An Automatic Framework for Parameter Extraction from Road Images with Potholes

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***Abstract* — With the massive improvements in the road transport network in India, the road safety is becoming the major concern of the authorities. The road safety is primarily defined by the motor skills of the driver. Nevertheless, the effects of road conditions on safety cannot be ignored. The authorities responsible for road maintenance are struggling to provide the higher maintenance of the roads to provide better, faster and safe transportation. Thus the demand for the research to automate the detection of the road conditions cannot be disregarded. A number of research attempts are carried out in order to detect the road condition based on the potholes. Nonetheless the detection process is highly time complex and makes the maintenance process delayed. Also, majority of the parallel research outcomes failed to measure multiple potholes in a single image and cannot distinguish the potholes based on the emergency of repair. Thus this work defines a newer dimension of pothole detection for road images, which contains higher number of potholes in a single image and makes the process faster by reducing the change of false detection. The false detection is usually the images in the dataset without having significant damages. Also, this work extracts the parameters for determining the potholes existence as the major outcome. Yet another outcome of this work is to classify the potholes based on the urgency of repair. The final outcome of the work is to automate the detection facility to provide a timely maintenance alert and deliver a better road condition in India.**

***Keywords* — Road Condition Detection, Pothole Detection, Road Image Segmentation, Parameter Extraction, Multiple Pothole Detection.**

I. INTRODUCTION

The Potholes is a type of road distract that effects the road condition and significantly put a threat to the road safety measures as suggested by H. Oliveira et al.[1] in their work. The authorities in India are making great efforts in order to make the roads every day ready. Nevertheless, the road maintenances are expected to be a regular task to achieve such goals. Thus checking the road conditions and getting the feedback about the potholes are essential task for authorities. The manual detection process for potholes is tedious, highly time inefficient and subjective process. The work by H. Cheng et al [2] in the year of 1999, work by H. Cheng et al. [3] in the year 2001, demonstrations by P. Subirats et al. [4] in the year of 2006 and the survey carried out by T. S. Nguyen et al. [5] in the year of 2009 have listed the mentioned hurdles in manual pothole or crack or any other road condition anomalies. Thus, due to higher demand of replacing the traditional methods of detection, the newer automatic methods for detecting road cracks and potholes are evolving. The most recent research outcome from H. Oliveira and P. L. Correia [6] have considered the outcomes from the previous researches and identified the significant improvement scopes. The road condition detection using image processing techniques are widely accepted.

A number or parallel researches have proven that the image processing methods are highly suitable for detecting the road conditions. The images of the road surface is usually comprised of multiple potholes and cracks, thus separation of each object is a primary task. The work by H. Oh et al. [7] has proven that using the image segmentation technique can solve this problem. Another approach, which separates the cracks or potholes from the road surface, is to deploy texture based segmentation of the image as proposed by M. Petrou et al. [8]. In order to detect the real cracks of the roads and reduce the chances of false detection, in the year of 2006 Y. Huang et al. [9] have proposed a distress mechanism. Collection of the road images for cracks and pothole detection is the major challenge as the images can demonstrate variations in during the capture process. The work by S. Cafiso et al. [10] have analysed the capture policies and recommended the solutions before analysis.

In the other hand, the detection mechanism can also be driven by the sensor network as suggested by M. Gavilán et al. [11]. Nonetheless, the detection process is highly depended on establishing the sensor networks across the road networks, thus this direction of the solution is not highly accepted by the research community. Yet another mechanism for the defect detection as proposed by R. Amhaz et al. [12], M. Avila [13] and S. Chambon [14] is to deploy Minimal Path Selection strategies. The results from these outcomes are high accurate. Nonetheless, the results are debatable on some image capture conditions.

A number of tools are developed other the years in order to provide the automatic road condition detection. The tools such as MPS [12], MPS with enhancements [14], Crack Tree [15] and FFA [16] are highly appreciated. Thus this work proposed to overcome these results in terms detection.

The rest of the work is elaborated such that in the Section – II, the outcomes of parallel researches on detection mechanisms of crack or pothole or both. The automatic framework is the one of the main outcomes of this work and demonstrated in Section – III with all components. The algorithm which drives the framework is furnished in the Section – IV. The outcomes of this work and the parallel works are compared based on frameworks, attributes or complexity in the Section – V. This work considers a unique dataset, collected in real time, from the Indian roads, thus in Section – VI the details are deprecated. The obtained results on this formulated dataset is analysed in Section – VII and the conclusion of this work is presented in Section – VIII.

II. Outcome from the Parallel Researches

In this section, discussion about the pothole detection for road images, after that, the extraction of parameters to determine the pothole existence for immediate renovation. Finally, we proposed an automated framework to speed up the pothole detection process.

A. Pothole Detection

From last decades, many of the researches are going parallel on crack detection and pothole detection of road images.

Existing works [1], [17] [18] [19] are mainly focused only on intensity-thresholding techniques for its efficiency and simplified nature. But, there were certain limitations like no guarantees of object coherency i.e. image may contains holes, extraneous pixels and also thresholding may produce incomplete solution.

Recent works on image pothole detection explores different challenges to be considered and are classified into five segments: Saliency detection, textured-analysis, wavelet transforms, optimal paths and machine learning. Analysis of these different detection methods are explained in [20] and [21].

Saliency Detection: Salient regions in image are clearly visualized due to their higher contrast compared to their backgrounds. Even though traditional methods [22] [23] are good at identifying salient regions in the Berkeley database [24], still they are not effective to detect potholes completely.

Textured-Analysis: Textured Analysis is introduced in pothole detection; because of the road surface images are highly textured. Winger Model and other Image Classification Methods are mostly used in recent works to differentiate the potholes and backgrounds in an image [8] [25]. These methods determine homogeneous pixels belong to a pothole using a binary pattern operator. But, these methods failed to represent potholes with non-homogenous intensities.

Wavelet Transform: Earlier works applied 2D continuous Wavelet Transformation techniques for pothole detection [26]. By this, complex coefficient maps will be plotted and wavelet coefficients values are gained for pothole detection. As a result, the pothole regions and pothole free regions could be estimated.

Potholes with low continuity and/or high curvature will not be identified properly because of its directional dependency nature.

Optimal Path Selection: Considering the both end points of a curve, the optimal path of a pothole will be identified [27]. Kaul *et al.* proposed a method to detect the similar image structures with less basic knowledge about topology and the endpoints of the chosen curves. Amhaz *et al.* [12], [14] proposed an enhanced algorithm to select endpoints at the local scale and then to select optimal paths at the global scale. It can also detect the width of the pothole. Nguyen *et al.* propose a method focuses on intensity and pothole form relevant parameters for pothole detection [18].

Machine Learning: Due to vast size of image data, it is difficult to analyze and detect the appropriate potholes. Machine learning approaches [3], [5], [15], [28] [29] [30] are introduced and developed to overcome this difficulty in finding potholes.

In another way, Artificial Neural Network (ANN) models are used to separate the extracted pixels from the background by selecting proper thresholds [4].These approaches deal with the detection of badly contrasted potholes in captured areas using a Markov random field model. AdaBoost Machine learning algorithm is used to distinguish images of potholes with defects from road surfaces based on textual information with patterns [28].

All the above-discussed methods do classification manually as sub image detection methods but still there exists a research gap in finding complete pothole curves over the complete image automatically.

B. Pothole Characterization

Existing methods characterizes the potholes based on shape descriptions, pothole seeds and pothole type on each effected block of the image.

Potholes are based on mathematical morphology and defined that a pothole is thought to be a series of saddle points with linear features [14]. The pixel direction indices of each pixel are to characterize potholes [4] [31]. Therefore, a pothole can be represented as a long sequence of 0 and 1.

The latest approaches classify the potholes into five types: longitudinal, transverse, diagonal, block, and alligator. B. J. Lee et.al. proposed ANN based method to search patterns of various pothole types horizontally and vertically [29]. Y. Huang et.al. [9], uses longitudinal, transverse, or diagonal pothole seeds to identify longitudinal and transverse potholes. Q.Zou et.al. Image Orientation and pothole depth information are taken into consideration by [20].

Potholes are classified majorly into three types as defined by the Portuguese Distress Catalog [6]. Mean and Standard deviation values of pixel normalized intensities categorize image block as longitudinal, transversal or miscellaneous.

CTA (Conditional Texture Anisotropy) estimates the distribution of the mean and the standard deviation values calculated on pixels to differentiate pothole pixels from defect free pixels.

Nonetheless, there are two main drawbacks in these traditional methods. First, new types of potholes cannot be detected in a single or multiple images. To extend the pothole types into multiple dimensions by applying structured tokens. Next, these methods work on the potholes with complex topology. Finally, the entire pothole analysis and detection process is manual.

To overcome these issues, we propose an automatic framework for parameter extraction from road images with potholes.

III. Proposed Framework

With the understanding and analysis of the outcomes from the parallel research outcomes, it is natural to understand that the single time optimized framework to extract the parameters from the road images is the demand of the modern research. Henceforth, this section of the work demonstrates the novel proposed parameter extraction framework and elaborates on the extracted parameters.

Also the comparative analysis parameters are also been proposed here.

A. Framework Description

As presented as one of the most significant outcome of this work, the time optimized parameter extraction framework is elaborated here [Figure – 1].

As understood the proposed framework is component based framework with multiple components.

- **Image Pre-Processing Tool**: The Image Pre-processing tool is another component in the framework for removing the noise. The work by this author demonstrates the significant improvements over noise and blurs reduction using an adaptive process [32]. The noises in the captured images are strongly influenced by the type of the capture device and impose variety of noise type and blur factors. Thus the adaptive noise filtration technique demonstrates higher and accurate results.

<table>
<tr><td>Matlab Image Processing Toolbox</td><td colspan="3">Image Pre-Processing Tool</td></tr>
<tr><td>Windows File System API</td><td>Image Dimension Processor</td><td>Threshold Based Binary Image Converter</td><td>Image Segmentation</td></tr>
<tr><td rowspan="2">Performance Evaluator</td><td colspan="2">Image Segmentation Processor</td><td>Segmentation Threshold Buffer</td></tr>
<tr><td colspan="3">Parameter Processing</td></tr>
</table>

Fig. 1 Proposed Parameter Extraction Framework

- **Threshold Based Image Converter**: The component responsible for converting a grayscale image into binary image is one of the strategically important parts. The segmentation and other techniques used in this work are highly dependent of on the image to be binary, making the further processing easy to be executed. Thus this component converts the image based on the grey intensity of the colour and produces the binary image.
- **Image Dimension Processor**: After the image is converted into binary image, the binary image is feed to the next component for dimension calculation. This component is responsible for separating the objects based on the white background. Further, for each object the height and width is calculated and then divided by the total image resolution. The result of this phase is actual height and width of each object in the image.
- **Image Segmentation**: The image segmentation is a standard process and accommodated in this component of the framework. The notable work by Dilpreet Kaur et al. [33] defines the benefits of segmentation techniques. The region based segmentation method is highly applicable to this study and deployed in this framework. The algorithm proposed by M. R. Khokher et al. [34] for image segmentation using multilevel graphs are been deployed in this work.
- **Segmentation Threshold Buffer**: The area of the objects considered to be potholes on the road are the most important detectable components of the image and the study demonstrates that for the objects to be considered as potholes a certain degree of radius is needed. Thus, this component generates an adaptive process for measuring the radius of the potholes and adjusts the values. The outcome from this component is to supply the segment radius for accepting or discarding the segment for parameter detection.

- **Image Segment Processor**: This component accepts the input from image segmentation and threshold buffer for accepting and rejecting the objects for further determination. The accepted objects are feed to the parameter processing component in order to generate the parameters.
- **Parameter Processing**: This component calculates the parameters such as number of objects as a result of segmentation and discarding process, distance between the objects, and calculation of the midpoints for each object with perpendicular distance at the midpoint, perpendicular width and area for each object. The generated data can be further utilized to generate recommendation system using any mining and parameter analysis algorithm to predict the nature of the algorithm.
- **MatLab Image Processing Toolbox and Windows File System API Support**: Firstly, this framework depends on the MatLab Image processing toolbox for executing the API. Thus the platform support for the framework is preliminary component. Secondly, during the simulation situation, the framework depends on the searching of the existing datasets. Thus these two are the auxiliary components for the framework to work. The advantages of these two modular components to be able to replace the platforms as any point of time for improvements of migration to different technology.

B. Parameter Description

In this section of the work, the detailed descriptions are presented [Table – 1].

TABLE I: PARAMETER DESCRIPTION

Parameter Name	Parameter Description
Object Number	The total number of potholes available in the single image
Max distance between Objects	The maximum distance between two nearing objects calculated from the centre points.
Perpendicular distance at midpoint	Get the profile perpendicular to the midpoint so it can be identified when it first enters and last leaves the object.
Average perpendicular width	Get the average perpendicular width. This will approximately be the area divided by the longest length
Area	Hold the total area for each object

Thus these parameters are analysed and extracted from the road images.

IV. PROPOSED ALGORITHM

The furnished framework in this work must be supported by the algorithm and the proposed novel algorithm is elaborated here:

Algorithm

Step -1. Read the standard image
Step -2. Convert the colour image into grey scale
Step -3. Calculate the objects in the image
Step -4. Repeat for all objects
a. Consider any point on the image region
b. Calculate the minimum colour variation in the segment
c. Grow the image point towards the boundary of the region
d. Identify the difference of intensity level of the grey scale
e. Identify the highest intensity different points as segments
Step -5. End;
Step -6. Calculate the image threshold of the image
Step -7. Convert each region
Step -8. Based on the image threshold convert each area into binary
Step -9. For each identified objects
Step -10. Fill the object with black colour
a. If the object is less than 10% of the image
i. Then discard the object
b. Else
i. Calculate the parameters
i. Calculate longSlope, perpendicularSlope, perpendicularSlope, Max distance between Objects, Perpendicular distance at midpoint, Average perpendicular width and Area
c. End
Step -11. End
Step -12. Calculate the time to build the model

The flow of the algorithm is also visualized here in Fig. 2.

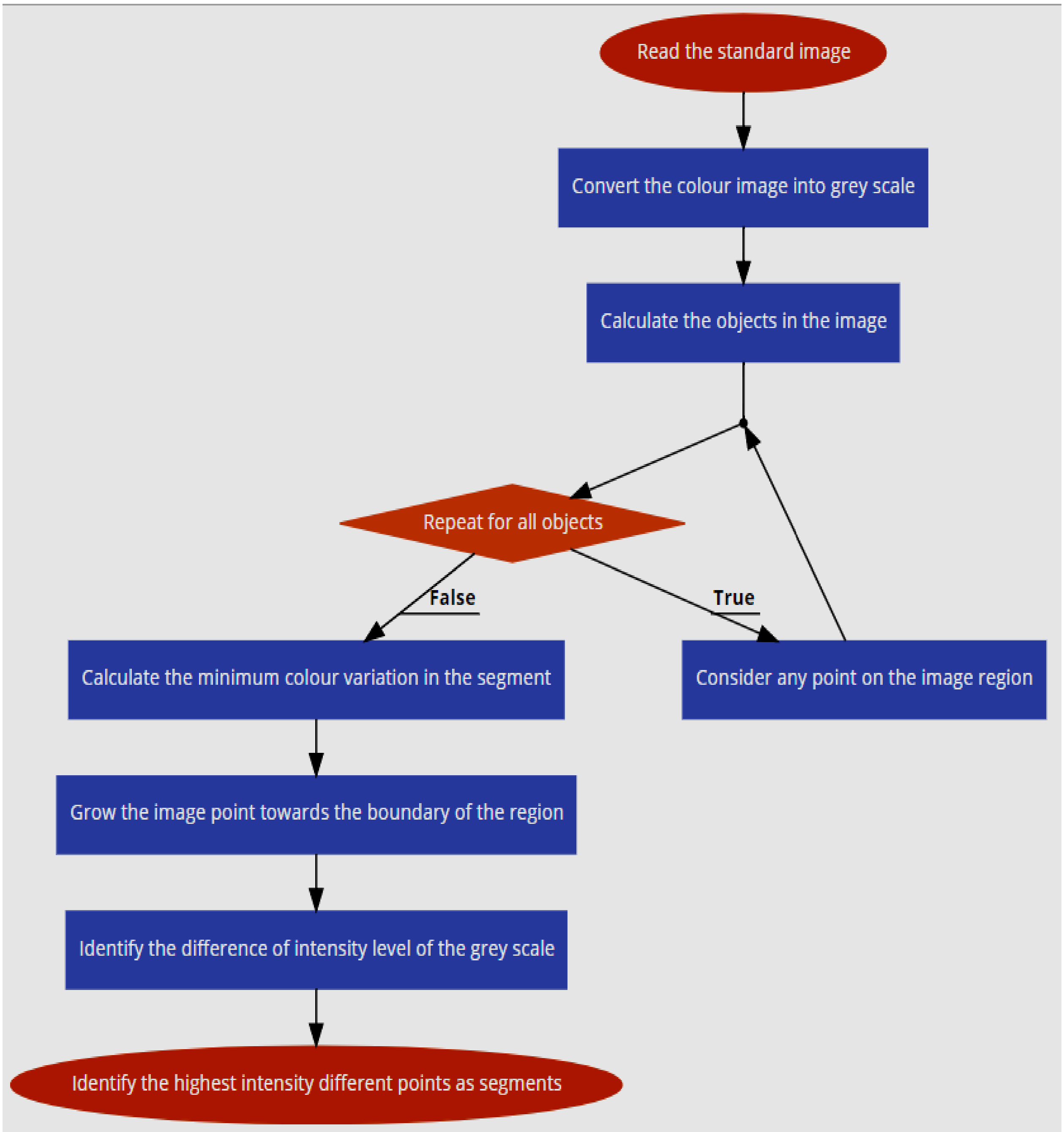

Figure 1. The algorithm.

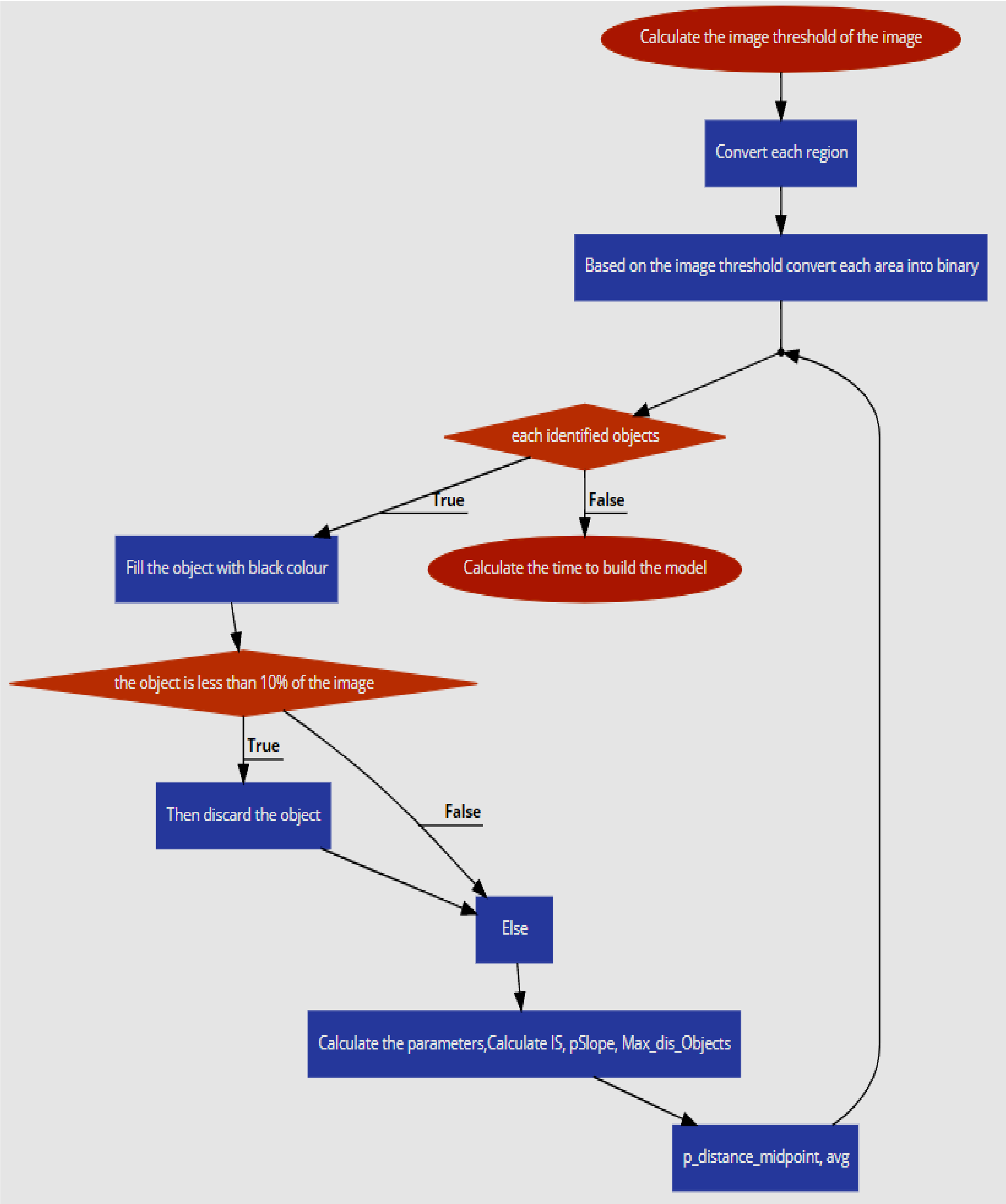

Fig. 2 Flow Analysis of the Algorithm

Henceforth, after the analysis of the proposed algorithm and flow of the algorithm, this work in the next section furnishes the comparative analysis.

V. COMPARATIVE ANALYSIS

In this section of the work, the comparative analysis is presented. This work analyses the existing popular frameworks based on the time taken to build the models and number of parameters considered. The proposed segmentation model also plays a major part in the final results, thus the comparison for segmentation methods are also been demonstrated.

A. Framework Description

The proposed framework in terms of time analysis is compared with the notable work by Edgar Xi et al. [35] presented in the year of 2017.

TABLE II: FRAMEWORK COMPARISON

Author	Framework Name	Time to Build the Model (Sec)
Edgar Xi, 2017	Good Road Points Detection	150
Umang Bhatt, 2017	Road Condition Detection	160
This Work Suwarna et al.	The Proposed Novel Parameter Extraction Framework	3.23

The visual analysis is also carried out for clear comparison, see fig. 4.

Fig. 3. Time Complexity Analysis

Thus it is natural to understand the significant reduction in the time complexity.

B. Parameter Description

Secondly, the comparative analysis is carried out based on the number of parameters considered in order to detect the potholes. The number of parameters used is significant as the complexity of the model will depend on this directly.
The analysis is furnished here [Table – 3].

TABLE III. PARAMETER COMPARISON

Author	Framework Name	Number of Parameters in the framework
Edgar Xi, 2017	Good Road Points Detection	10
Umang Bhatt, 2017	Road Condition Detection	10
This Work Suwarna et al.	The Proposed Novel Parameter Extraction Framework	7

Thus it is natural to understand the high reduction in the time complexity is majorly influenced by the reduction of parameters in the proposed system.

C. Segmentation Duration

Finally, as the segmentation is one of the key elements in the proposed algorithm, thus this work also compares the segmentation time complexity with the widely accepted segmentation methods. The comparison is furnished here [Table – 4]

TABLE IV. SEGMENTATION COMPARISON

Image Size	Segmentation Method	Time to Segment (Sec)
512 X 512	K – Means	1.64
512 X 512	Watershed	4.35
512 X 512	Proposed Method	3.00
1024 X 1024	K – Means	3.28
1024 X 1024	Watershed	8.75
1024 X 1024	Proposed Method	7.1

The results are analysed visually, see figure 4.

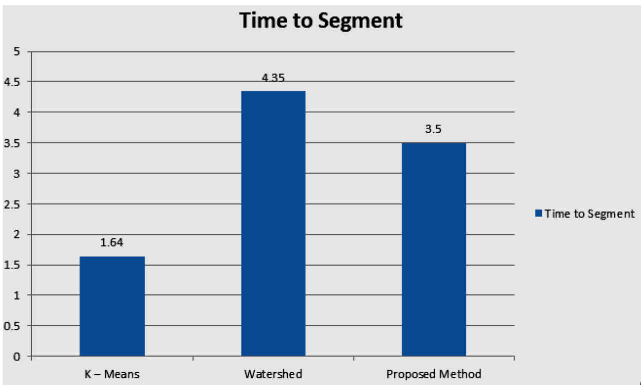

Fig. 4. Time Complexity Analysis

Thus the proposed segmentation method is also less time complex than few of the widely accepted segmentation methods.

VI. DATASET INFORMATION

The proposed framework is simulated over a customized data set, thus in this section the dataset information is furnished [Table – 5].

TABLE IV. DATASET INFORMATION

Parameter Name	Descriptions
Dataset Name	Indian Surface Maintenance Authority Image Samples
Dataset Source	Indian Surface Maintenance Authority
Number of Images	300
Images with Potholes	270
Images without Potholes	30
Maximum Image Width	397.55
Maximum Image Height	774.36
Minimum Image Width	27.47
Minimum Image Height	21.17
Maximum number of Potholes in image	3
Minimum number of Potholes in image	0
Maximum Image Area	382272
Minimum Image Area	3413

The sample images used from this dataset is overviewed here in figure 5.

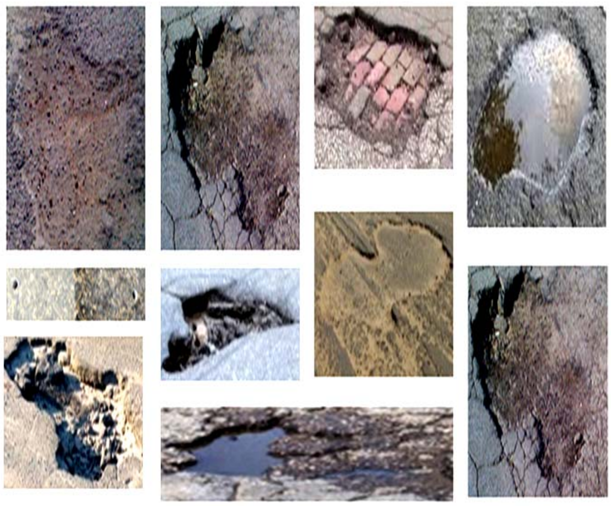

Fig. 5 Sample Data from the Dataset .

VII. RESULTS AND DISCUSSION

In this section of the work, the results obtained by deploying the framework are analysed.

Firstly, the number the objects per item are presented here, Table 6. Thus from this result it is natural to understand that multiple potholes can be detected from a single frame of road image. This significant improvement is due to the enhanced segmentation method used in this work.

TABLE VI. POTHOLE DETECTION

Data Item Name	**Scaled Area (mm)**	**Pothole Sequence Number**
Image 1	22263	1
Image 2	8579	1
Image 3	235494	1
Image 4	19994	1
Image 4	9110	2
Image 4	7644	3
Image 5	9333	1
Image 6	360747	1
Image 7	268105	2
Image 7	101208	1
Image 8	382272	1
Image 9	3413	1
Image 10	31347	1

TABLE VII. SLOPE ANALYSIS

Data Item Name	**Long Slope**	**Perpendicular Slope**
Image 1	-0.21	4.71
Image 2	0.33	-3.00
Image 3	-0.21	4.70
Image 4	-0.30	3.29
Image 4	-0.15	6.78
Image 4	0.23	-4.30
Image 5	0.65	-1.54
Image 6	0.72	-1.40
Image 7	0.78	-1.28
Image 7	0.60	-1.67
Image 8	0.75	-1.33
Image 9	0.17	-5.97
Image 10	0.45	-2.23

Secondly, in order to estimate the depth of the potholes which will be significant for determining the severity of the potholes and can enhancement the maintenance sequence. The results are furnished here [Table – 7]. The negative slopes defines the upwards slope in the potholes.

Finally, the height and width of the potholes are been analysed. The measures are in terms of the relative values based on the edges of the image. The results are furnished here, Table 8.

TABLE VIII: MEASURE ANALYSIS

Data Item Name	**Max distance between Objects**	**Perpendicular distance at midpoint**	**Average perpendicular width**
Image 1	250.46	122.23	88.89
Image 2	199.22	65.21	43.06
Image 3	976.34	266.06	241.2
Image 4	402.39	189.53	49.69
Image 4	246.64	182.18	36.94
Image 4	278.23	185.52	27.47
Image 5	166.98	99.18	55.89
Image 6	907.43	648.38	397.55
Image 7	870.4	755	308.03
Image 7	602.82	692.67	167.89
Image 8	1029.8	774.36	371.21
Image 9	175.41	21.17	19.46
Image 10	354.05	158.68	88.54

Also, the time complexity is analysed for each items in the dataset in order to calculate the average time in sec. The result is presented here, Table 9.

TABLE IX: MEASURE ANALYSIS

Data Item Name	Time to Complete the Analysis
Image 1	23.7738
Image 2	0.853967
Image 3	1.012129
Image 4	1.012515
Image 4	1.250677
Image 4	1.325774
Image 5	0.56209
Image 6	1.698221
Image 7	1.113475
Image 7	3.162341
Image 8	4.882278
Image 9	0.525377
Image 10	1.311954

Thus it is natural to understand the average time complexity to complete the process is 3.26 Sec. The result is analysed graphically, Figure 6.

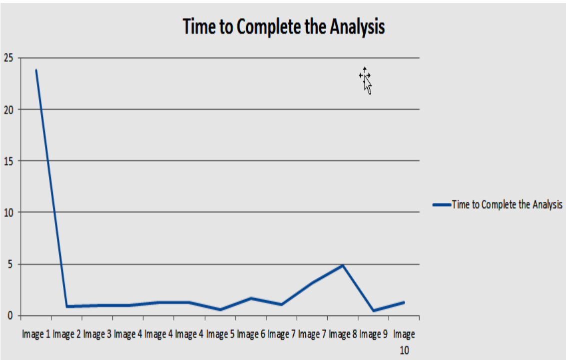

Fig. 6. Time Space Analysis

Also, this work presents some of the results after detection, see figure 7.

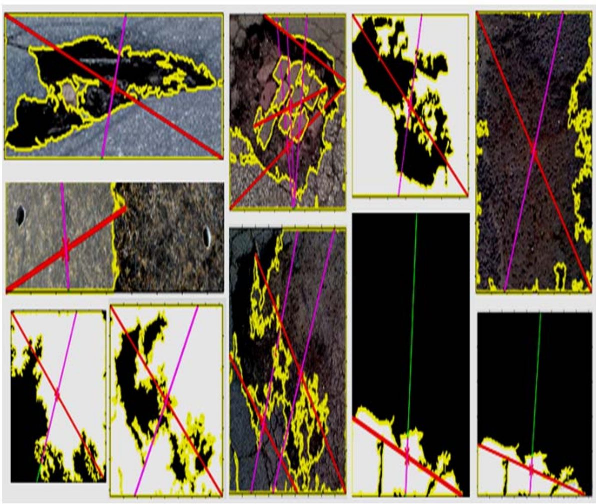

Fig. 7. After Detection results.

Hence, the results obtained from the framework are highly satisfactory and in the light of the experimental results, this work presents the conclusion in the next section.

VIII. CONCLUSION

For a growing nation, the road transport plays a major role in development and growth in terms of faster transport. The authorities are making significant efforts in order to make the roads better, faster and safer. Nonetheless, the roads demand a constant observations and regular maintenances. The traditional process of road maintenance is highly time complex and subjected greater human efforts. Thus the demand from the modern research is to build a framework for automatic detection of the road conditions by detecting the potholes on the road surface and generate automatic recommendation system for maintenance. This work presents a novel approach to detect the road potholes with significantly less time complexity and also capable of detecting multiple potholes in a single picture frame. Another outcome of this work is to discard the effects of colours and lighting during the image capture process and nullify the chances of false detection. The results from this framework is highly satisfactory with lesser number of parameters used compared to other existing parallel researches. Finally, the results of this work will significantly make the road surface maintenance easier and help the nation to grow faster.

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