Rail Flaw Detection Using Image Processing Concepts- A Review

Gimy Joy[1], Hyfa N[2], Remya Krishnan[3]
[1]PG Scholar, College of Engineering, Karunagapally
[2]PG Scholar, College of Engineering, Karunagapally
[3]PG Scholar, College of Engineering, Karunagapally

Abstract:**Rail inspection is a very important task in railway maintenance and it is periodically needed for preventing dangerous situations. Inspection is operated manually by trained human operator walking along the track searching for visual anomalies. This monitoring is unacceptable for slowness and lack of objectivity, because the results are related to the ability of the observer to recognize critical situations. Some years ago two railway inspection trains already equipped with ultrasound, had additional advanced eddy current techniques installed. Recently a new RIT was equipped with a system that was designed, from the beginning, to employ a combination of these two techniques for non-destructive rail inspection. Experience gained from application has shown that clear improvement on rail inspection can be achieved if VIS is used. VISyR is a patent pending real time Visual Inspection System for Railway maintenance. VISyR acquires images from a digital line scan camera. ViSyR achieves impressive performance in terms of inspection velocity. Data are simultaneously preprocessed and then it cuts the subimage of rail track by the track extraction algorithm. Subsequently, VIS enhances the contrast of the rail image. Different contrast enhancement methods are used for different application which can be compared and analysed, like the Otsu method, CLAHE etc and finally localizes the defect. Then a defect localization method can be applied to the image to localize. VIS is very fast comparing with the existing systems. After analyzing the crack the position of the crack is also found out in addition to the detection. Thereby it can be located as a step for the safety procedure.**

Keywords: Discrete surface defects, local normalization(LN), projection profile, visual inspection.

I. INTRODUCTION

RAIL inspection is an important task in railway maintenance. The speed and loads of trains have been increasing greatly in recent years, and these factors inevitably raise the risk of producing rail defects. For the safe operation of railway systems, the quality of rails must be closely and frequently monitored.

The detection of cracks in rails is a challenging problem, and much research effort has been spent in the development of reliable, repeatable crack detection methods for use on in-service rails. While crack detection in the rail head and shear web is reliably achieved using ultrasonic and eddy current methods, neither technique is particularly effective for the detection of cracks in the rail foot. The results of these studies confirm the ability of the proposed method to locate and quantify surface-connected notches and cracks.

Rail defect detection has highly concerned railway operators, and related techniques have been improved greatly in last decades. Traditionally, a rail defect was inspected manually by a trained person who views rails visually. Human inspection is slow, subjective, and dangerous. The limitation of human inspection led to many advanced nondestructive testing (NDT) techniques, which acquire the condition of a rail by certain sensors (such as visual and ultrasonic sensors) and then detect defects with sophisticated software. Nowadays, available NDT techniques for rail inspection include the use of visual cameras, ultrasonics, eddy current, etc. Recent surveys of NDT of rails can be found. Ultrasonic inspection has the best performance for detecting internal cracks. However, its inspection speed is slow (no more than 75 km/h); furthermore, it cannot detect surface defects. Several improved ultrasonic techniques were proposed to increase the inspection speed, such as electromagnetic acoustic transducers, lasers, and air coupled ultrasonics, but they did not achieve enough progress to detect surface defects.

Eddy current testing identifies defects using magnetic field generated by eddy currents. It has relatively high inspection speed and is able to detect surface defects, so it is widely combined with ultrasonics for rail inspection. However, the sensor of eddy current is so sensitive to the lift-off variation that the probe should be positioned at a constant distance (no more than 2 mm) from the surface of the rail head. As a result, the operation of eddy current testing is complex and sensitive; furthermore, the reported highest speed of this testing is also no more than 100 km/h.

Visual inspection has been developed in recent years with the great progress of image processing techniques. In a visual inspection system (VIS), a high speed digital camera, which is installed under a test train, is used to capture images of a rail track as the train moves over the track, and then, the obtained images are analyzed automatically using a customized image processing software. Typical applications include bolt detection, corrugation inspection, and crack detection. Visual inspection has the advantages of high speed, low cost, and appealing performance and is regarded as the most attractive technique for surface defect detection. In ideal conditions, the gray level of defects is lower than that of background (defect-free areas); however, this order is often broken by illumination inequality and the variation of reflection property of rail surfaces. This disorder of gray level between defects and background brings out challenges for VISs.

II. EXISTING METHODOLOGIES

A. Ultrasonic Characterization[1]

Samuel Tony Vipparthy et.al.suggests nowadays, rails are systematically inspected for internal and surface defects using various Non-Destructive Evaluation (NDE) techniques. During the manufacturing process rails are examined visually for any surface damage, while the presence of any internaldefects is assessed mainly through ultrasonic inspection. Similarly, ultrasonic wheel probes have been extensively used by the rail industry for theinspection of rail services. During the inspection of rails using conventionalultrasonic probes a beam of ultrasonic energy is transmitted into the rail.The reflected or scattered energy of the transmitted beam is then detectedusing a collection of transducers.Ultrasonic testing (UT)[3] is a non-destructive inspection method thatuses high frequency sound waves (ultrasound) that are above the range ofhuman hearing, to measure geometric and physical properties in materials.To perform UT, electrical energy is converted to mechanical energy, inthe form of sound waves, by a transducer. The transducer accomplishesthis energy conversion due to a phenomenon referred to as the piezoelectric effect. This occurs in several materials, both naturally-occurring and manmade. Quartz is a naturally occurring piezoelectric material. A piezoelectricmaterial will produce a mechanical change in dimension when excited withan electronic pulse. Similarly, this same material will also produce an electric pulse when acted upon mechanically.

B. Eddy Current Detection[4]

Tsutomu Yamada et al. suggest eddy current testing is a nondestructivetesting method, which is used to detect discontinuities and defects in conductive materials. Using this technique, two different types of artificial defectsin a railhead were evaluated in order to analyze the relationship between different types of defects and eddy current signals, and to obtain data onthe size of the rail surface defects and crack location. The actually used railsample was also studied. Surface cracks and defects were clearly observedas amplitude and phase changes of detected signals. This study succeeds inquantitatively analyzing and discriminating the damage types. An inspection system of rail flaws used in this study included a detection coil and anexcitation coil, which formed an eddy current sensor probe.Two eddy current sensor probes were used. One was for detecting thesignal from a rail. It was positioned on a tested sample and scanned alongthe rail length. Another was for reference. It was positioned in air far froma sample. Thecontroller supplied an excitation current to a series connection of two excitation coils and amplified a signal from the detection coils. The width of therailhead was 65 mm; thus, the detection coil in the sensor probe could noteffectively evaluate the entire plane of the rail top. Therefore, the positionof the sensor probe was varied in fivedifferent positions along the width. The scan speed of the sensor probe was 2.5 mm/s andthe data acquisition rate was 8 point/s (3.2 point/mm). The frequency ofthe exciting magnetic field was 5 kHz.

C. Ultrasonic and Eddy Current [6]

Hans-Martin et al. suggest that at present the inspection ultrasonic and eddycurrent results are still evaluated separately as well as they usually are presented in separate test reports. One finds certaincase in general with welds, rail joints, wheel burns and often with head checking, squats andcorrugation. A new RIT was equipped with a system that was designed, from the beginning, to employ a combination of these two techniquesfor non-destructive rail inspection [4]. The eddy current technique has beendeveloped to enable identification and evaluation of rolling contact fatigue defects. The ultrasound technique is aimed at measurements in the rail bulkvolume, which are not feasible using the eddy current technique. Experiencegained from application has shown that clear improvement on rail inspectioncan be achieved. But due to the reason of high cost and complex network this method was inefficient.It is slow in real time too.

III. IMAGE PROCESSING METHODS

Pictures are the most common and convenient means of conveying or transmitting information. A picture is worth a thousand words. Pictures conciselyconvey information about positions, sizes and inter-relationships between objects. They portray spatial information that we can recognize as objects.Human beings are good at deriving information from such images, becauseof our innate visual and mental abilities. About 75% of the information received by human is in pictorial form. Aswill become Evident shortly, digital image processing, as we have definedit, is used success fully in a broad range of areas of exceptional social andeconomic value.

Acquisition

Image is acquired as jpeg images more frequently using a good resolutioncamera. According to [9],ViSyR acquires images of the rail by means of aDALSA PIRANHA 2 line scan camera [Matrox] having 1024 pixels of resolution (maximum line rate of 67 kLine/s) and using the Cameralink protocol[MachineVision]. Furthermore, it is provided with a PC-CAMLINK framegrabber (Imaging Technology CORECO) [Coreco]. In order to reduce theeffects of variable natural lighting conditions, an appropriate illuminationsetup equipped with six OSRAM 41850 FL light sources has been installedtoo. In this way the system is robust against changes in the natural illumination. Moreover, in order to synchronize data acquisition, the line scan cameracan be triggered by the wheel encoder. This trigger sets the resolution along y(main motion direction) at 3 mm, independently from the train velocity; thepixel resolution along the orthogonal direction x is 1 mm. The acquisitionsystem is installed under a diagnostic train during its maintenance route.A long video sequence captured by the acquisition system can be fed into Prediction Algorithm Block (PAB)[9], were coordinates of the railways geometry by RD and TB is provided. PAB exploitsthis knowledge for extracting 24x100 pixel windows where the presence of abolt is expected.

Figure 1: Acquisition System.

Either images or a video can be considered. The captured images are inspected in order to detect rail defects. A long video sequencecaptured by the acquisition system is fed to analyze. According to my review,acquisition system can take videos or images to localize the defected frame. The basic component is a DalsaSpyder 2line-scan camera, which has 1024 pixels of resolution and a maximum linerate of 65 000 lines/s. A PC-CamLink frame grabber is utilized to capture rail images based on the Cameralink protocol. An illumination setupequipped with four LED light sources is installed in order to reduce the effectof natural light. Moreover, the line-scan camera is triggered by a wheel encoder to synchronize data acquisition. This trigger sets the pixel resolutionalong longitudinal direction Y (or motion direction) at 1 mm. The IAS isinstalled under a test train andhas to note that the quality of railimages captured by IAS is inevitably affected by natural light and the shakeof the train. This is really efficient and time saving.Unlike others they high rate of readable rates per second with good resolution images.

Preprocessing

From ref.[8],its seen that after acquiring image, it can be processed through various image processing methods for performing different tasks required forvision systems. However, the required tasks may not be achieved if the obtained image is not a satisfactory one.Due to this reason, Google Maps Images of railway tracks from the thirdworld countries are used. In thePreprocessing phase, the input image is undergoes Noise Removal.The Noise Removed image is sharpened.Preprocessing is the major step in the processing of digital images as this enhances the quality of input acquired image. In pre-processing certain stepscan be performed.

The First Step is converting the image from C2G level. Means image isconverted into gray scale level. This converted gray scale image. The secondstep is noise removal. Averaging filtered produced the best result image for noise removal. The noisy removedimage becomes blurring and needs enhancement by means of sharpening.The reason for sharpening is that while noise removal some information becomes blur. In order to regain the information the image is sharpened.

VISyR[9] performsthis task by using Rail Detection and Tracking Block.In this it forecasts the position of the bolts along the ydirection. To reach this goal, it uses two kinds of search:

- Exhaustive search
- Jump search.

In the first kind of search, a window exhaustively slides on the areas ata (well-known) distance Dx from the rail location, until it finds contemporaneously (at the same y) the first occurrence of the left and of the right bolts.

At this point, it determines and stores this position (A) and continues in thisway until it finds the second occurrence of both the bolts (position B). Now,it calculates the distance along y between B and A (Dy) and the processswitches on the Jump search. In fact, as it is well known, the distance alongy between two adjacent sleepers is fixed. If, during the Jump search, VISyR doesnot find the bolts in the position where it expects them, then it stores theposition of fault (this is cause of alarm) in a log file and restarts the Exhaustive search.

2-D DWT Preprocessing: In pattern recognition, input images are generally pre-processed in order to extract their intrinsic features. The wavelet transform is a mathematical technique that decomposes a signal in the time domain by usingdilated/contracted and translated versions of a single finite duration basisfunction, called the prototype wavelet. This differs from traditional transforms (e.g., Fourier Transform, Cosine Transform, etc.), which use infiniteduration basis functions.Due to the discrete nature (both in time and amplitude) of most applications, different Discrete Wavelet Transforms (DWTs) have been proposedaccording to the nature of the signal, the time and the scaling parameters.

Haar DWT Preprocessing: Computationally, Haar Transform is a very simple DWT. Therefore, anycoefficient $H_{\_LL2(i,j)}$ can be computed in one step according to:

$$H_{\_LL2(i,j)}=1/16\sum_{l=0}^{l=3}\sum_{k=0}^{k=3}p(4i+k,4j+l)$$

Contrast Enhancement Method

Image enhancement techniques improve the quality of an image as perceivedby a human. These techniques are most useful because many satellite imageswhen examined on a color display give inadequate information for image interpretation. There is no conscious effort to improve the fidelity of the imagewith regard to some ideal form of the image. There exists a wide variety oftechniques for improving image quality. The contrast stretch, density slicing, edge enhancement, and spatial filtering are the more commonly usedtechniques.

Contrast enhancement is used to either increase the contrast of an image withlow dynamic range or to bring out image details that would be otherwise hidden. The enhanced image subjectively looks better than the original image asthe gray-level differences (i.e., the contrast) among objects and backgroundare increased. The conventional approach to enhance the contrast in an image is to manipulate the gray level of individual pixels.Global HistogramEqualization (GHE) uses an input-to-output mapping derived from the Cumulative Distribution Function (CDF)of the image histogram. AlthoughGHE utilizes the available gray scale of the image, it tends to

over enhancethe image if there are large peaks in the histogram, resulting in a harsh andnoisy appearance of the enhanced image. It does not always produce satisfactory enhancement for images with large spatial variation in contrast.Local Histogram Equalization (LHE) algorithms have been developed, toaddress the aforementioned problems. These algorithms use a small windowthat sequentially slides over every image pixel, and the histogram of pixels within the current position of the window is equalized. LHE sometimesover enhances some portion of the image and any noise and may produceundesirable checkerboard effects. Other algorithms that focus on improvingGHE can achieve satisfactory contrast enhancement, but the variation in thegray-level distribution may result in image degradation.

Thresholding is the process of partitioning pixels in the images into object and background classes based upon the relationship between the graylevel value of a pixel and a parameter called the threshold. Because of itsefficiency in performance and its simplicity in theory, thresholding techniqueshave been studied extensively and a large number of thresholding methodshave been published. Usually, automatic thresholding[13] approaches areclassified into two main groups: global and local. In global methods, a fixedthreshold is used for the whole image, whereas in local methods the threshold changes dynamically (local methods are often used when the backgroundis uneven due to the poor illumination condition) and the threshold valueis computed for each pixel on the basis of information contained in a localneighborhood of the pixel.

Spatial contrast enhancement[10] is one of the most populartechniques in image contrast enhancement.An algorithm based on local meanand variance in which each pixel is required to have a "desirable" local meanmd and a "desirable" local variance $v_d$such that

$$x_{i,j}= m_d+\frac{\sqrt{vd}}{v(i,j)}(x_{i,j}-m_{i,j})$$

where, $m_{(i,j)}$ and $v_{(i,j)}$are local mean and variance. It is easy to verify that thex_{1y} has a mean md and varianceV_d if we consider $m_{(i,j)}$and $v_{(i,j)}$ as the true mean and variance of $x_{(i,1)}$. The main drawback of this technique is that ittends to enhance subtle details at the expense of the principal features whichare lost in the process. The river like things in the original image and other large objects are difficult to recognize in the processed image.

Contrast Limited Adaptive Histogram Equalization[11] is an adaptive contrast enhancement method.It is based on adaptive histogram equalization, where thehistogram is calculated for the contextual region of the pixel. The pixel's intensity is thus transformed to a value within the display range proportional tothe pixel intensity rank in the local intensity histogram.The enhancement isthereby reduced in very uniform areas of image, which prevents over enhancement of noise and reduces the edge-shadowing effect of unlimited AHE.Theclip level of the histogram is the parameters of this method.According to [12] a simple geometrical approach based on graylevel histogram curve has been proposed to locate defects on smoothed rail headsurface image.

Defect Localizing Methodologies

A. Motivation of GLGHC

For locating rail defects efficiently, the following issues should be considered:

Robust to noise: There is still random noise existing on smoothed rail headsurface images, which has similar texture properties with defect. Image noisewill probably decrease detection performance. Consequently, the defect locating method should not be sensitive to noise.

Real-time processing: The number of rail image collections captured by camera is huge, thus fast defect locating method is needed.According to above issues, a statistical texture analysis method solelybased on first-order histogram statistics has been fully investigated. It considers the average intensity value of smoothed rail head surface image alongx or y axes represented as gray-level histogram, and it can eliminate thenegative effect of noise pixels in a certain extent. Then a simple geometricalcalculation is directly performed on the gray-level histogram curve to locatedefects, which is simple and effective.

B. Geometrical Defect Locating on Gray-level Histogram Curve

The gray-level histogram curve of smoothed rail head surface image inhorizontal direction is calculated as:

$$g_n=1/M\sum_{m=1}^{M} g_{mn} \; n\in[1,N]$$

where g_n represents the average gray value of the pixels in nth column of theimage, and g_{mn} represents the gray value of the pixel in mth row and nthcolumn of the image.

According to Adaptive Thresholding[11] during the defect identifying procedure, the gray residual feature of suspect defect region, fig , has to comparewith a threshold value in the cascade structure for filtering fake defects. Inorder to select optimal threshold value, an adaptive thresholding methodshould be concerned.According to [13]Automatic Threshold Selections, the Otsu method forselecting optimal image threshold. It showed the problem of using the Otsumethod in thresholding small defects in an image.Then presenting the valley emphasis method, a revised version of the Otsu method for detecting smallto large defects.

The Otsu Method

An image can be represented by a 2D gray-level intensity function f(x,y). The value of f(x, y) is the gray-level, ranging from 0 to L-1, where L isthe number of distinct gray-levels. The Otsu method works well when theimages to be threshold have clear peaks and valleys. For the defect detection applications, defects range from small defects to large defects. The desired threshold should be the value that separates thesmall contaminant from the background. However, the Otsu method givesthe incorrect threshold value that fails to isolate the contaminant.

The Valley-Emphasis Method

The objective of automatic thresholding is to find the valley in the histogram that separates the foreground from the background. The important observation here is that the probabilityof occurrence at the threshold value (pt) has to be small.With this observation in mind, it’s proposed a method to improve theOtsu method for selecting threshold values. It is called the valley-emphasismethod. The idea of the valley-emphasis method is to select a thresholdvalue that has small probability of occurrence (valley in the gray-level histogram), and it also maximizes the between group variance, as in the Otsumethod.The key of the valley-emphasis formulation is to apply a weight, to Otsu threshold calculation. The smaller the pt value, the larger the weightwill be. This weight ensures that the result threshold value will always be avalue resides at the valley or bottom rim of the gray-level distribution. Using the valley-emphasis method on the contamination application, were itsable to find the correct threshold value that isolates the contaminant in thetest image.

Based on certain considerations of railhead, LN method can be inspired. Supposing a wxh window W, and arelated pixel (x, y), the intensity of the pixel is transformed by

$$L(x,y)=\frac{\left(F(x,y)-E(x',y')\right)}{var\left(F(x',y')\right)},(x',y')\in W$$

where E(.) is the mean of F(x',y') in W and Var(.) is the correspondingstandard variance. Note that a small constant is added to the variance inimplementation in order to avoid dividing by zero. The transformed imageL is called local normalized image (LNI). LNI has the following properties,which will be of benefit to defect detection.Therefore those mentioned methods are less reliable than local normalization enhancement.This review paper also incorporatesa system to indicate the location of the defect, so that it can be easily be rectified.

Image segmentation is the key step of the process from image processingto image analysis. The quality of segmentation effect influences the follow-upanalysis of the images directly. Therefore accurate segmentation of image isvery essential. The purpose of image segmentation is to divide the image into a number of significant regions based on some characteristics (intensityinhomogeneities here), making these characteristics to display similarity insingle region and display difference between different regions. In the processof detecting defects in glass, region based active contour model in a variational level set formulation has been implemented for segmentation whichuses intensity inhomogeneity as a region descriptor to identify the region ofinterest that is to be segmented.

A time consuming procedure was improved by Pizer with his adaptive histogramequalization technique. In this method, the local histogram is calculatedonly at a number of sample points, which are distributed equally about theimage. The new pixel value at each point is then a bilinear interpolation ofthe four nearest sample points.A method developed in VIS for discrete surface defects of rail heads is Local Normalization method for contrast enhancement of rail images. This method is nonlinear and illumination independent, so it is ableto overcome the challenges: illumination inequality and the variation of reflection property of rail surfaces. In addition,DLBP algorithmto locate defects in a normalized image. DLBP is based on local gray-leveldistribution and robust to noise. I thoroughly analyze the parameters of VISand compare the LN method and DLBP algorithm with the related classicmethodologies.VIS basically comprises three parts namely image acquisition system,contrast enhancement system and a defect localization system. With thehelp of these subsystems a VIS can effectively detect a surface defect. Imageacquisition system acquires the rail image which is further enhanced using acontrast enhancement method and finally the defect is localized by a defectlocalization method. As a consequence in DLBP, the mean of gray value on a transversal line will besmall if the line crosses a defect. Similarly, the mean on a longitudinal line ina local window will also be small if the line passes through a defect, thereby cropping out the defected area from image.

IV. CONCLUSION

Railway inspection is a important challenge in real time, rail defects have to be inspected more keenly for safety. Many hardware equipped methods were implemented existingily. Ultrasonic sound detection and eddy current methods are some of them. Even trains already equipped with ultrasound,had additional advanced eddy current techniques installed. Recently a newRIT was equipped with a system that was designed toemploy a combination of these two techniques for non-destructive rail inspection. The problem for them is that they have a complex network to be attached and high cost. The lag caused by them could also be improved if image processing techniques are used. VISyR is a patent pendingreal time Visual Inspection System for Railway maintenance. It’s very fast with a linear computational timecomplexity. It can acquire images from a digital line scan camera.ViSyRachieves impressive performance in terms of inspection velocity. Data aresimultaneously preprocessed and then it cuts the subimage of rail track bythe track extraction algorithm. Subsequently, different enhancement methods can be used. VIS enhances the contrast ofthe rail image.Different contrast enhancement methods are used for different application which can be imported and finally localizes the defect. DLBP algorithm to locate defects in a normalizedimage can be better than GHE and CLAHE.It can be in real time to runon a 216-km/h placed under test trains.DLBP is based on local gray-leveldistribution and robust to noise.

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