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Detection and Characterization of Rumble Strips in Roadway Video Logs

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Abstract

State departments of transportation often maintain extensive "video logs" of their roadways that include signs, lane markings, as well as non-image-based information such as grade, curvature, etc. In this work we use the Roadway Information Database (RID), developed for the Second Strategic Highway Research Program, as a surrogate for a video log to design and test algorithms to detect rumble strips in the roadway images. Rumble strips are grooved patterns at the lane extremities designed to produce an audible queue to drivers who are in danger of lane departure. The RID contains 6,203,576 images of roads in six locations across the United States with extensive ground truth information and measurements, but the rumble strip measurements (length and spacing) were not recorded. We use an image correction process along with automated feature extraction and convolutional neural networks to detect rumble strip locations and measure their length and pitch. Based on independent measurements, we estimate our true positive rate to be 93% and false positive rate to be 10% with errors in length and spacing on the order of 0.09 meters RMS and 0.04 meters RMS. Our results illustrate the feasibility of this approach to add value to video logs after initial capture as well as identify potential methods for autonomous navigation.

Keywords: *computer vision, autonomy, transportation systems, deep learning, segmentation*

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Introduction

In our modern economies, transportation is vital for the flow of goods to maintain and increase economic prosperity. In the United States in particular, roadways are critical to meeting the mobility and economic needs of the nation. The responsibility for ensuring proper maintenance of this infrastructure is shared between federal and state departments of transportation. In the United States, many state department of transportation create and maintain "video logs" or "photo logs" of their vital roadways which include a variety of information about the roadway characteristics, including signage, lane markings, and information about the geometry of the road itself such as lane width, shoulders, etc [1, 2]. These video logs are created by a variety of methods, including instrumented vehicles [3] which acquire various measurements in conjunction with GPS systems. Such video logs can also be vital resources for scientific understanding of driver behavior. In 2001, the Transportation Research Board of the US Academy of Sciences recommended the Second Strategic Highway Research Project (SHRP2) [4], which included an extensive naturalistic driving study (NDS) where approximately 3000 drivers were recorded with dedicated data acquisition systems (DAS) in their personal vehicles [5,6].

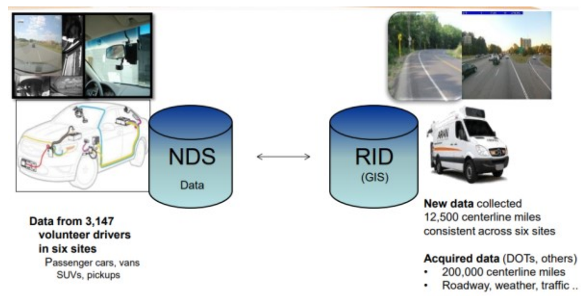

Figure 1*The SHRP2 RID contains extensive measurements of the most commonly used roadways in the NDS.*

As part of this tremendous resource, a Roadway Information Database (RID) was created which consisted of a video log compiled by FUGRO Inc using instrumented vans [7]. The RID was created across all six geographic regions of the United States where the NDS was conducted, with a goal of acquiring roadway data driven by NDS participants to enhance understanding of driver behavior with improved safety of drivers and roadways as the foremost goal. The RID includes a variety of ground truth information such as road characteristics (see Figure 1).

In this work we seek to use the RID as a video log proxy to understand a particular roadway feature: rumble strips. Rumble strips are grooves or raised structures along a roadway that are intended to cause audible alerts, primarily to warn drivers of potential roadway departures when they drive too close to the shoulder line or center line of a road. Rumble strips have been shown to reduce accidents in some studies [8,9,10]. The distinct features of rumble strips, including visibility and the audible response, have been suggested as key fiducials for autonomous applications [11]. Rumble strips have also been specially constructed for specific applications. In particular, [12] reports a study where strips were used to alert drivers of the improper direction on one-way roads. More esoteric uses include encoding spoken warnings into roadways [13, 14] or even musical pieces [15, 16]; although these may seem trite, they can encourage drivers to slow down to match the perceived timing of the pieces.

Some key measurements of rumble strips include the length, width, and spacing of the strip [17] which are not always well documented by the entities which install and maintain them. Other measurement methods [18] have been discussed in recent literature; we believe the work here compliments these methods, which could potentially be combined into simple tools to improve roadway condition awareness and generally serve to improve the important objectives for modern economies: safety and mobility. This paper is organized as follows. First, we describe the motivation and the need for the

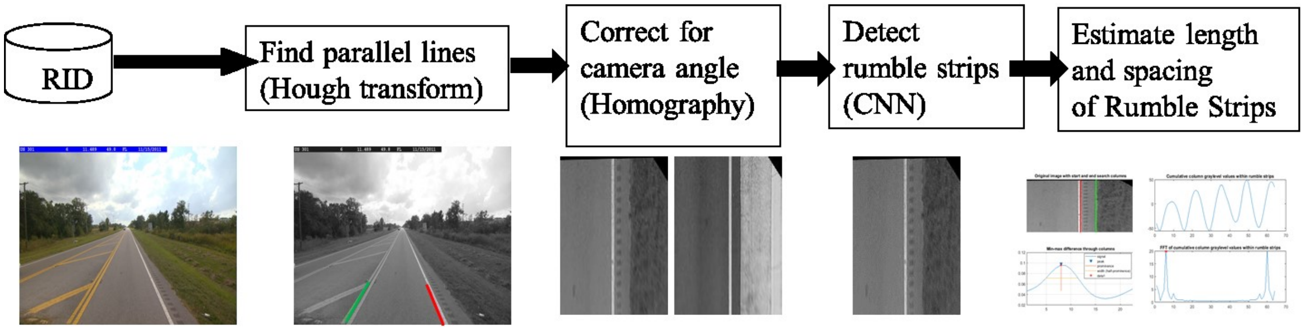

Figure 2 *The entire process of detecting and characterizing rumble strips*

approach. We then explain the entire process of detecting and characterizing the rumble strips. We present results of the tests of the algorithms and conclude with a discussion of limitations and next steps.

Detection and characterization of rumble strips

Motivation

Roadway departure crashes are frequently severe and account for most highway fatalities in the US. Roadway departure can occur either when vehicle gets into the lane in the opposing direction or when the vehicle exits the lane towards the shoulder and hits an object on the side of the road. In both cases, injuries to the occupants of vehicle can be fatal. Rumble strips are a commonly used countermeasure to reduce the frequency of roadway departures [17,19]. Two general types of rumble strip installations are common: (1) centerline rumble strips are placed between opposing lanes of travel to limit the potential for head-on collisions, and (2) shoulder rumble strips are installed on the shoulder of the roadway for possible lane departure towards the shoulder. An example of a shoulder rumble strip is shown in Figure 3. There are reports that show milled shoulder and edge rumble strips provide significant reduction in fatal crashes [20].

Figure 3 *Example of shoulder rumble strip*

Our experiments focus on RID video logs to detect and characterize these shoulder rumble strips so that measurements eventually can be added to the road characteristics in a video log. For this paper we focused on more common shoulder rumble strips with lengths 6”, 8” and 12”.

Procedure

RID images are high resolution 1920x1080 images, taken every 10-feet along the route. To test, we selected a collection of RID images from the RID database, which ranged from randomly chosen frames from multiple routes to every frame in a mile-long route. The entire process of detecting and characterizing rumble strips is shown in Figure 2. First, lane markings in the plane of the road were found using Hough transform. The goal was to convert the perspective view to plane view by finding the homography to transform those lines into parallel lines in the plane of the road. The parameters from FUGRO were used for intrinsic camera calibration. We specifically focused on RID images from year 2011 which came from a single FUGRO van.

For the extrinsic camera calibration, we must map the real-world coordinates of fiducial points in a given RID frame to their corresponding image points. First, we undistort the image using the intrinsic parameters, and then compute the mapping (using a translation and rotation) from the 3D real-world coordinates to the 2D image plane [21]. We selected points in Google Earth [22] and in the corresponding RID frame as shown in Figure 4. As a result, the planar image was generated for each RID image, which were then cropped to focus on the right shoulder of the road for rumble strip detection (Figure 2).

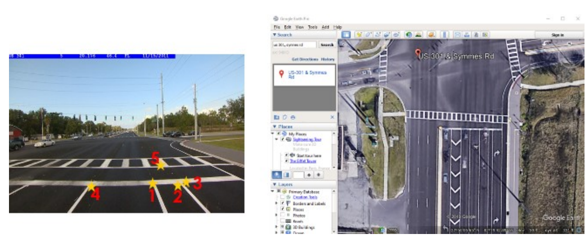

Figure 4 *Selection of points in a RID location for extrinsic camera calibration and corresponding Google Earth location.*

These cropped planar RID images were the processed with a convolutional neural network, based on a pretrained AlexNet [23] network. The network was tuned to discriminate rumble strips through a simple transfer learning process. Those cropped planar images were then classified as "no rumble strip" and "rumble strip" cases (Figure 5) by the trained rumble strip detector.

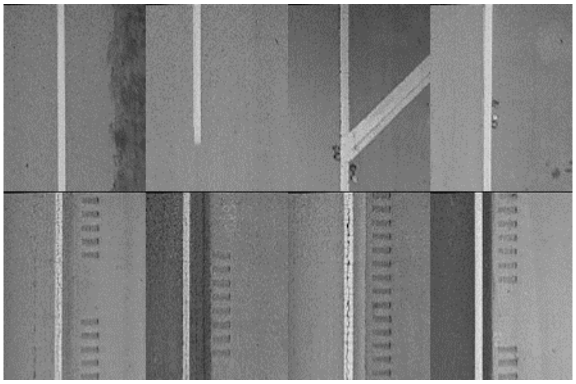

***Figure 5** Examples of no rumble strip (top images) and rumble strip (bottom images)*

The cropped planar RID images with rumble strips were processed with the rumble strip characterization code. The nomenclature used for describing rumble strips is shown in Figure 6. The characterization code estimates the length and spacing of rumble strips based on the planar RID image

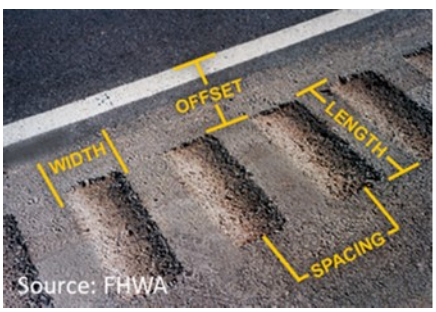

***Figure 6** Actual rumble strip for reference*

During the process, the contrast was calculated column by column starting from start to edge of the shoulder (Figure 7). The peak contrast identifies the center of the rumble strips if there is high contrast through the rumble strips. Unfortunately, sometimes there are factors causing the peak to have a rounder shape instead of a more box shape such as nonuniform gray level distribution within the rumble strip and blur at the edges of rumble strips. We found heuristically that the length of rumble strip can be estimated as the value at full width at half-maximum (FWHM) of the contrast peak.

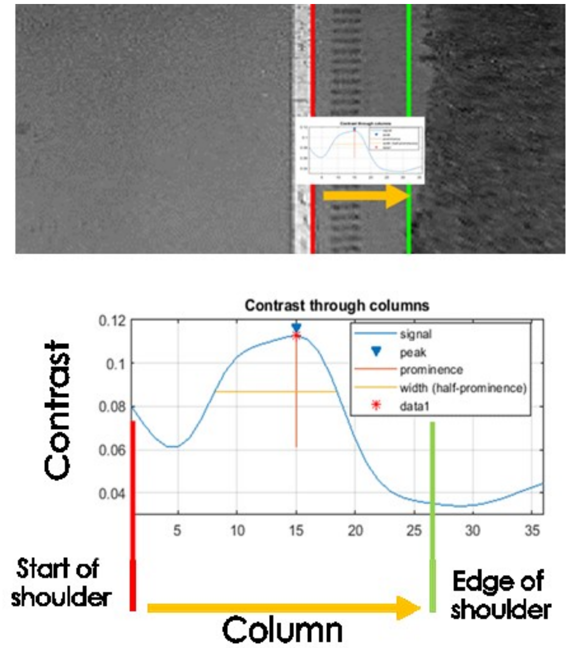

***Figure 7** The rumble strip search area marked by start (red line) and end (green line) columns shown at the top. At the bottom plot of contrast through the columns*

All the measurements were scaled with respect to real-world values. To do the ground truth measurement, lane width in the direction of travel in planar image was measured. Lane width in the same route from the closest RID measurement location was used to calculate the scale (Figure 8). The scale was defined as the ratio of the lane width ground truth value in RID to the lane width measurement in planar image. the scale value was estimated as 1.05. This value was included in all length and spacing measurements.

Another parameter in rumble strips is the spacing. To estimate the spacing of rumble strips we first needed to estimate the pitch of rumble strips. that the pitch is estimated by integrating the column gray level values up to the peak of contrast in Figure 7, which is an indicator of pixels within the rumble strip region. Once pitch is found, the spacing can be estimated. The Fourier transform (FFT) of the integrated column gray level values were calculated with a moving window along the column as shown in Figure 9 with alternating solid and dashed yellow boxes. The integrated column gray level value plots corresponding to each of those 4 moving windows are also shown in Figure 9 to illustrate the process.

In each 64-pixel window the frequency of the rumble strips was estimated for a total of 9 windows. The frequency value with the most occurrence was then selected as the pitch of the rumble strips for the given RID planar image. Finally, the spacing was estimated based on the selected pitch value and the window size.

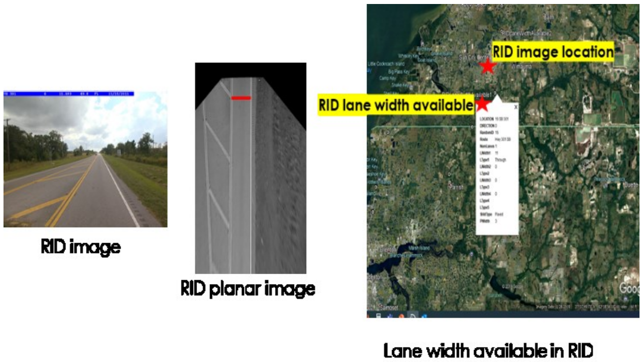

Figure 8 *Estimating the scale suing the lane width from the RID frame to actual lane width measurement in RID.*

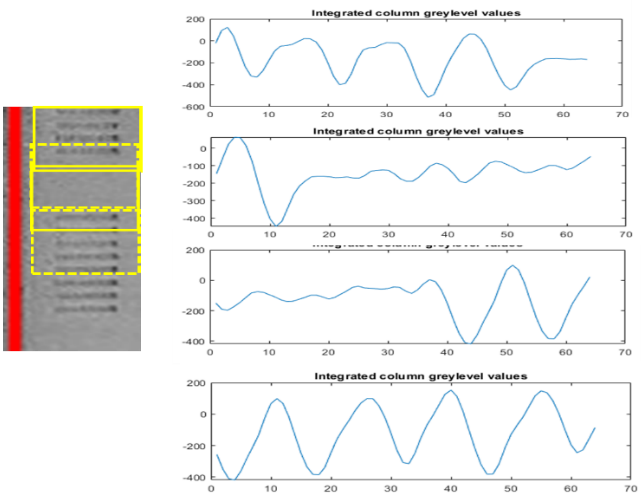

Figure 9 *On the left 4 out of 9 moving windows for FFT calculation shown only in part of the integrated column gray level values, on the right corresponding integrated column gray level plots*

Results

For the deep network training process 697 images for training and 150 images for validation were randomly selected. The validation accuracy was 93.3%. This rumble strip detector was also tested on a blind set of 4838 RID images. The accuracy of that blind testing was 92% and corresponding ROC curve is shown in Figure 10.

After detecting the presence of rumble strips (RS) the method was tested on the aspects of estimating the rumble strip measurements. The method was tested mostly on two different sizes of RS, 8" (0.20 meters) and 12" (0.31 meters). The length and spacing measurements were scaled based on the ground truth lane width measurements from RID. Once the presence of RS was detected in planar image, characterization code was used to estimate the length and spacing.

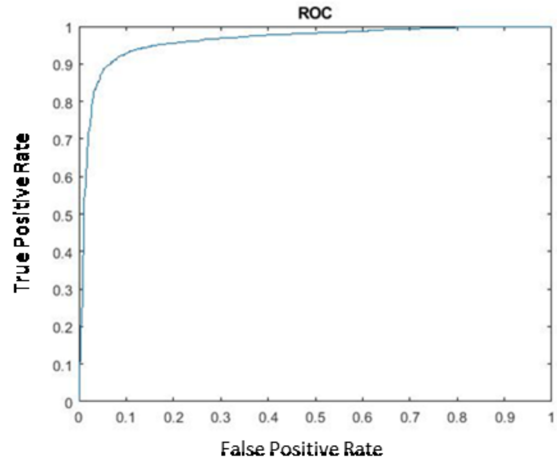

Figure 10 *Receiver-operating characteristics (ROC) of blind testing*

To evaluate the performance of the method, we applied 3 different tests. The first test was done on selection of consecutive RID images taken from 120 feet stretch of the same route. The estimated average RS length was 0.23 ± 0.01 meters and RS spacing was 0.32 ± 6E-17 meters among the total of 12 images. The histogram of resulting RS length estimates is shown in Figure 11.

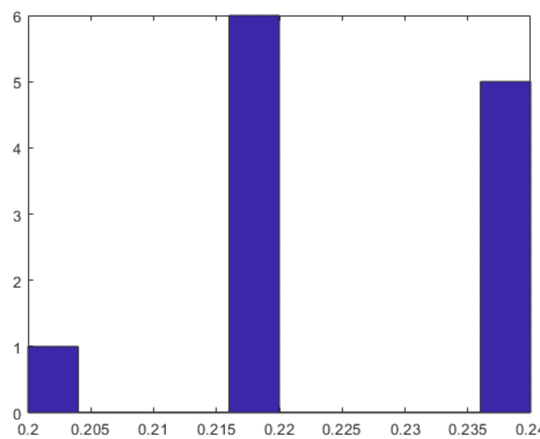

Figure 11 *The histogram of RS length estimates from test 1, where rumble strip length and spacing measurements were made on 8" RS detections*

The second test was performed on total of 14 RID frames from randomly selected routes which comprised of two different sizes of RS shown in Figure 12. Among the RS type 1 estimated RS length was 0.22 ± 0.01 meters and RS spacing was 0.32 meters. Among the RS type 2 estimated RS length was 0.35 ± 0.08 meters and estimated RS spacing was 0.32 meters. The histogram plot of the estimates is shown in Figure 12.

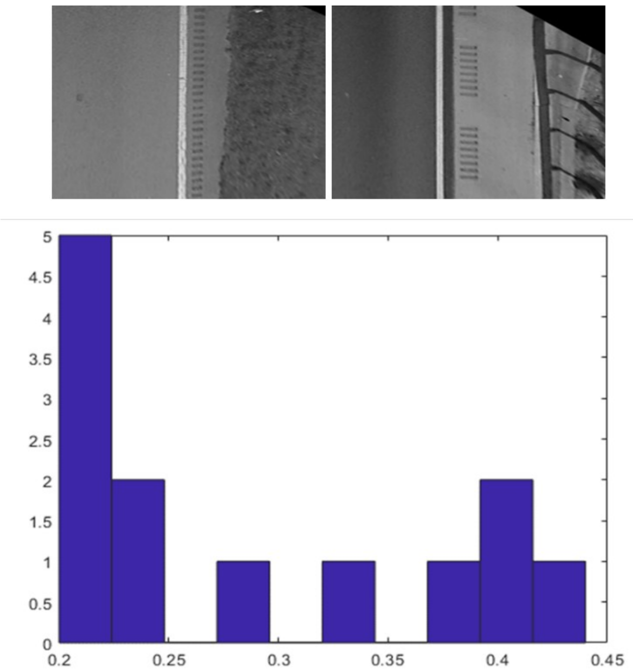

__Figure 12__ Example of different sizes of rumble strips from test 2, where rumble strip length and spacing measurements were made on 8" and 12" RS detection. Top: On the left RS type 1 (8") and on the right RS type 2 (12"). Bottom histogram of RS length estimates.

The third test was performed on a collection of 499 images from a mile-long stretch of the same route. All cropped planar RID images were processed with the rumble strip detector to identify the frames with RS. 87% of "No RS" cases and 91% of "RS" cases were identified correctly. All "RS" cases were processed by the characterization code to get estimated length and spacing measurements. For the detected "RS" cases average estimated RS length was 0.35 ± 0.09 meters and RS spacing was 0.31 ± 0.04 meters. The purpose of the rumble strip detector was to have a means of sorting through a very large dataset like RID for frames with RS The method we used was able to handle intermittent RS cases in which RS periodically start and stop compared to continuous RS cases. The contrast plots for example frames with intermittent RS are illustrated in Figure 13. The corresponding integrated column gray level and FFT plots are shown in Figure 14. For those examples the method yielded the same RS length of 0.4 meters and RS spacing of 0.32 meters. The mile-long test had frames with continuous RS in addition to intermittent ones as shown in Figure 15.

Conclusions

In this work we estimated the length and spacing of right-side shoulder rumble strips. Currently, we can distinguish 8" and 12" rumble strips however there is room for improvement particularly in distinguishing 6" and 8" rumble strips. Although the RID was acquired under good conditions (daylight, good weather) there are still issues with image quality at times with respect to rumble strips affect the resulting measurements. The RID lacks "real" ground truth for rumble strips so we are limited by measurements yielded by the characterization code. Also, the sparse availability of lane width measurements limits the precise measurement. There are a few unknowns related to the measurements available in RID such as how the lane widths were measured, excluding the lane markings or partially including lane markings on both sides of the lane. Another factor affecting the measurement is that ground truth measurement was rounded to the nearest number. Since with the current available lane width RID measurements precise rumble strip measurement can't be obtained, we tried to select the closest available RID lane width measurements to make the best judgement.

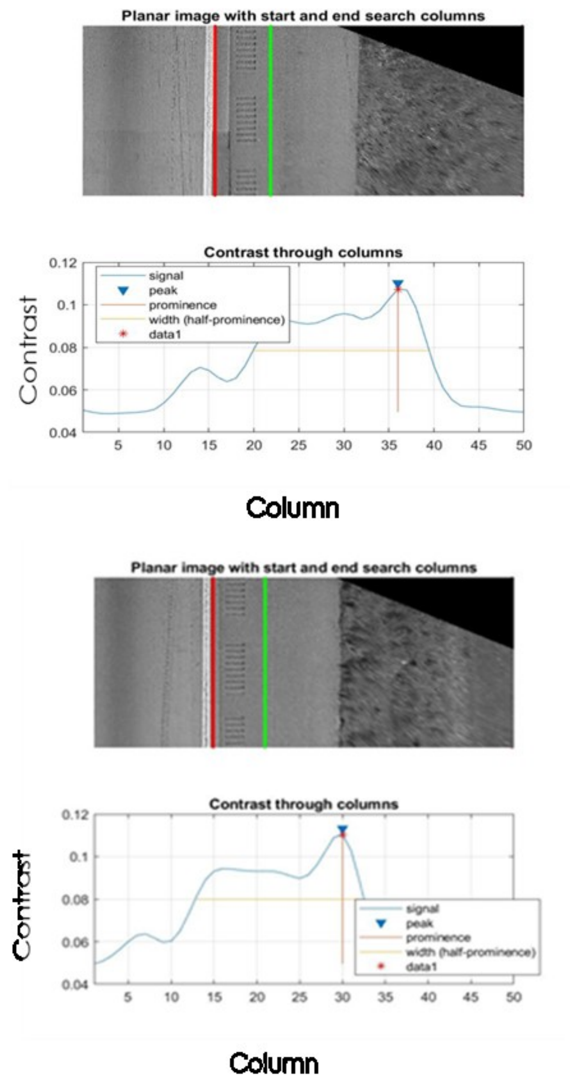

__Figure 13__ Both top and bottom examples have the same RS length

The techniques in this paper could be used to enhance the value of the RID and extended to videologs by adding more information about the rumble strips to the imagery. The method operates on single images and therefore could be easily parallelized in the proper compute environment. Our next steps are improving the implementation to make such scaling possible, as well as further tests on roadway features, perhaps with real ground truth from field measurements.

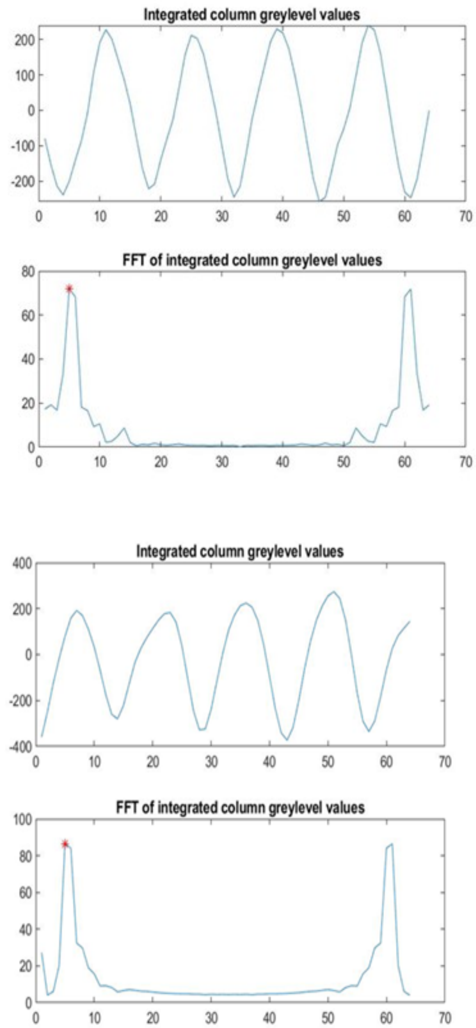

Figure 14 *Both top and bottom examples have the same RS spacing (corresponding RID frames are in Figure 13)*

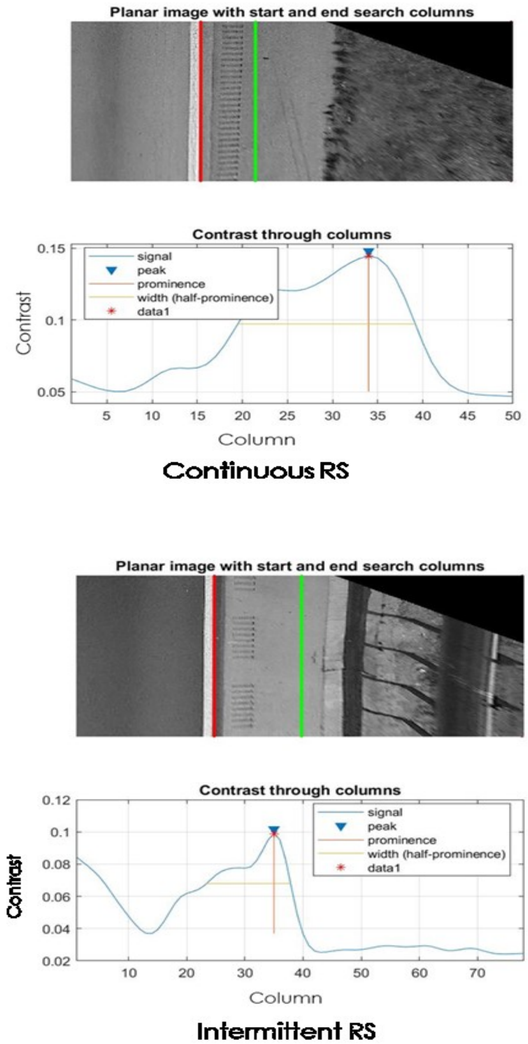

*Figure 15**Top is an example of continuous RS from mile-long test, bottom is an example of intermittent RS from mile-long test.*

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