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Intelligent Image-Processing for Crack Detection on Rail Surface

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ABSTRACT- Rail inspection is an essential task in railway maintenance. It is periodically needed for preventing dangerous situations and ensuring safety in railways. Currently, most of the inspections are manual and are conducted visually by railroad track inspectors. Inspections include detecting defects on rail. This work presents a vision-based technique to automatically detect the presence of a defect on rail surface. The system uses acquired digital images of rail. An intelligent image-processing algorithm capable of detecting defect on rail surface is the used to achieve hig performance automated detection. Various algorithms related to morphological operations, edge detection, thresholding, segmentation and feature extraction are applied for processing the images of rail surface defect and cracks. For better speed and accuracy, the algorithm was implemented on Matlab.
KEYWORD: Rolling contact Fatique, Visual Inspection System, SR.

INTRODUCTION

Railway networks are among the major ways to release traffic congestion in urban areas. Though, due to effects such as aging, thermal expansion and contraction, human damage, and topographic change, railway tracks suffer from breaks in their surfaces and internal structures. These split and slender defects are generally known as cracks, which reflect on the health of the railway tracks. Appropriate and accurate management of railway tracks is essential for the maintenance of the rail structures and stoppage of accidents. An additional important motivation of carrying out inspections and detections on railways is to lower the infrastructure and rolling stock maintenance costs that still form a main fraction of the total operation cost of the rail transformation systems. The massive reductions that occurred over some years back in many countries has really contributed to their economy which largely made inspection and detection systems more powerful and useful. Also, decrease in maintenance budgets in some countries of railways has led to the growth of the frequency of hazardous defects and that will cost them much more when trying to maintain the hazardous defects.

Based on Magel et al (2005), the problem of rolling contact fatigue (RCF) in rail that comprises of head checks, shelling, squats on the rail surface and deep-seated shell on subsurface developed both domestically and internationally around the 1990s, and came to worldwide notice through the loss of life in the Hatfield (UK) derailment that occurred in 2000. From FRA statistics, within eight years from 1995 to 2002, rolling contact fatigue (RCF) was powerfully involved in 122 derailments, and may have added 160 more. Network rail describes that certain parts of track rail steel are subjected to bending moments and impact forces, while rail head material is governed by compressive loading and sliding forces within a comparatively small contact patch known to result in wear and rolling contact fatigue (RCF) damage.

Martin and Tosunoglu, (2000) said that in some few decades back, experienced inspectors have done inspection of cracks on rails manually, which is not adequately accurate. Consequently, the development of an automatic crack detection and classification technique is the only way to solve this problem, which uses image-processing techniques. To be efficient, image-processing techniques used should be able to provide high detection rate and accurateness. Some of the image-processing techniques that are suitable in detection of cracks in rail are: Morphological image processing technique, image thresholding, segmentation technique, feature extraction technique, color based processing technique, shape based processing technique, edge detection technique, etc. the implementation of machine vision and image processing algorithms are succeeded using a very competent and dependable computer software packages (platforms), which are MATLAB, OpenCV library in C/C++, etc.

LITERATURE REVIEW

Bello et al (2016) proposed a paper on the development of an intelligent image-processing algorithm capable of detecting fatigue defects from image of the rail surface. The algorithm generates statistical data such as total number of defects per image. Adaptive histogram equalization was used for the local contrast enhancement so the defect regions are clearly visible. Then an adaptive thresholding was applied to segment the defects.

A more robust visual inspection system (VIS) was described by Quingyoung et al (2012), it focused on the local contrast enhancement in addition to segmentation by thresholding algorithm. However, feature extraction of detected defects was not investigated.

Jyoth, and Gimy, (2014) presented a paper on VIS based contrast enhancement, projection profile of the mean intensity of each transversal and longitudinal line pair forming a suspect rectangle (SR) was described. Defects were segmented using threshloding algorithm. The method is capable of only extracting the longitudinal and transverse positions of defected defects.

Muhammad, et al (2001) proposed a paper on defects inspection method based on computer vision system on railroad tracks, work that centers on the analysis of railroad track surface to detect diverse kinds of problems to avoid any kind of possible accidents. The paper centers on detecting defects on railroad tracks, which are:

i. Crack detection
ii. Object detection
iii. Detection of rail head spalling

The images of the railroad track surface were taken by CCD camera in a very high frame rate then the image was processed using different softwares to remove the defects and also parameter computation. The diverse image processing algorithms that was applied in the images of the railroad track defects and cracks are de-noising, filtering, thresholding segmentation and feature extraction which is regularly implemented on computer. These were developed on diverse embedded platforms like MATLAB and C++, which use the openCV library.

Liu (2010) proposed a rail surface defects inspection method centered on automated machine vision system. The main focus of the paper was on two different types of defects on rail surface, which are spalling of the railhead and cracks in the surface. The image processing algorithms used for the processing of images of rail surface defects are de-noising, image segmentation and feature extraction. Then dynamic thresholding and feature matching were applied to extract and recognize region of defect correctly. At the end, percentage of wear of railhead and length of cracks in the rail surface were calculated. The adaptability of algorithm required to be proved by processing more images next.

Zhang (2014) wrote a paper that emphasis on automatic crack detection and classification method for subway tunnel safety monitoring. General cracks are a fundamental indicator for the safety status of an infrastructure. Based on the paper, high-speed complementary metal-oxide-semiconductor (CMOS) industrial camera was utilized to capture and store the tunnel surface. Then morphological techniques of image processing and thresholding operations are used to segment the local dark areas with potential crack defects from the original gray-scale images. In the feature extraction process, a distance histogram based shape detector is used to define the shape difference amid cracks and other irrelevant objects. And it is developed for achieving high performance in the subsequent aspects, detection rate, and detection accuracy and detection efficiency.

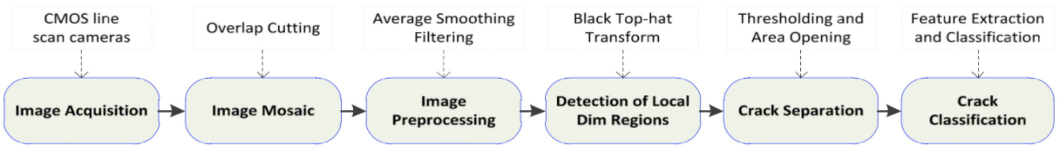

Figure 1: flowchart of the proposed approach (Zhang W. 2014)

Deutschi (2004) proposed a new vison-based inspection technique for rail surface defects. This method really can substitute visual inspections with an automatic inspection system. Color line-scan cameras and a special image acquisition method, which is usually called Spectral Image Differencing

Procedure (SIDP) permit the automatic 3D detection of defects on rail surfaces for example crack, break-offs, flakes, grooves by the methods of image processing. Image enhancement with more emphasis on illumination method is made on shading correction computed based on nonlinear differential function, scale enables differentiating among cavity or elevation type of defects.

I. DEVELOPMENT OF IMAGE PROCESSING ALGORITHMS FOR CRACK DETECTION ON RAIL

The image proposes to be used in this paper is shown in the Figure below.

Figure 2: shows the image of the cracked rail to be used for the analysis

METHODOLOGY

The Image Processing Techniques used for designing the algorithm for crack detection and length measurement on rail are:

Cheng, et al (2010) presents a paper for visualization of damaged rail, in which the damage has been recognized using wavelet transform. The paper focuses on general identification of rail damage. The paper follows the method of finite element analysis (FEA) simulation of intact and damaged rail, to identify displacement mode difference. Wavelet transform applied to the displacement mode difference and wavelet coefficients are used to specify damage. The damage detection results are visualized through volume visualization method.

Description and Justification of the Image-Processing Algorithm (Methodology)

RGB to gray scale image:

Based on Kanan and Cottrell, (2012) the reason for applying this function is to convert the true color image, which is the RGB image to a gray scale intensity image, the function of this is to eliminate the hue and saturation information on the image while retaining the illuminance.

Gray scale to black and white image:

The reason for applying this function is in order to find the region of interest, the portions of the image that is of interest for further processing. The intension is binary; “yes” means the pixel is of interest while “no” means the pixel is not of interest.

Edge detection (prewitt):

Based on Maini and Aggarwal, 2009, and Maar and Hildreth (1980), we decided to apply edge detection (prewitt) to the black and white image because edge detection is regarded as the initial step in object recognition. Edge detection refers to the process of identifying and locating sharp discontinuities in an image. Discontinuities are abrupt changes in pixel intensity, which characterize the boundaries of objects in a scene.

$$M(x,y) = \sqrt{I_x^1(x,y)^2 + I_y^1(x,y)^2} \qquad (1)$$

The Infinite Symmetric Exponential Filter uses another optimization function to find the edge in an image and it can be written as follows:

$$C_N^2 = \frac{4\int_0^\infty f^2(x)dx.\int_0^\infty f'^2(x)dx}{f^4(0)} \qquad (2)$$

C_N will be reduced with an optimal smoothing filter for an edge detector. It can be called symmetric exponential filter (ISEF):

$$f(x) = \frac{P}{2}e^{-p|x|} \qquad 1D \qquad (3)$$

$$f(x,y) = a.e^{-p(|x|+|y|)} \qquad 2D \qquad (4)$$

The filter from the ISEF Edge Detector is given as one-dimensional recursive filter. By assuming the 2D-filter function real and continuous, it can be given as below:

$$f[i,j] = \frac{(1-b)b^{|x|+|y|}}{1+b} \qquad (5)$$

Using recursive filter speeds up the convolution. b Can be entered by the user.

Morphological operation dilation:

Based on Ledda, (2007), I decided to apply morphological operator dilation after the edge detection basically to gradually enlarge the boundaries of the foreground pixels that is the white pixels. Thus are area of the white pixels grow in size while holes within those regions becomes smaller.

Morphological operation dilation is defined as follows;

$$A \oplus B = \{c = a + b \ for\ some\ a \ \in b \ \in B\} \qquad (6)$$

Dilation is also associtive and also commutative

$$(A \oplus B) \oplus C = A \oplus (B \oplus C) \qquad (7)$$

Morphological operation erosion:

Based on Ledda, (2007), we then applied morphological operator erosion so that the function erosion will shrink the enlarged boundaries of the foreground pixels, which are the white pixels. That makes the boundaries slimmer which is more accurate. The whole idea from the application of morphological operators' dilation and erosion is to improve the quality of the edge detection, which was done and a better result was achieved.

Morphological erosion can be defined as given below:

$$A \ominus B = \{x + b \in A \ for\ every\ b \ \in B\} \qquad (8)$$

Unlike dilation, erosion is not commutative. Much like how addition is commutative whereas subtractive is not. And again, also unlike dilation, erosion is not associative.

$$(A \ominus B) \ominus C = A \ominus (B \ominus C) \qquad (9)$$

Implementation of the Developed Algorithm on Matlab to Analyze Cracks on Rail Surface

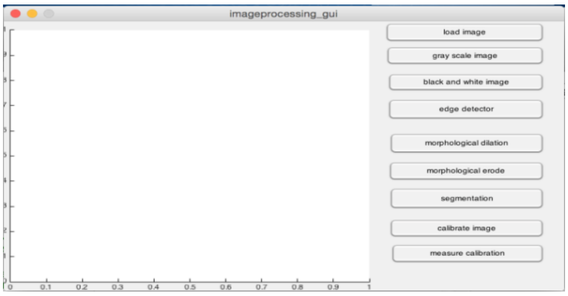

Figure 3: A blank GUI before loading an image

Step 1: Load an image into the workspace.

This step involves using the imread command to load an image into the workspace. It reads the rail crack image stored in the toolbox as shown in the Figure below.

Segmentation:

Image segmentation technique is applied in order to divide the image into regions or categories, which correspond to different parts of the image. Every pixel in the same category have similar greyscale of multivariate values and form a connected region, while neighboring pixels which are in a different category have dissimilar value, which also form a connected region as well.

Calibrating image:

The main aim is to calculate the length of the crack in millimeter, but Matlab gives measured length in pixels. The length of the railhead in millimeter is known which is 72mm while the length of the railhead in pixel can easily be measured on Matlab, which I did. Using mathematics, I related the two to find my unknown, which is the length of the crack in millimeter.

Measure calibration:

The length of the crack in length is calculated in millimeter and also displayed on the screen.

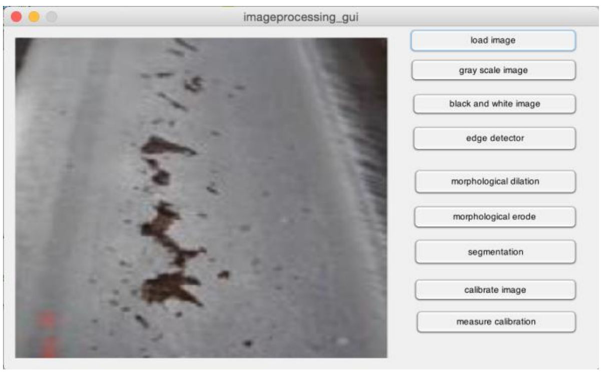

Figure 4: An image loaded on the GUI

Step 2: conversion from RGB to grayscale image.

A grayscale image sometimes called gray-scale, gray scale, or gray-level is a data matrix whose values represent intensities within some certain range. MATLAB saves a grayscale image as an individual matrix,

and every element of the matrix corresponding to one image pixel, as shown in the Figure below.

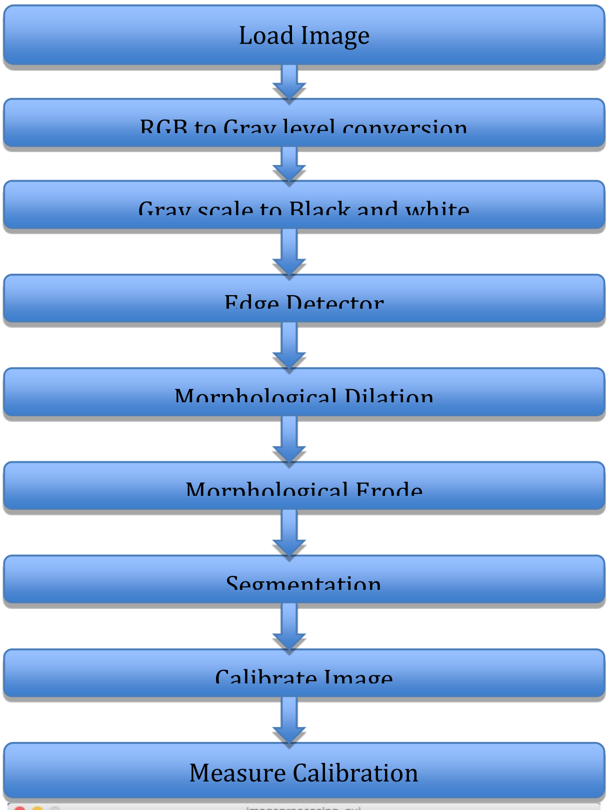

Figure 5: A grayscale image

Step 3: Conversion of the processed image to binary image (black and white).

Creating a binary version of the processed image so toolbox function for analysis is been used, as shown in the Figure below.

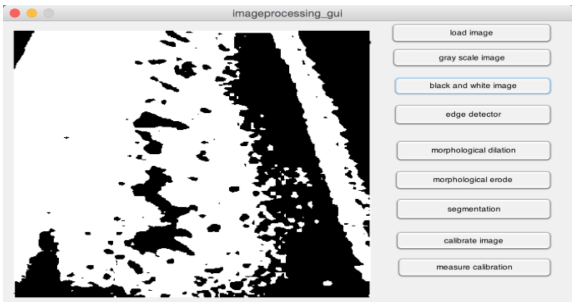

Figure 6: A black and white image

Step 4: Applying edge detector to the processed binary image (black and white).

In an image, an edge is said to be a curve that follows a path of quick change in image intensity. Edges are normally associated with the boundaries of objects in a scene. Edge detection is utilized to locate the edges in an image, as shown in the Figure below.

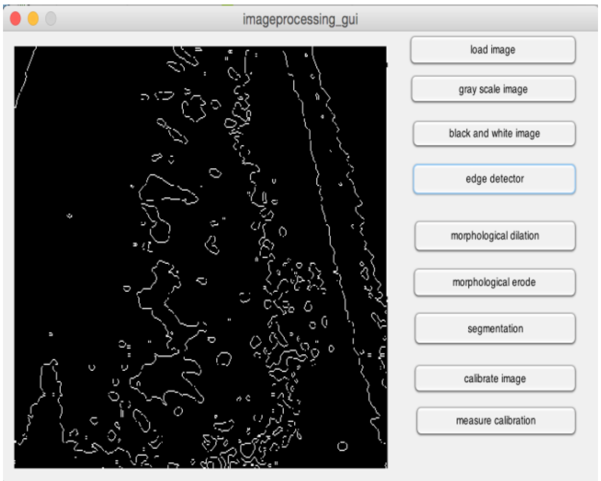

Figure 7: An edge detector applied to the image

Step 5: Applying morphological dilation to the edge-detected image.

Dilation involves the addition of pixels to the boundaries of the objects in the image, as shown in the Figure below.

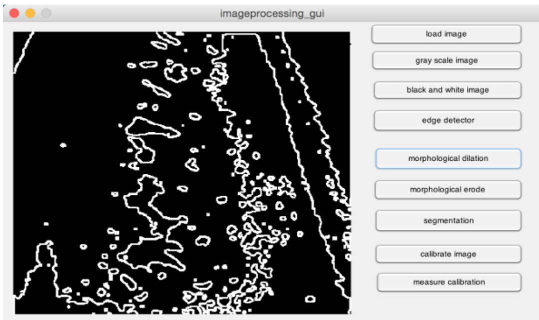

Figure 8: A morphological dilation applied to the image

Step 6: Applying morphological erosion (erode) to the edge-detected image.

While in the other hand erosion involves the removal of pixels on the object boundaries of the image, as shown in the Figure below.

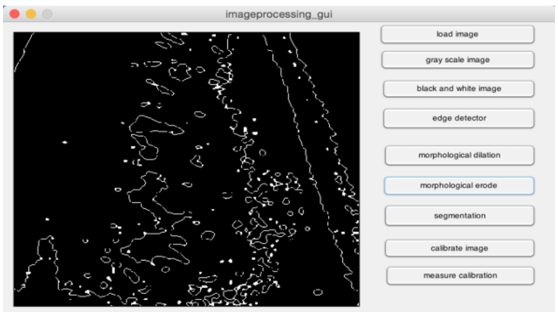

Figure 9: A morphological erode applied to an image

Step 7: Applying segmentation to the eroded image.

Image segmentation is the process of dividing an image into 2 different parts or regions. This division into two parts is often based on the characteristics of the pixels in the image, as shown in the Figure10.

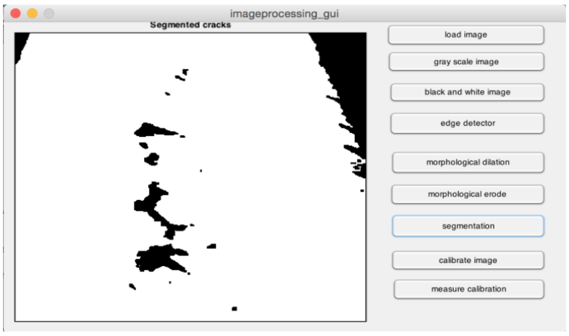

Figure 10: A segmentation done on the image

Step 8: Calibration of the image
Cropping.
To remove a rectangular portion of an image, the imcrop function is used. Using imcrop, the crop region can be specified interactively using the mouse or programmatically by identifying the size and position of the crop area, as shown in the Figure11.

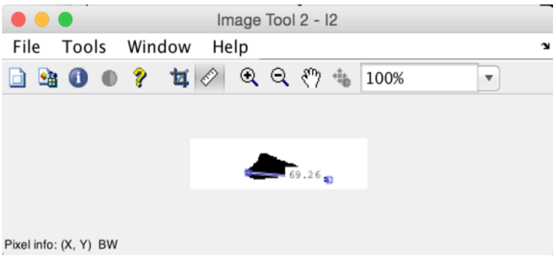

Figure 11: An image calibration

Step 9: Measuring the image in pixels.
The length of the crack of interest is measured to be 69.26 pixels, as shown in the Figure below.

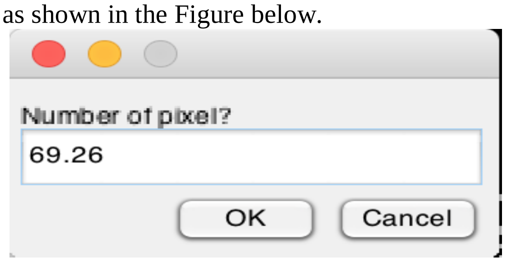

Figure 12: Measured crack length in pixel

Step 10: Converting the measured length in pixels to millimeter (mm).
The measured length in pixels is then converted to millimeter (mm), as shown in the Figure13.

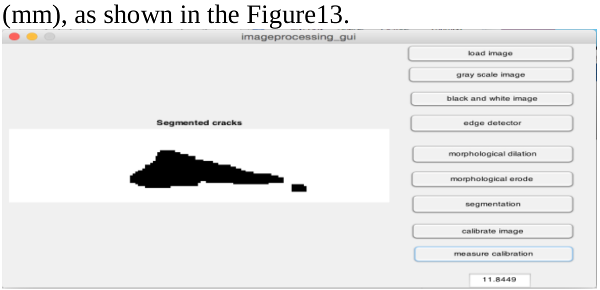

Figure 13: Measured crack length in millimeter (mm)

CONCLUSION

The aim of this paper has been achieved which involves developing an intelligent image processing technique that is able to detect fatigue defects on the image of a rail surface and thereby measuring the length of the detected defect.
In this paper, a surface rail defect has been considered for the detection because most of the rail incidents that occur are due to bad condition of the rail surface defects. In doing so, based on the wide literature review on the different image-processing techniques used for defect detection on general surface and also on rail surface, an intelligent image processing algorithm was developed capable of detecting defects on rail surface, some of the image processing techniques used are edge detection technique, morphological operations (dilation and erosion) techniques, segmentation techniques etc.

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