], no 3-dimensional data processing or modelling is required.

Halcon’s template matching capabilities are particularly powerful. The templates are derived from actual images. Halcon’s matching algorithm allows scaling and rotation of the template. Restricting the search regions is effective in preventing spurious matches and increases the reliability of the analysis. However, some images do not have sufficient contrast to match the templates and recognise the horns successfully, leading to a small false positive rate.

Pancam requires limited facilities for each installation. Two cameras, four lights and one backboard are the main visual inspection components. The remaining components are sensors to detect the locomotive and pantograph, AVI tag readers and a PC. Thus, Pancam can be replicated without excessive cost.

8. Conclusion

Pancam successfully monitors in-service locomotives for wear and damage to the pantographs, operating day and night. The reporting mechanisms provide timely information that allows maintenance staff to repair damaged and worn pantographs before they cause greater damage to themselves or the overhead wiring.

Pancam is a successful and cost-effective application of machine vision technology to an important monitoring task.

9. References


Table 2. Side view analysis results

<table>
<thead>
<tr>
<th></th>
<th>Day</th>
<th>Night</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missed</td>
<td>150</td>
<td>169</td>
<td>319</td>
</tr>
<tr>
<td>OK</td>
<td>699</td>
<td>655</td>
<td>1354</td>
</tr>
<tr>
<td>Damaged</td>
<td>66</td>
<td>55</td>
<td>121</td>
</tr>
<tr>
<td>Worn</td>
<td>101</td>
<td>91</td>
<td>192</td>
</tr>
<tr>
<td>Total</td>
<td>1016</td>
<td>970</td>
<td>1986</td>
</tr>
</tbody>
</table>
