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Assessment of Road Surface Condition Using Digital Image Processing

Ankita Khatri [a], Umesh Sharma [b] and Manoj K. Arora [c]

[a.]Department of Civil Engineering, Punjab Engineering College (Deemed to be University), Chandigarh, India, 160012 **(Corresponding Author)**
[b]Department of Civil Engineering, Punjab Engineering College (Deemed to be University), Chandigarh, India, 160012,
[c]Department of Civil Engineering, Punjab Engineering College (Deemed to be University), Chandigarh, India, 160012, Indian Institute of Technology Roorkee, Roorkee, India, 247667.

Abstract. The Road Surface Monitoring (RSM) is an essential activity which is used for the assessment of road surface distresses in order to provide adequate repairs in time. However, with the incessant growth in vehicular population, the road agencies are now facing problems related to the inspection and maintenance of the increasing road lengths. It is estimated that every year infrastructure worth billions of dollars is lost due to premature failure of roads as a result of inadequate maintenance. Apart from the lack of funds, one of the major reasons for improper management or delay of road maintenance activities is due to the currently used traditional road inspection methods. These methods are expensive, create interruption to the moving traffic and often delay the maintenance process. In the recent years, various attempts have been made for automating the data collection process in the form of videos and images by using different imaging systems. However, the analysis and processing of the collected data in order to quantify the extent of surface deterioration is still predominantly done manually. The present study, therefore, investigated the usefulness of some of the image processing techniques and proposed a method for automated detection and classification of potholes, cracks and patches from ground images of Indian roads. The performance of the method was evaluated through Accuracy, Precision and Recall matrices and the results showed that an overall accuracy of above 95% in the detection and classification of potholes, cracks and patches was attained when compared to the manual field observations. It was observed that the road surface assessment using the image processing approach also saved considerable amount of time as compared to the manual inspection method.

Keywords: Road Deterioration, Maintenance, RSM, Image Processing Techniques

1 Introduction

The extensive and persistent growth in the traffic volume on roads has necessitated the construction of new road infrastructure at a fast pace. Globally, it is estimated that an addition of minimum 25 million kilometers of new roads is expected by the year 2050 resulting in about 60 percent increase in the present total road length [1]**.** Furthermore, it is anticipated that nearly 90 percent of all road construction is likely to occur in developing countries, like India which currently has a total road length of 5.3 million kilometers [1], [2]. Although, in the present scenario, the construction of new roads is the major requirement but in order to provide safe and comfortable ride to the increasing road users the maintenance of the existing roads is also unavoidable. However, in India this is quite a difficult task, as the roads often deteriorate faster than they are being maintained. It is always desirable to repair the pavement at an early stage of deterioration as with time the accumulated damage will require a more costly approach for maintenance [3].

Generally, pavement failure occurs due to structural and functional factors [4]. Structural failure occurs when the pavement fails to absorb and transfer the wheel load through its structure whereas the functional failure includes lack of pavement performance in providing resistance to skid and riding comfort [5]. The performance of a road surface can thereby be monitored by observing its structural and functional factors on the basis of four main aspects i.e. riding quality, surface distress, structural capability and resistance to skid [6]. Among these, surface distress assessment is the most common way to evaluate pavement condition as they are the external indicators of pavement performance [7]. The presence of these distresses on the pavement not only reduces the efficiency of the road transport, but also increases the vehicle operating cost [8]. The bituminous pavements mainly comprise of four types of surface distresses which includes cracking, surface deformation, surface defects and disintegration [9], [10]. The various types of distresses observed on bituminous pavements along with their suitable maintenance measures are shown in table 1 [10], [11], [12].

Table 1: Types of surface distresses on bituminous pavements

Type of distresses	Categorization	Maintenance Measure
• Cracking Visible discontinuities on pavement surface which represents pavements structural condition.	• Fatigue cracking • Longitudinal cracking • Transverse cracking • Slippage cracking • Reflective cracking • Edge cracking • Block cracking • Diagonal cracking	• Filling and Sealing the crack • Patching the area • Resurfacing • Full depth reconstruction
• Surface Deformation Change in the appearance of road surface as a result of weakening or failure of one or more layers of the pavement.	• Rutting • Corrugations • Shoving • Depressions • Swell • Upheaval	• Removing the damaged pavement and providing overlay • Patching the area • Resurfacing • Reconstruction
• Disintegration Continuous breaking of the pavement into small and loose pieces, which with time can lead to complete damage of the pavement.	• Potholes • Patches	• Cleaning the hole and filling it with bituminous wearing course material • -The size of patching can be reduced by making regular and detailed inspection of the pavement

• Surface Defects Occurs mainly because of problems in the surface layer.	• Ravelling • Bleeding • Polishing • Delamination	• Removing the damaged pavement and providing overlay • Applying coarse sand to soak the excess asphalt bind • Patching and Resurfacing

Thus, in order, to provide appropriate road maintenance operations, the identification and documentation of various road distresses is quite necessary. The pavement condition assessment usually consists of three main steps that are distress data collection, identification and characterization and quantification of distresses [6]. In current practices, the use of traditional (manual) methods for the purpose of data collection has majorly been discouraged and is being replaced by various automated approaches [13], [14]. However, the further steps involved in the comprehensive pavement condition assessment are still performed manually. This makes the RSM process expensive and slow, for providing maintenance operations in time.

In view of this, a lot of research has been carried out in order to overcome the limitations of traditional methods by introducing the use of automated techniques. Most of the techniques used by various researchers for distress detection and characterization are mainly based on 3D-based laser scanning, vibration-based accelerometers and imaging systems [15]. The 3D-based laser scanning methods generally have high computational cost as the analysis of the pavement surface data using such methods involves the use of sophisticated high cost equipments [15], [16]**.** The vibration-based methods use accelerometers to assess pavement condition on the basis of mechanical responses of the vehicle carrying the equipment [17]. Although, the equipments used in this method are cost effective but it lacks accuracy and the results produced are less reliable [17]. Further, most of the image based methods simply focus on the detection and quantification of cracks and potholes. However, the exhaustive assessment of the road surface condition generally involves the simultaneous detection, characterization and quantification of various types of distresses. In actual practice, the effective implementation of image processing techniques for the identification and characterization of various distresses from road videos, especially in the developing country like India needs to be explored. Furthermore, while undertaking different maintenance measures the engineers and concerned authorities often uses data like construction history, past and present traffic counts, road inventory details, maintenance records, etc. The handling and maintaining of such data can be made simple and convenient by the application of GIS technologies which offer appropriate tools to store such kind of data.

In the present study a comprehensive RSM technique is used for automated identification and classification of potholes, cracks and patches observed on bituminous roads. The study also developed a road data management system by exploring the use of GIS technologies for recording, managing and updating the road related data which can be readily used by local road authorities for predicting future road assessment and maintenance operations.

2 Material and Methods

The main objective of the study was to examine the performance of the proposed method for the prompt and accurate assessment of Indian road condition using image processing techniques. The site selected for the study was Chandigarh which is a city and a Union territory in India that serves as a joint capital of two states i.e. Punjab and Haryana. The city, commonly known as 'The City Beautiful' was planned by the well known French architect, Le Corbusier, and is recognized as one of the early planned cities of India after independence. It has a geographical area of about 114 sq. kms accommodating a population of about 1.2 million [18]. The city is recognized as the country's first planned city, with a unique feature in the design of its road infrastructure. The total road length of Chandigarh is about 1536 kms, consisting of seven types of roads commonly known as the 7 V's (Voies) which are designated as V1, V2, V3, V4, V5, V6 and V7 [18]. The roads in the city are classified in accordance to their functions as shown in table 2.

Table 2. Types of roads and their functions in Chandigarh

Type of Road	Functions
V1	The roads connecting Chandigarh with other nearby cities.
V2	Major streets of Chandigarh, with important commercial and institutional buildings located along them.
V3	The roads surrounding the sectors and has no access to buildings on them.
V4	The roads in front of market area.
V5	The roads are responsible for circulation within sectors
V6	The roads providing access to houses
V7	The roads meant for the pedestrians and cyclists

This organized arrangement of road infrastructure leads to a remarkable hierarchy of traffic movement and at the same time ensures that the residential areas are segregated from the noise and air pollution of traffic. However, with time and increasing urbanization the city has developed beyond its designed capacity. However, in spite of having a well-designed and planned road network, the city is currently facing congestion related problems because of the extensive increase in the number of motorized vehicles, which grew up from about 0.74 million in the year 2010 to 1.37 million in the year 2016 [19]. The excessive traffic volume on Chandigarh roads drives a need for the periodic assessment of road condition so as to maintain their efficiency. In the present study, an automated approach is used for assessment of surface condition of selected V4 type of roads and a GIS based database is created for the relevant road information data. The study area along with the selected roads is shown in fig. 1.

Figure. 1. Roads Seleceted for the Study

2.1 Overall Methodology

The overall methodology used in this study was divided into different steps as shown in fig. 2.

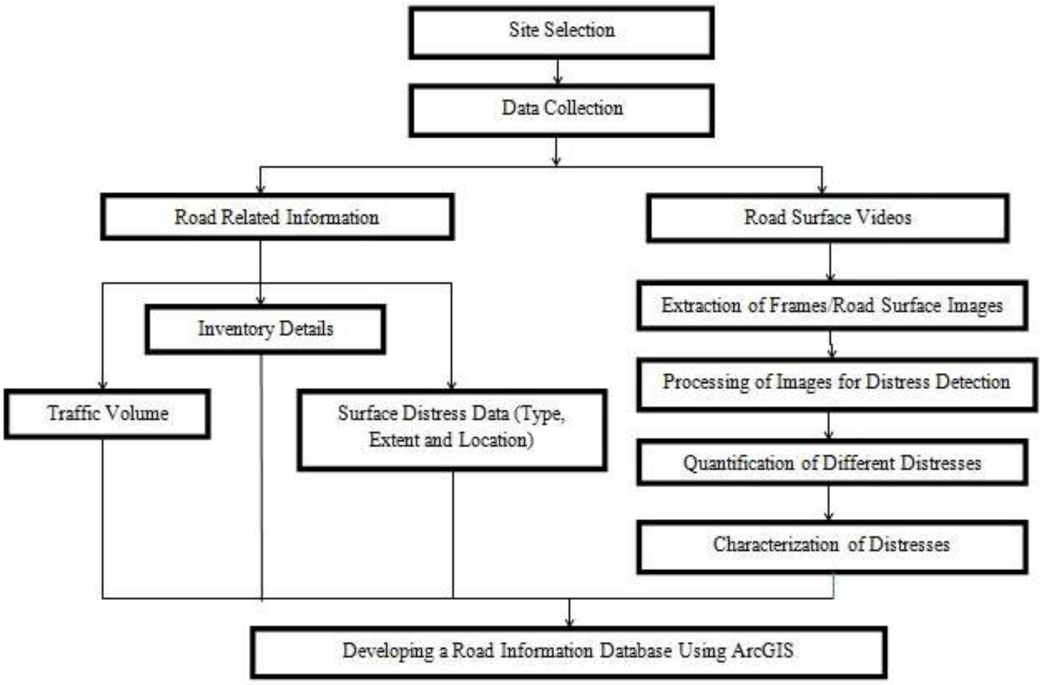


Figure. 2. Overall Methodology

Data Collection

Road Related Information

A manual inspection was done on the selected roads to collect information about the Inventory details, Road type, Pavement material type, Traffic volume [20], Road surface condition, Type, Extent and Location of the distress as shown in table 3 and table 4.

Table 3. Inventory details of selected roads

S. No.	Road Name	Road Length (m)	Peak Hour Traffic Volume (in terms of Passenger Car Unit (PCU)) (PCU/hr)		Road Type	Road Width (m)
			Working day	Non-Working day		
1.	V4- 41	600	580	468	Four-lane undivided carriageway	11.20
2.	V4- 42	1000	626	509		12.10
3.	V4-43	850	876	808		12.60
4.	V4-44	950	678	565		12.70
5.	V4-45	900	536	483		13.50

*In road name V4 stands for the type of road and number stands for the sector name.

Table 4. Road distress data by manual survey

S.No.	Road Name	Type of Distress	Road Distress Data: Quantification of Distresses	Extent of Distresses (Total distressed area of road) (m^2)	Location of Distresses
1.	V4-41	Potholes, Patches, Cracks	Potholes-3; Patches-9; Cracks-3	18.80	The location of each type of distress was recorded using hand held Global Positioning System (GPS) device.
2.	V4-42	Potholes, Patches, Cracks	Potholes-2; Patches-7; Cracks-6	24.41	
3.	V4-43	Patches, Cracks	Patches-8; Cracks-4	21.42	
4.	V4-44	Patches, Cracks	Patches-7; Cracks-2	12.02	
5.	V4-45	Potholes, Cracks	Potholes-6; Cracks-6	18.52	

The most common type of defects observed on these roads included patches, potholes and cracks (fig. 3). The surface condition data collected through manual survey was further used for validating the results obtained from proposed approach.

Figure. 3. Common types of defects on the selected roads

Road Surface Videos

A high resolution DSLR camera (1920 x 1080, 60 frames/sec) was mounted at the back of a survey vehicle at a height of 2 m above the ground (fig. 4) to record the videos of the road surface. The camera was connected with a laptop placed inside the survey vehicle, so as to control and save the recordings without any interruption from the vehicle itself. The on road area covered by one video frame was approximately 4.05 m^2 with 1.39 mm pixel size, which was sufficient enough to provide a detailed description of the distresses from the images. No artificial means of lighting was used during the recording of the videos. A total of 1454 images (frames) were then extracted from the videos [21] which included images of distresses and distress free road surface.

Figure. 4. Camera setup for recording road surface videos

3 Data Analysis

The extracted images (frames) were then processed in MATLAB 2015a with the help of various image processing techniques for the detection and classification of different distresses. The algorithm proposed for the study (fig. 5) consisted of five main steps which include image enhancement, image segmentation, extraction of visual properties of distresses, detection and classification of distresses and finally quantification of distresses.

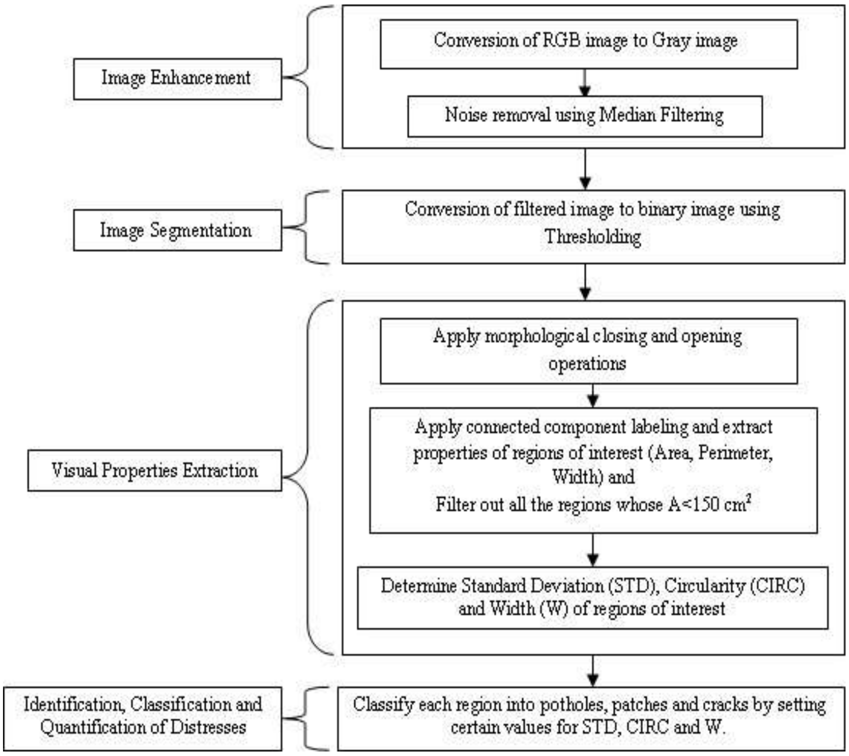


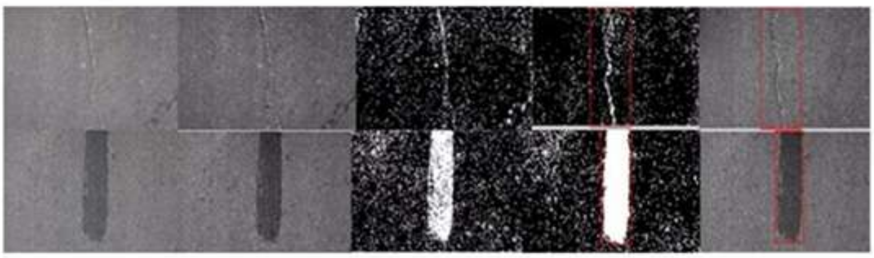
Figure. 5. Algorithm for automated identification and classification of road distresses

The visual properties selected were based on the information such as texture, shape and dimension of the observed distresses as shown in table 5.

Table 5. Information used for extraction of Visual properties of distresses

Property of Distresses	Texture	Shape	Dimension
Description	The texture of a distress is more in contrast as compared to the surrounding road surface. The amount of contrast varies for different types of distresses.	Pothole-Circular Patch- Rectangular Cracks-Continuous irregular elongated appearance	The width of pothole and patch is more than that of cracks.

The image enhancement was done by converting the extracted image format from 24 bit to 8 bit so as to make the image compatible to the proposed processing techniques and to save processing time. In order to remove/reduce noise from the acquired images, median filtering was applied to the gray (8-bit format) image. The size of the neighborhood used for filtering was 5 x 5 pixels [22]. The next step was image segmentation [23], [24] which was done to determine which pixels belong to region of interest. It was performed using adaptive thresholding based on the weighted mean of neighborhood area [22]. The optimal neighborhood region and the value of constant were determined by trial and error method. After the application of adaptive thresholding, the gray image is converted into a binary image with black pixels representing the road surface and white pixels representing a distress or noise. Further processing of the binary image was done using morphological operations (erosion and dilation) and connected component labeling so as to extract the visual properties of the distresses [22]. On the application of the above techniques, an image containing the possible regions of interest is obtained. For the purpose of simplification of the distress detection process, only the regions of interest (distresses) with area more than 150 cm^2 were considered for the study. The minimum value of area used in the present study can be altered in accordance with the respective requirements. The extracted visual properties such as STD, CIRC and W were then used to automatically classify various distresses using user defined decision logic. Depending upon the results from the manual inspection, the decision logic was developed by testing the different values for extracted properties on about 120 images containing cracks, potholes and patches. The procedure applied to detect distress using the proposed algorithm is shown in fig. 6.



a) Original image with crack and patch b) Noise removal using median filtering c) Image segmentation using adaptive thresholding d) Image after morphological operations e) Distress detected

Figure. 6. Procedure applied to detect distress

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4 Developing a Road Information Database Using ArcGIS

The road related information like construction history, past and present traffic volumes, road inventory details, previous maintenance records, RSM data etc. is often used for planning of maintenance and repair strategies. Although, it is a quite difficult task to effectively make use of such large volume of data for suggesting repair solutions and hence causes delays in the maintenance process. However, the handling of maintenance related data can be made simple and convenient by the application of GIS technologies which provide appropriate tools to store such kind of data [25]. In the present study, the collected road related information or attributes (table 6) was saved as an excel file which was then imported to the ArcGIS software (version 10.1) so as to create a permanent and editable database in a digital format.

Table 6. Road Network Attributes

S. No.	Feature	Attributes	Description
1.	Road	Road Surface type	Type of road surface is either -Bituminous Surface -Concrete Surface
		Road type	-Two Lane -Four Lane undivided carriageway - Four Lane divided carriageway -Multi-Lane undivided carriageway -Multi-Lane divided carriageway
		Distress location	Geographic location of distresses (GPS data)
		Distress Count	No. of distresses present on a selected road
		Traffic volume	Peak hourly data for both working and non-working days
		Inventory details	-Road length -Road width -Shoulder width -Median type -Median width -Median height

The Google Earth Images (.jpeg) of the selected roads were used for the representation of the ground data. The sequence of the steps involved in importing and plotting the data on ArcGIS platform is shown with the help of a flowchart (fig. 7).

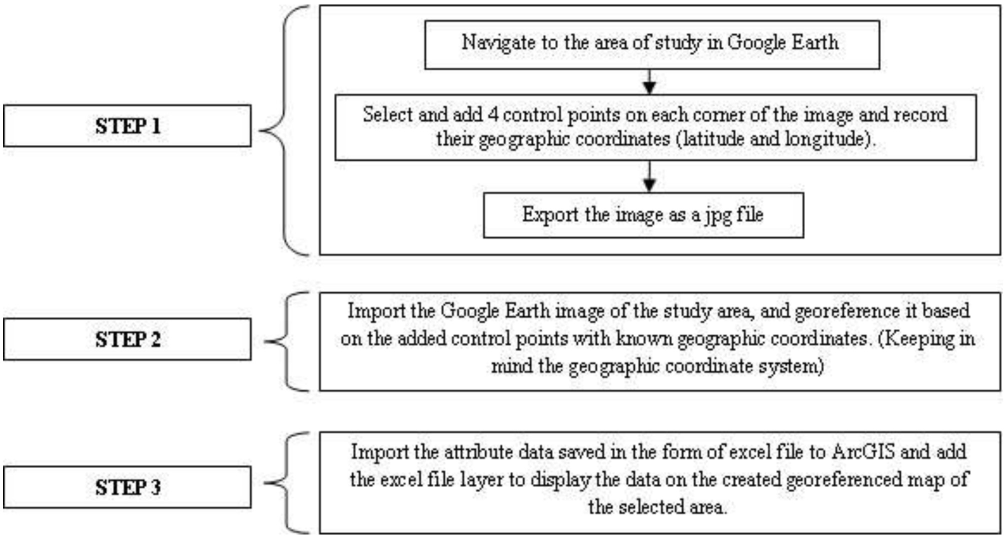

Figure. 7. Steps involved in creating road information database in ArcGIS

A typical display of road related information in the form of attribute table along with the locations of distresses is shown in fig. 8.

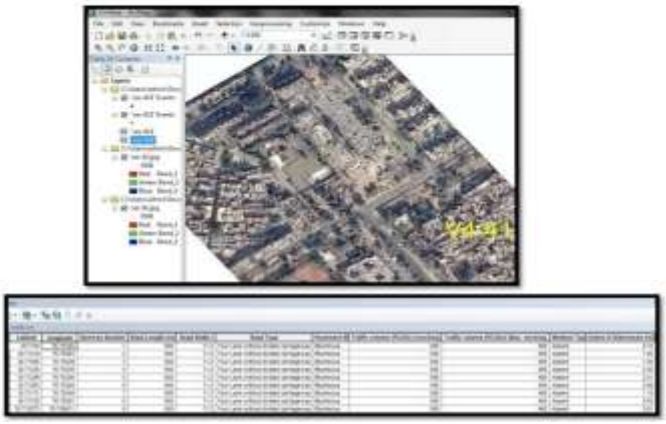

Figure. 8. Location of distresses plotted on the georeferenced map and the attribute table of road information

5 Results and Discussions

5.1 Detection and Characterization of distresses using proposed algorithm

The proposed algorithm was successfully implemented on the road video data of the selected roads and the results for the detection and characterization of various distresses are presented in table 7.

Table 7. Distress Detection and Characterization using proposed Algorithm

S.No.	Road Name	Detection and Characterization of Distress by	
		Manual Method	Proposed Method
1.	V4-41	Potholes-3; Patches-9; Cracks-3	Potholes-3; Patches-7; Cracks-4
2.	V4-42	Potholes-2; Patches-7; Cracks-6	Potholes-1; Patches-7; Cracks-6
3.	V4-43	Patches-8; Cracks-4	Patches-9; Cracks-3
4.	V4-44	Patches-7; Cracks-2	Patches-7; Cracks-1
5.	V4-45	Potholes-6; Cracks-6	Potholes-6; Cracks-6

5.2 Performance Evaluation of proposed Algorithm

Using Accuracy, Precision, Recall and Error metrics

The performance of the proposed algorithm was evaluated using the accuracy, precision, recall and error metrics which were calculated using equations (I- IV).

Accuracy (%) = {(TP + TN) / (TP + TN + FP + FN)} x 100 …………… (I)
Precision (%) = {(TP) / (TP + FP)} x 100 …………… (II)
Recall (%) = {(TP) / (TP + FN)} x 100 …………… (III)
Error (%) = {(FN + FP) / (TP + TN + FP + FN)} x 100 …………… (IV)

TP - True Positives (indicates number of frames detected as frames with distress when the distress is actually present in the frame)
TN - True Negatives (indicates number of frames detected as frames without distress when the distress is actually not present in the frame)
FP - False Positives (indicates number of frames detected as frames with distress when the distress is not actually present in the frame)
FN - False Negatives (indicates number of frames detected as frames without distress when the distress is actually present in the frame)

From the thorough analysis of the results, it was found that the proposed algorithm attained an overall accuracy of 97 % with 93% precision and 78% recall in identifying frames with potholes, accuracy of 97% with 91% precision and 81% recall in detecting frames with patches, and accuracy of 95 % with 80% precision and 82 % recall in detecting frames with cracks. The above performance measures clearly indicate that most of the potholes, patches and cracks were detected and characterized successfully from the road surface videos.

Comparing the Extent of the Detected Distresses

The results obtained from the proposed algorithm were further assessed by comparing the Extent (total distressed area) of the Detected Distresses with the manual survey data (table 8). The percentage error calculated for the extent of the detected distresses using manual survey method and proposed approach was found to be varying from 1.60 % to 9.96 %.

Table 8. Comparisons of extent of detected distresses obtained with manual inspection method and proposed algorithm

S. No.	Road Name	Detected Distresses	Extent of distresses measured by (m^2)		Error (%)
			Manual Method (1)	Proposed Method (2)	
1.	V4-41	Potholes, Patches, Cracks	18.80	19.10	1.60
2.	V4-42	Potholes, Patches, Cracks	24.41	22.35	8.44
3.	V4-43	Patches, Cracks	21.42	22.15	3.41
4.	V4-44	Patches, Cracks	12.02	11.80	1.83
5.	V4-45	Potholes, Cracks	18.52	18.10	2.27

Comparing the time taken in detection and characterization of distresses

A significant amount of time is saved by using the proposed approach for the detection and characterization of road distresses as shown in table 9.

Table 9. Comparison of time taken by manual method and proposed method

S.No.	Road Name	Road Length (m)	Manual Method (1)	Proposed Method (2)	
			Data acquisition time (mins)	Data acquisition time (mins)	Data processing time (mins)
1.	V4-41	600	160	10	20
2.	V4-42	1000	170	16	24
3.	V4-43	850	130	14	21
4.	V4-44	950	110	15	18
5.	V4-45	900	140	14	21

6 Conclusions

Adequate maintenance of road infrastructure not only helps in preserving the value of the investment, but also ensures the reduction in road user cost eventually leading to economic benefits. The road surface condition assessment is an important task for the development of maintenance strategies. In current practices, the condition of road surface is assessed with the help of various imaging systems which collects the data in the form of videos and images which are later inspected manually by the experts. Although, this type of data collection activities reduces the manual efforts up to a certain limit but the analysis of the data is again time consuming, costly and highly dependent on the knowledge of the expert. The present study developed a method by exploring and demonstrating the use and efficiency of digital image processing for road surface condition assessment. It was observed that the road distress assessment using the remote sensing methodologies saved considerable amount of time as compared to the manual inspection method. The total time taken for the manual inspection of the selected roads was observed to be around 710 minutes with the total road length of 4.30 km, whereas the time taken for recording the road surface video is about 69 minutes depending upon the speed of the vehicle. Furthermore, it was seen that the time taken for the processing of all the extracted images with proposed algorithm was about 104 minutes. In order to validate the performance of the proposed approach, surface condition assessment of a random road was carried out and it was found that the results attained from proposed approach were reasonably close to those measured by manual methods. Also, an acceptable error was observed on comparing the extent of distresses obtained from the manual inspection method and the proposed method. Thus, the results of the presented study very much support the implementation of image processing techniques for road surface condition assessment. In addition to this, it was also observed that by using the satellite images and the GIS based database, the location of the detected distresses along with the other road details can be clearly identified. Hence, the use of GIS platform, for creating a road information database is observed to be beneficial as this information can be used for prioritizing the maintenance and repair strategies. It is thus believed that the replacement of traditional methods with the image processing techniques will be more effective and less time consuming in meeting the challenges faced by the highway authorities for evaluation and maintenance of road condition.

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