

Computer-Vision Based Visual Inspection and Crack Detection of Railroad Tracks

Mohammad Farukh Hashmi¹, Avinash G. Keskar²

^{1,2}Department of Electronics Engineering

^{1,2}Visvesvaraya National Institute of Technology, Nagpur, India

farooq78699@gmail.com, agkeskar@ece.vnit.ac.in

Abstract-Surface analysis is a very important measurement for track maintenance for Railroad Tracks, because deviations in surface geometry indicate where potential defects may exist. A rail surface defects inspection method based on computer vision system is proposed in the paper. Various algorithms related denoising, filtering, thresholding; segmentation and feature extraction are applied for processing the images of Railroad surface defect and cracks. It has mostly been implemented on computers. For better speed and complexity, the algorithms need to be implemented on embedded platforms. These methods were designed for different software setups, namely MATLAB and C++ using the Intel OpenCV library. Then accurate region of Interest in respective to defect is extracted and recognized by adaptive thresholding and feature matching methods. Percentage of wear of rail head and length of cracks in surface are calculated next as an evaluation of flaw on inspected rail head section. Experimental results of the proposed algorithms are presented in the results sections along with bench marking with software algorithms.

Keywords- OpenCV, Track Inspection, Dynamic Threshold, Computer Vision, Optimal Thresholding.

I. INTRODUCTION

The incidence of railway accidents in our country is greater as compared to other countries of the world. Accidents occur due to the errors and negligence of the employees. Many high speed and heavy railways have been built and applied in recent years. The reliability of railway tracks needs to be paid more attention than before. In the past, majority of rail problems were attributed primarily to the propagation of internal defects in the rail web and head due to fatigue and excessive wear. As some advanced manufacturing technology were introduced, such as higher carbon steels and cleaner steel-making processes, the probability of inner defects reduced a lot.

Rail failures caused by surface defects in the rail head have become much more common within the rail industry these days. Surface defects can be distinguished into following types:

- a) The cracks in the rail surface and the rolling contact fatigue damage which have occurred due to high stresses and resistance. In most cases, cracks grow out of some internal defects and can be defined as severe damage directly.
- b) The main two kinds of rolling contact fatigue damage, including spalling of rail head and rail corrugation, are also of great significance to the track inspection [15, 16].

Experiments have shown that the rolling contact fatigue damage could exert a negative effect on ultrasonic rail track inspection and moreover, corrugation of rail is able to expand downward and turn into some more threatening flaws, such as nucleus flaw [2]. A machine vision system is being developed to automate, or enhance the visual inspection of track and track components [4]. Machine vision algorithms are being designed to recognize track components, identify their proper location and condition, and detect and quantify the extent of the defects found. Automated vision systems are typically used to measure the rail profile and calculate the percentage of wear of the rail head [1, 3].

The primary focus of this research is inspection of Indian railroad mainline and siding tracks, as these generally experience the highest traffic densities. Although the primary focus of this research is the inspection of high-density track, algorithms are also being tested on lower track classes to ensure robustness to component variability and condition. The algorithms currently under development will also be adaptable to many types of track and track components [9]. These interim solutions include video capture using vehicle-mounted cameras, image enhancement using image processing software, and assist the system automatically using various vision based algorithms [8, 17].

In this paper, the continuous images of rail track surface acquired by CCD camera in a high frame rate is taken and the image is processed using various software's to extract the defects, and other purposes like parameters computation, and information extraction using a personal computer. If the defects found are negligible, tracks need not be replaced whereas in the case of considerable amount of crack or wear in the railway track, immediate action needs to be taken. Using the information of the defects found, tracks can be replaced in time and many railway accidents can be avoided.

II. SYSTEM OVERVIEW

Railway applications of computer-vision technology that were previously developed have three main components is shown in Figure 1. The first component of this system is the image acquisition system, in which digital cameras are used to capture the video or images in the visible or infrared spectrum [4, 14]. The next element is the

image analysis system, where the images or videos are processed using computer-vision or image processing based algorithms that identify specific parts of interest and assess the condition of the detected parts [5, 7]. The final element is the data analysis system or embedded processing hardware, which compares and verifies whether or not the condition of track features or mechanical components comply with parameters specified by the individual railroad tracks. Finally the data is transported to embedded Image processing system [8, 17].

The work of image processing algorithms which finished in embedded system consists of three main parts. First, some pre-processing should be used to acquire the original image. Then finally apply the designed algorithm for selecting the region of interest and extract all valuable defects from the processed images. At last, required features of defects are computed and classified for calculating evaluation of defects on the target rail track section [6]. Block Diagram of Vision based Railroad Detection/Inspection System is shown in Fig. 1.

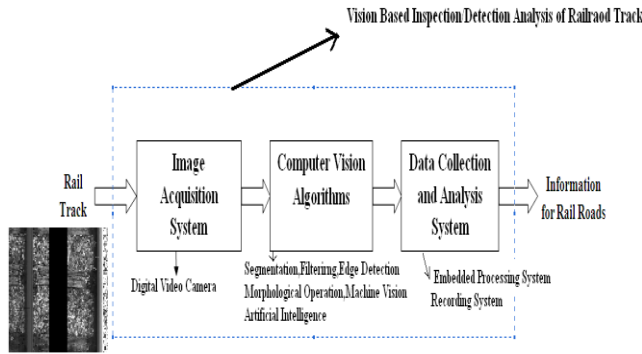


Figure 1. Block Diagram of Vision based Railroad Detection/Inspection System

III. METHODS AND MATERIALS

A. Thresholding

Gray-level thresholding is the simplest segmentation process. Many objects or images regions are categorized by constant reflectivity or light absorption of their surfaces; a brightness constant or threshold can be determined to segment objects and background. Thresholding is computationally inexpensive and fast-it is the oldest segmentation method and it still widely used in simple applications; thresholding can easily be done in real time using specialized hardware [10, 11].

A complete segmentation of a Railroad image R is a finite set of regions R_1, \dots, R_s ,

$$\bigcap_{i=1}^s Ri \quad Ri \cap Rj = 0, \quad i \neq j. \quad (1)$$

Complete segmentation can result from thresholding in simple process. Thresholding is the transformation of an

input image f to an output (segmented) binary image g as follows:

$$g(i, j) = 1 \quad \text{for } f(i, j) \geq T \\ = 0 \quad \text{for } f(i, j) < T \quad (2)$$

Where T is the threshold $g(i,j)=1$ for image elements of objects, and $g(i,j)=0$ for image elements of the background (for vice versa).

Algorithm-1: Basic Thresholding

Search all the pixels $f(i, j)$ of the image. An image element $g(i, j)$ of the segmented image is an object pixel if $f(i, j) \geq T$, and is a background pixel otherwise [11].

Segmentation using variable thresholds (also called adaptive thresholding), in which the threshold value varies over the image as a function of local image characteristics, can produce the solution in these cases.

A global threshold is determined from the whole Railroad image f :

$$T = T(f) \quad (3)$$

On the other hand, local thresholds are position dependent

$$T = T(f, f_c), \quad (4)$$

Where f_c is that image part in which the threshold is determined.

B. Optimal Thresholding

Methods based on approximation of the histogram of an image using a weighted sum of two or more probability densities with normal distribution represent a different approach called optimal thresholding [11].

Algorithm -2: Iterative (optimal) threshold selection

1. Assuming no knowledge about the exact location, consider as a first approximation that the four corners of the image contain background pixels only and the remainder contains object pixels.

2. A step t ,

$$\mu_B^t = \frac{\sum_{(i,j) \in \text{background}} f(i, j)}{\#\text{background_pixels}},$$

$$\mu_O^t = \frac{\sum_{(i,j) \in \text{objects}} f(i, j)}{\#\text{objects_pixels}},$$

3. Set $T^{(i+1)} = \frac{\mu_B^t + \mu_O^t}{2}$

$T^{(i+1)}$ now provides an upward background-object distinction

4. If $T^{(i+1)} = T^{(t)}$, halt; otherwise return to step 2.

This method performs well under a large variety of Railroad image contrast conditions.

A combination of optimal and adaptive thresholding (equation) was used for Railroad images segmentation from cracks of Tracks image data. The method determines optimal gray-level segmentation parameters in local sub-regions for which local histograms are constructed.

C. Morphological Analysis

a) Dilation

Mathematical Morphology is one of the most productive areas in image processing. The content of mathematical morphology is based on set theory [10, 11].

The morphological transformation dilation \oplus combines two sets using vector addition (or Minkowski set addition e.g. $(a,b)+(c,d)=(a+c,b+d)$). The dilation $X \oplus B$ is the point set of all possible vector additions of pairs of elements, one from each of the sets X and B .

$$X \oplus B = \{p \in \mathcal{E}^2 : p = x + b, x \in X \text{ and } b \in B\} \quad (5)$$

Dilation with an isotropic 3x3 structuring element might be described as a transformation which changes all background pixels neighbouring the object to object pixels.

Dilation is an increasing transformation:

$$\text{If } X \subseteq Y \text{ then } X \oplus B \subseteq Y \oplus B \quad (6)$$

b) Erosion

Erosion \ominus combines two sets using vector subtraction of set elements and is the dual operator of dilation. Neither erosion nor dilation is an invertible transformation

$$X \ominus B = \{p \in \mathcal{E}^2 : p = x + b, x \in X \text{ for every } b \in B\} \quad (7)$$

The formula says that every point p from the image is tested; the result of the erosion is given by those points p for which all possible $p+b$ are in X .

Erosion is used to simplify the structure of an object-object or their parts with width equal to one will disappear. It might thus decompose complicated objects into several simpler ones.

And like dilation, is an increasing transformation:

$$\text{If } X \subseteq Y \text{ then } X \ominus B \subseteq Y \ominus B \quad (8)$$

c) Opening and Closing

Erosion and dilation are not inverse transformations, if an image is eroded and then dilated, the original image is not re-obtained. Instead, the result is a simplified and less detailed version of the original image [10, 11].

Erosion followed by dilation creates an important morphological transformation called opening. The opening of an image X by the structuring elements B is denoted by $X \circ B$ and is defined as

$$X \circ B = (X \ominus B) \oplus B \quad (9)$$

Dilation followed by erosion is called closing. The closing of an image X by the structuring element B is denoted by $X \bullet B$ and is defined as

$$X \bullet B = (X \oplus B) \ominus B \quad (10)$$

IV. PROPOSED METHODOLOGY

Rail inspection is the practice of examining rail tracks for flaws that could lead to catastrophic failures. The proposed work is based on analysis of railway track surface to detect various problems to avoid any kind of possible accidents as these days most of the accidents in railways are happening due to railway track surface defects. This

proposed work successfully helps in determining some kind of track defects which are:

A. Crack detection

Rail crack is a kind of severe damage which will lead to rail track fracture. Timely detection of crack in the rail track is crucial for the safety of railway transportation. Avoiding this problem may cause accidents as well as the might become larger. In this work, an image of the track is taken and is processed in MATLAB to detect the crack. The image is divided into horizontal strips (for profiling) and vertical columns, such that one point from each strip belongs to a column. An image profile is then taken along a strip of the image and is checked if there is any crack. However there are some cracks in the railway track profile that cannot be detected through software simulation due to surface irregularities and noise.

B. Object detection

The railway tracks must be smooth and should not have any obstacles on them. A stray rock or any object on the railway track can scratch, wear and damage the railway track as well as the railway wheels and can even cause major accidents. In this work, the unwanted objects on the railway track are detected using frame differencing method. Detection of object on the railway track in advance, can avoid accidents by removing the object from the track before the train arrives. It can also avoid suicide problems on railway tracks by detecting human on the track and alarming the railway station about the problem.

C. Detection of Rail head Spalling

The spalling of rail head, widespread over rail track in service, is able to increase noise and instability of fast moving trains. Failure to detect this problem in time causes increase of the track wear. If the amount of spalling is large, it may lead to accidents as well. In this work, an image of the track is taken and is processed using MATLAB as well as OpenCV [12]. The exact amount of track wear is obtained and the percentage area of wear is also calculated. In this paper, the continuous images of rail track surface acquired by CCD camera in a high frame rate is taken and the image is processed using various software's to extract the defects, and other purposes like parameters computation, and information extraction using a personal computer. The proposed work uses visual inspection to determine defects in the rail surface. Two different platforms (OpenCV and MATLAB) are tried for software simulation [13, 18].

V. EXPERIMENTAL RESULTS

A. Inspection of rail head spalling using OpenCV

The spalling of rail head i.e. upper surface of the rail track, widespread over rail track, is able to increase noise and instability of fast moving train. Information about percentage of wear of rail track is very useful which can be acquired from the area of spalling. The objective of image processing is to extract regions of wear, then get some valuable features belong to those regions and compute the

results. This has been implemented using MATLAB and embedded C language using OpenCV functions [12, 13]. The image processed and used in this paper is shown in the following Fig .2.



Figure 2. Railway track with spalling

Algorithm:

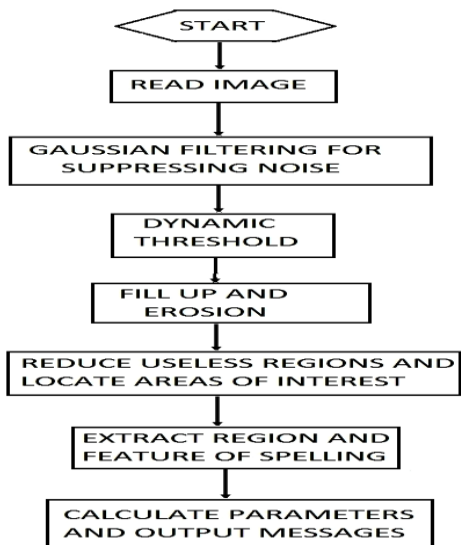


Figure 3. Proposed Flow chart of Track wears examination

Images of spalling and wear on the railway track are taken and it is processed using OpenCV library functions [18] with the method shown in the above flowchart given Fig. 3. The application of Gaussian filter suppresses noise in the image and obtains a foggy image meanwhile. The foggy image will be used as a local background in the operation of dynamic threshold next. Filter is designed in such a way and of suitable size so that it is ensured that all local structures are eliminated by the smoothing, and hence to better suppress noise in the segmentation. The image of railway track surface is always influenced by many factors such as in homogeneous illumination and motion speed difference. Typical threshold operation based on gray value histogram of the image cannot fulfill requests anymore. It can be seen that the defects and wear of interest can be characterized by being locally brighter or darker than their local background. Therefore, instead of specifying global thresholds or using multiple thresholds, the work changes to specify by how much a pixel must be brighter or darker than its local

background. The dynamic threshold with local background estimated by the mean filter is superior to other methods. Information about defects shows clearly and the edges-effect is suppressed a lot too.

It is observed that there are many little holes in connected regions and some regions are linked by just a few pixels. Relative algorithms need to be employed to avoid having influence on the following operation. First find the holes inside and fill it up. Then select proper structuring element of erosion to separate two regions if their connection is very small. At the same time, single tiny regions including several pixels caused by noise are eliminated. The next step is to reduce useless region in the binary image and locate regions of interest. All the connected regions are extracted and some feature parameters are computed. After analyzed from the processed image, it is found that the width of region is able to be used to remove the two long borders. One other point needs to be mentioned is the computation of rail head surface area. Two regions of borders have been recognized, so the area between them is able to stand for the total area of rail surface and the value will be applied for the following calculation. After locating area of interest i.e. rail head spalling area, edge detection of these areas is done followed by area calculation of the wear included in these edges. Percentage wear area is also calculated [1]. Results obtained for rail head wear detection are shown in Fig. 4.

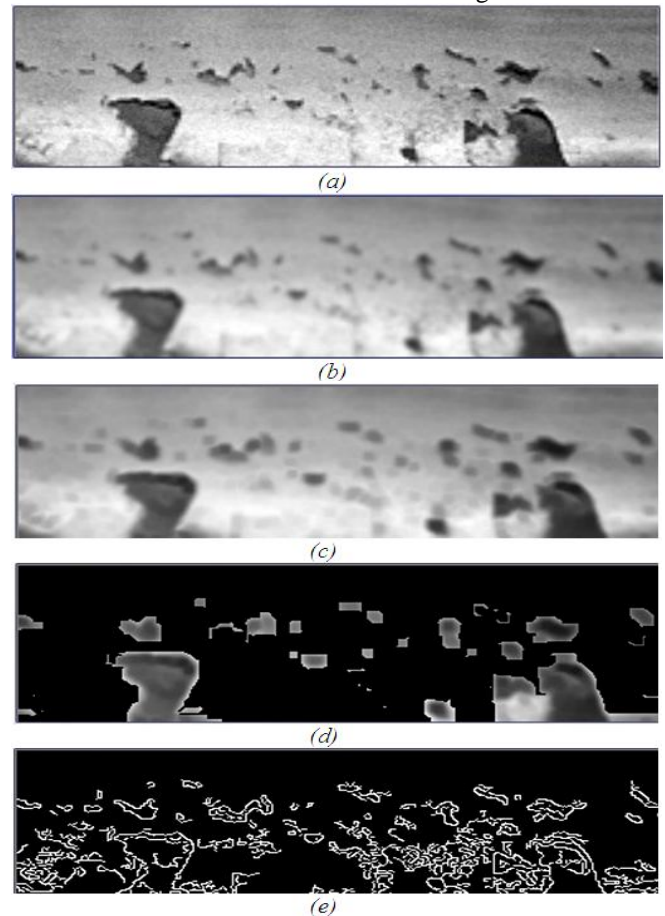


Figure 4. Results obtained for rail head wear detection: (a) source image, (b) filtered image, (c) eroded image, (d) image obtained after thresholding, (e) image showing edges of wear area, (f) final image showing track wear.

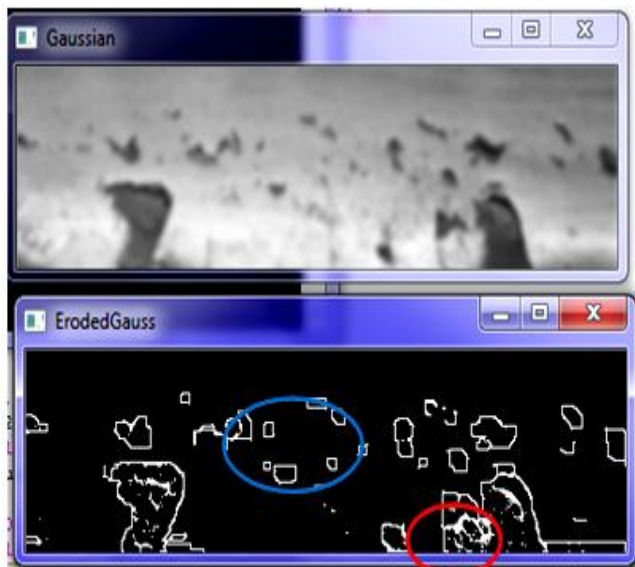
The percentage of wear calculated the given image comes out to be 9.229737. The time required to calculate the surface wear area is 0.535 seconds.

B. Selection of suitable filter and Thresholding :

The current module required the selection of a filter which would clear out the noise (granular) present on the rail track image and would smoothen the overall image without affecting any of the spalled zones. Both the Gaussian and Median filter with the same kernel sizes were tried, but the Gaussian filter yielded far more satisfactory results, which are illustrated in Fig.5 shown below. Comparison of different threshold methods is shown in Fig. 6 [11].

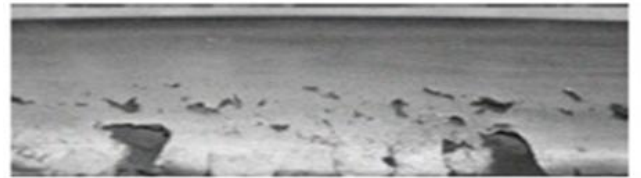


(a)



(b)

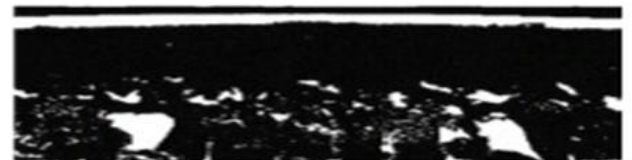
Figure 5. Results of erosion and adaptive thresholding after (a) median filtering with 3x3 kernel and (b) Gaussian filtering with 3x3 kernels. The highlighted areas show where spalled areas are removed by the median filter.



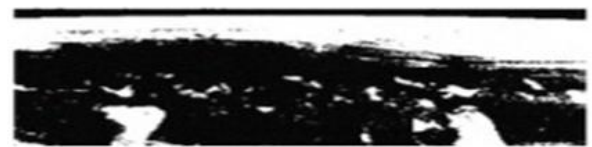
(a)



(b)



(c)



(d)

Figure 6. Comparison of different threshold methods: (a) source image, (b) image obtained by Auto thresholding, (c) image obtained by Dynamic thresholding, (d) image obtained by Manual thresholding.

The dynamic threshold with local background estimated by the mean filter is superior to other methods. Information about defects shows clearly and the edges-effect is suppressed a lot too.

C. Inspection of rail head spalling using MATLAB

The Image of a worn track surface is first read. This image is then converted into gray scale image. A global threshold is applied on the entire grayscale image and the image is converted into a binary image. The pixels in grayscale image with their pixel values greater than the threshold value are represented as black pixels in the binary image. Similarly, the pixels with their pixel values smaller than or equal to the threshold value are represented as white pixels in the binary image. The amount of wear area detected depends on the value of the global threshold applied. Hence, the value of the global threshold must be

selected appropriately. The wear is detected and is represented as black pixels in the binary image.

Algorithm:

The flow chart of calculation the area of the worn surface on the railway track is as follows as shown in Fig.7.

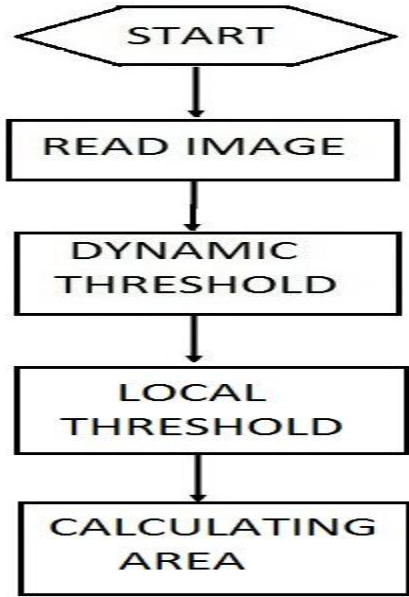


Figure 7. Proposed Flowchart of wear area calculation using MATLAB

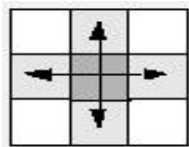
• *Pixel Connectivity:*

A pixel is surrounded by 8 neighboring pixels. Connectivity defines which pixels are connected to other pixels. A set of pixels in a binary image that form a connected group is called an object or a connected component. Determining which pixels create a connected component depends on how pixel connectivity is defined.

Pixel connectivity in a 2D image can be of two types:

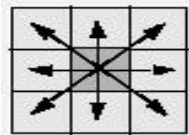
• 4 Connected

Pixels are connected if their edges touch. This means that a pair of adjoining pixels is part of the same object only if they are both on and are connected along the horizontal or vertical direction.



• 8 Connected

Pixels are connected if their edges or corners touch. This means that if two adjoining pixels are on, they are part of the same object, regardless of whether they are connected along the horizontal, vertical, or diagonal direction.



Thus, we have objects that contain number of connected pixels in them. The value of objects is the number of pixels

connected. We apply local thresholding that removes from the binary image all connected components (objects) that have fewer than 100 pixels. Thus small patches (objects with less than 100 pixels in them) of white pixels in black background are removed in our example.

The white patches in the detected wear area are removed after applying local thresholding.

• *Image Complementation and wear area calculation:*

The image is complemented. By complementing a binary image, we simply convert the white pixel into black and black pixels into white. The worn railway track surface is now represented by the white pixels. To calculate the area of the railway track, we basically calculate the area of the white pixels in the binary image. The area of an individual pixel is determined by looking at its 2-by-2 neighborhood. There are six different patterns, each having different area values:



Patterns with zero white pixels have area = 0



Patterns with one white pixel have area = 1/4



Patterns with two adjacent white pixels have area = 1/2



Patterns with two diagonal white pixels have area = 3/4



Patterns with three white pixels have area = 7/8



Patterns with all four white pixels have area = 1

Thus each pixel is part of four different 2-by-2 neighborhoods. This means, for example, that a single white pixel surrounded by all white pixels has a total area of 1 (1/4*4=1). Thus we calculate the area of each white pixel in

the binary image and sum it up to get the total area of the wear on the railway track [1]. Results of wear area calculation using MATLAB are shown in Fig.8.

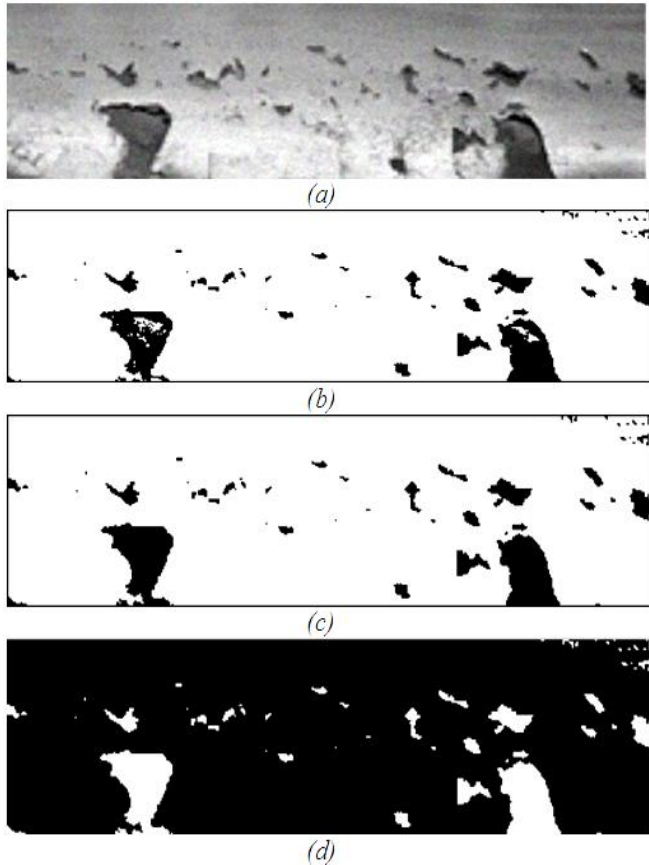


Figure 8. Results of wear area calculation using MATLAB (a) grayscale image of railway track wear, (b) Binary image obtained by global thresholding, (c) Binary image after applying local thresholding, (d) Complemented binary image of worn railway track

The percentage of wear calculated the given image comes out to be 8.346. The time required to calculate the surface wear area is 1.064653 seconds.

D. Detection of foreign objects on railway tracks

The railway tracks must be smooth and should not have any obstacles on them. A stray rock or any object on the railway track can scratch, wear and damage the railway track as well as the railway wheels. In this method, the unwanted objects on the railway tracks will be detected using frame differencing methods.

The method for detecting change between two frames is by using frame differencing and background subtraction. This method directly compares the similar pixels of two frames to decide whether they are the same. In the simplest form, a binary difference picture $B(x, y)$ is difference between frames $F1(x, y)$ and $F2(x, y)$ obtained by: τ

$$B(x, y) = \begin{cases} 1, & F1(x, y) - F2(x, y) > \tau \\ 0, & \text{otherwise} \end{cases} \quad (11)$$

where $F1(x,y)$ is the latest image with the object to be detected in it and $F2(x,y)$ is the previous image without object in it. In a difference picture, pixels which have value 1 may be considered to be the result of object motion or illumination changes [10, 11].

Algorithm:

- i. Take images of railway track after fixed time intervals.
- ii. Compare the present image (the image has object to be detected in it) with previous image (image which does not have object in it) by using frame differencing method.
- iii. The frame differenced image contains zero ($R=0, G=0, B=0$) and non zero value pixels in it.
- iv. A pixel to be categorized as a non-zero pixel, it has to have its pixel value above a fixed threshold. In this method the threshold applied is of the value 20.
- v. The non-zero value pixels (pixels with pixel value above the threshold) are the pixels of the object to be detected and zero value pixels (pixels with pixel value equal or below 20) are that of the background.
- vi. These non-zero value pixels are then replaced by the corresponding pixels of the image with object in it and zero valued pixels are given zero pixel value.
- vii. Thus the final image only consists of the object that was to be detected.

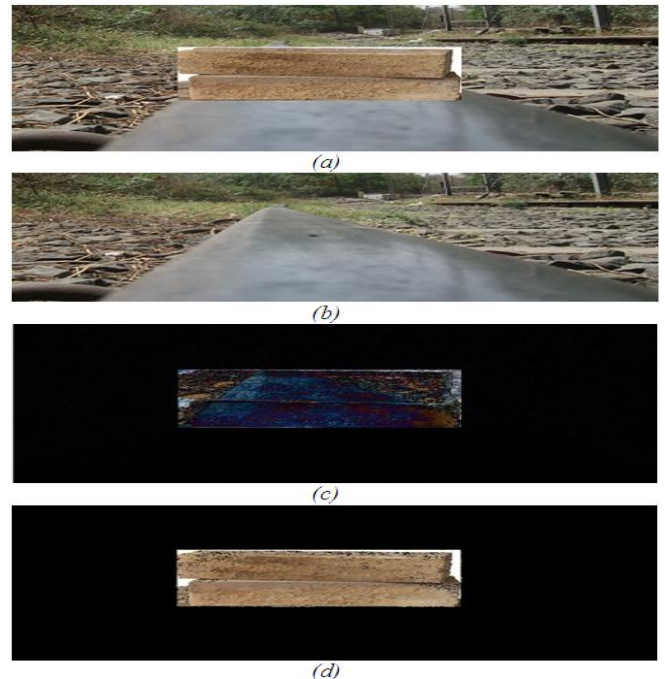


Figure 9. Results of object detection (a) Track image with the object to be detected, (b) Track image without object, (c) The frame differenced image, (d) Final image containing the detected object.

The non-zero value pixels in the frame differenced image are replaced by the corresponding pixels of the image with object in it and zero valued pixels are given zero pixel value.

The final image contains the object to be detected in it and results of object detection are shown in above Fig. 9.

E. Crack Detection

Extreme temperature differences, wearing, faulty manufacture or accidents can crack a railway track. A crack in the railway track must be detected at an early stage. The crack widens and expands each time the heavy railway passes over it. These cracks can later break the railway track and fatal accidents can occur. Basic Block Diagram of processing of crack detection system is shown in Fig.10.



Figure 10. Block Diagram for Proposed crack detection system

Algorithm:

- The image is read into the system memory for processing using the computer vision tools.
- The image is analyzed and the corresponding intensity histogram is obtained. The histogram contains the pixel intensity values in all three primary colour spaces (red, green and blue). A uniform surface should show homogeneity in the intensity levels throughout the image, which is indicated by the entire histogram lying in a specific band of values.
- The histogram obtained in the above step is analyzed for regions where the pixel intensity values (red, green and blue) show an immediate and large departure from the rest of the graph. These areas indicate that the surface at these points is not uniform as the rest of the image, and hence are an indication of deformities on the surface. Such areas are identified as cracks.

Results of crack detection with Test image containing crack, and Image test profile showing crack location are shown in Fig.11.

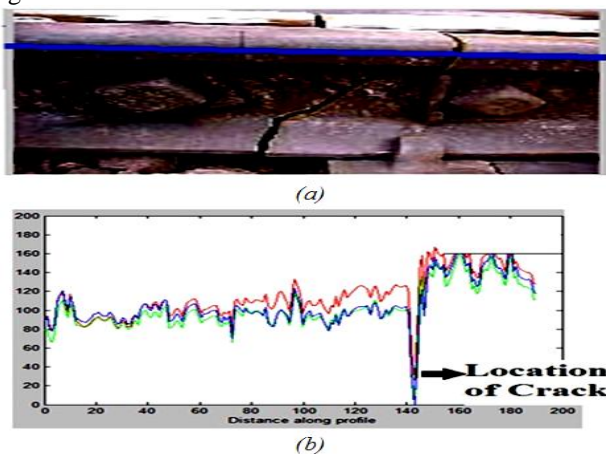


Figure11. Results of crack detection (a) Test image containing crack, (b) Image test profile showing crack location

VI. CONCLUSION

A sharp drop in the intensity values, which is consistent for a significant number of strips, indicates a crack on the surface. In this paper, we have developed computer vision methods for reliable identification and localization of structural defects in railroad tracks. Percentage of wear of rail head and length of cracks, as evaluation of defects of rail head section, Object detection, are calculated by various image processing methods and compare the simulation results using OpenCV and MATLAB. We have developed three software modules for analysis of different types of defects in railway tracks, namely, stray objects on the track, cracks on the track surface and wear of the rail head due to spalling. While the methodology developed and described in this paper involves a purely software-based approach, a conceptual hardware schematic is included which shows how the techniques can be successfully implemented by mounting the required hardware on a rail carriage and the measurements can be conducted without much disruption to the regular functioning of the railways.

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