Detection and Counting of Pothole using Image Processing Techniques

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Abstract—**Pothole are the primary cause of accidents, hence identification and classification using image processing techniques is very important. In this paper image pre-processing based on difference of Gaussian-Filtering and clustering based image segmentation methods are implemented for better results. From the results the K-Means clustering based segmentation was preferred for its fastest computing time and edge detection based segmentation is preferred for its specificity. The main goal of this paper is to identify a better method which is highly efficient and accurate compared to the conventional methods. Different image pre-processing and segmentation methods for pothole detection where reviewed using performance measures.**

Keywords—pothole; image processing; detection; identification; segmentaion

I. INTRODUCTION

Potholes are uneven surface found on roads and highways, which are made by constant vehicular traffic and weather conditions. These potholes are the main cause for the accidents which may be fatal.

Buza E.[1], Seung-KiRyu[2], Christian Koch[5], Manisha Mandal [6] used histogram and canny edge detection based segmentation for detection of Potholes. Many researchers most commonly use edge detection technique and thresholding technique to detect potholes.

Detection and counting of potholes using different image processing techniques helps in classification of different types of road profile. Pothole detection involves different processing methods such as image filtering, image segmentation and clustering techniques like edge detection, thresholding, K-Means and Fuzzy C-Means. The result where evaluated based on the traditional performance measures - accuracy, sensitivity, specificity and computational time.

II. IMAGE PRE-PROCESSING

A. *Image Resizing*

The original pothole image captured has high resolution and hence more information stored. Using original pothole image may take more computational time. So the image has to resized into lower resolution for faster processing and optimal segmentation. The main challenge in resizing the original image is to obtain a lower resolution image without losing its required properties and not losing its quality. So finding the resizing resolution is the first step for achieving better and faster results in image segmentation process. In resizing we should not have a fixed resizing resolution for example [200,200], because it may affect the aspect ratio of the image. If the aspect ratio is changed it badly affects the final results. So we have to resize without finite resizing resolution for example [NaN,200], it won't affect the aspect ratio of the image and provide a resized image with original shape properties.

B. *Grayscale Conversion*

The next step required for pre-processing is to convert RGB-image (original pothole image) into grayscale image using standard techniques to restrict the images to a single plane before image segmentation process.

C. *Median-Filtering*

The Median filter was used to remove random noise in grayscale image and give a smoothed output image. Also median filter maintains the integrity of image regions and boundaries.

D. *Difference of Gaussian-Filtering(DoG)*

The *DoG*- Filter was applied as a pre-processing filter to original pothole image for better edge detection with reduced noise. It finds the difference between two sigma values of two Gaussian profiles and find the edges in the grayscale image, refer [12]. It is given by (1),

$$\mathrm{DoG}_{\sigma}(x,y) \stackrel{\text{def}}{=} \frac{1}{2\pi\sigma^2}\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) - \frac{1}{2\pi(0.5\sigma)^2}\exp\left(-\frac{x^2+y^2}{2(0.5\sigma)^2}\right) \quad (1)$$

III. IMAGE SEGMENTATION METHODS

After image pre-preprocessing the next important step for pothole detection is image segmentation. The image segmentation uses different techniques for separating pothole area and non-pothole road area from the original pothole image. The original pothole image is manually segmented using GIMP2 software (open-source tool).

A. *Edge detection technique*

Canny edge detection technique was applied for identification of pothole edges and segmentation [6], [5], [2], [8]. Canny edge detection failed to give satisfactory performance with noisy image, hence the pothole image has to

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be pre-processed with filter for better results. The combination of canny edge detection technique and DOG-filter results in a better segmented image as proposed method.

B. Thresholding technique based on Otsu's method

Otsu's thresholding is an image segmentation process based on gray level intensity value of pixel in image. It involves segmentation of isolated objects by converting the grayscale pothole image into a black and white image. Image thresholding is an effective way of partitioning an image into a foreground and background. Image thresholding is most effective in images with high levels of contrast [1], [2], [11].

C. K-Means based Image clustering technique

The K-Means based image segmentation was done by taking a least square partition and cluster into a k-groups of objects. The clustering was grouped based on the n-observation and k- clusters of the nearest mean [1].

Observation are taken as a set of d-dimensional real vector (x_1, x_2......., x_n), where clustering was done based on n-observation into k ($\leq$n) sets of S= {S_1, S_2…., S_n} as to achieve cluster sum of square to minimum. It is given by (2),

$$arg \min_{S} \sum_{i=1}^{k} \sum_{x \in s_i} \|x - \mu_i\|^2 \quad (2)$$

- Random points are assigned for clustering at initial stage. The mean value was obtained for each clustering.
- The distance was calculated for each point from each cluster and assigned to each point to nearest to the mean value obtained from the corresponding cluster.
- The iteration continues until the sum of squared within group errors cannot be reduced anymore. The groups are obtained based on the geometrical compactness around their respective mean value.

D. Fuzzy C-Means based Image clustering technique

The Fuzzy C-Means based image segmentation was done by taking a degree of belonging to clusters. It allows clustering of one object which belong to two or more clusters. Thus the edge object in a cluster may be present more than the object present in the center of cluster.

In fuzzy c-means the means of all point is the center of cluster, weighted by their degree of belonging. At point x the set of coefficient that gives the degree of belonging in the k^{th}cluster- $w_k(x)$. The degree of belonging is inversely related to the distance center of cluster to the point x, and given by the parameter m which measure the weight of the nearest center.

The minimization is done based on (3),

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^m \left\|x_i - C_j\right\|^2 \quad (3)$$

Where m is a real number <1, c_j is the d-dimension center of the cluster , u_{ij} is the degree of membership of x_i in the cluster j, x_i is the i^{th} of the d- dimension measured data, and $\|*\|$ is the norm of measured data and the center.

Let X={x_1,x_2,……,x_n} be the set of data points and V= {v_1, v_2,….., v_c} be the set of centers

- The centers of the cluster 'c' are randomly selected.
- The fuzzy membership 'μ_{ij}'are calculated using (4),

$$\mu_{ij} = 1/\sum_{k=1}^{c}\left(d_{ij}/d_{ik}\right)^{(2/m-1)} \quad (4)$$

- The centers of fuzzy 'v_j' are calculated using (5),

$$v_j = \frac{\left(\sum_{i=1}^{n}(\mu_{ij})^m x_i\right)}{\left(\sum_{i=1}^{n}(\mu_{ij})^m\right)}, \ \forall_j = 1,2, \ldots\ldots c \quad (5)$$

- The iteration is repeated until the minimum 'J' value is achieved i.e. as in (6),

$$\left\|U^{(k+1)} - U^{(k)}\right\| < \beta \quad (6)$$

where,

'k' is the iteration step number

'β' is the termination criteria between [0,1].

'U = $(\mu_{ij})_{n*c}$' is the fuzzy membership matrix.

'J' is the objective function.

IV. POTHOLE IDENTIFICATION AND COUNTING

A. Black and white-Convexhull

It was used for generation of convex hull image from binary image. It computes the convex hull of each connected component of black and white individually. The convex hulling helps in shaping the connected black and white components i.e. pothole segmented area which provides better results for pothole detection.

B. Number of Black and white-connected components

By find the number of connected components in binary image i.e. the segmented image we can find number of pothole present. Eight neighborhood pixels where considered for identifying connected components [11].

C. Red-mask pothole detection

After detection of pothole to highlight the pothole area, perimeter of the black and white connected components is obtained. By changing the perimeter detected pixel as true in red-plane of the original RGB-image provides the red mask around the detected potholes [9].

V. PERFORMANCE MEASURES FOR VALIDATION OF IMAGE SEGMENTATION

After image segmentation the performance of the different segmentation techniques where evaluated. The following performance measures given in the literature [12] where considered for our study namely accuracy (Acc) as in (7), sensitivity (Se) as in (8), specificity (Sp) as in (9) and computation time.

$$Accuracy(Acc) = \frac{(\mathrm{TP+TN})}{N} \quad (7)$$

$$Sensitivity(Se) = \frac{\mathrm{TP}}{(\mathrm{TP+FN})} \quad (8)$$

$$Specificity(Sp) = \frac{TN}{(\text{TN+FP})} \qquad (9)$$

Where,

TP-number pixel that are correctly identified,

TN-number pixel that are correctly rejected,

FP-number pixel that are incorrectly identified,

FN-number pixel that are incorrectly rejected,

N-Total number of pixels, it is given by (10),

$$\text{N} = \text{TN} + \text{TP} + \text{FN} + \text{FP} \qquad (10)$$

VI. RESULTS AND DISCUSSION

A. *Original Pothole image sample*

The original pothole images, i.e. both single pothole and multiple pothole images are shown in *Figure 1*.

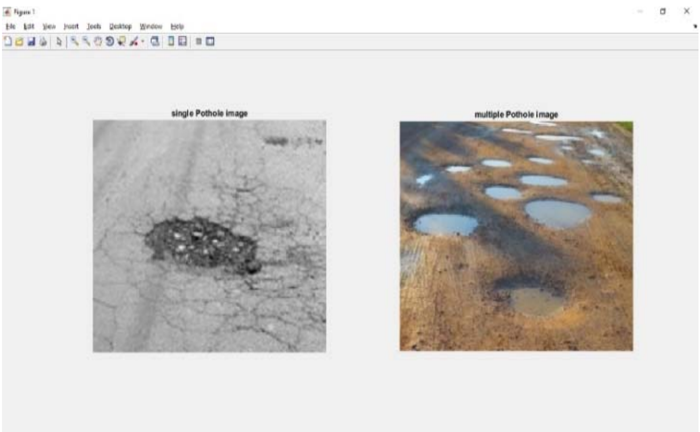

Figure 1

B. *Manually Segmented image sample*

The manually segmented images, i.e. the manual pothole segmentation is done by using GIMP2 software (open-source tool) for result validation are shown in the *Figure 2*.

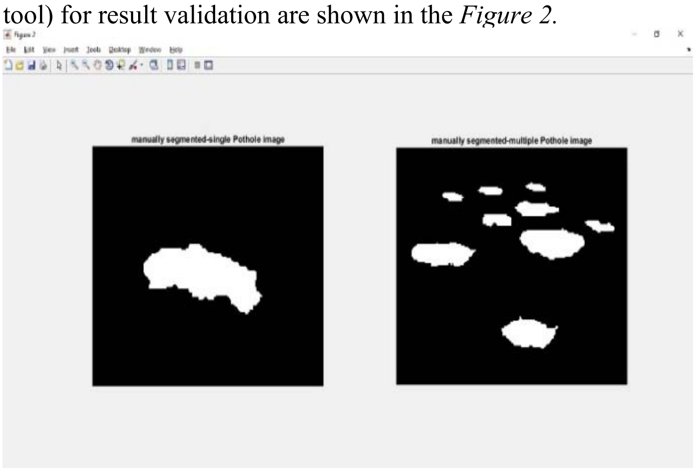

Figure 2

C. *Thershold segmented and pothole detected image sample*

The thershold based segmented image and the pothole counted and detected image are shown in the *Figure 3*.

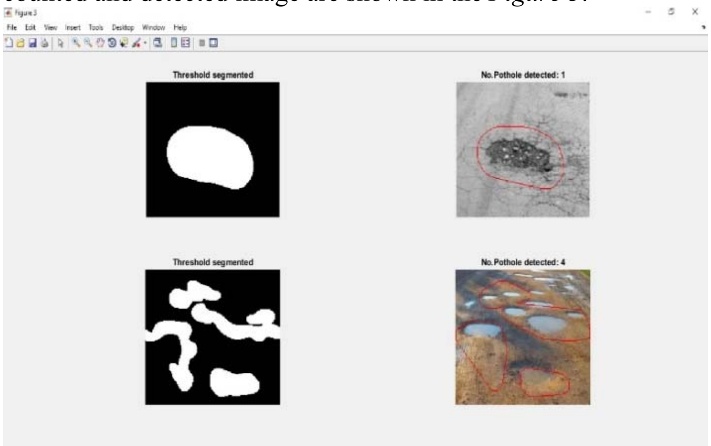

Figure 3

D. *Edge segmented and pothole detected image sample*

The edge detection based segmented image, the pothole counted and detected image are shown in the *Figure 4*.

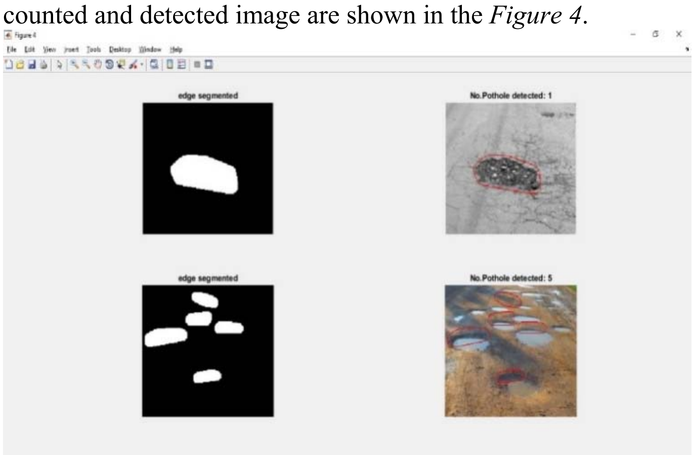

Figure 4

E. *K-Means segmented and pothole detected image sample*

The K-means clustering based segmented image, the pothole counted and detected image are shown in the *Figure 5*.

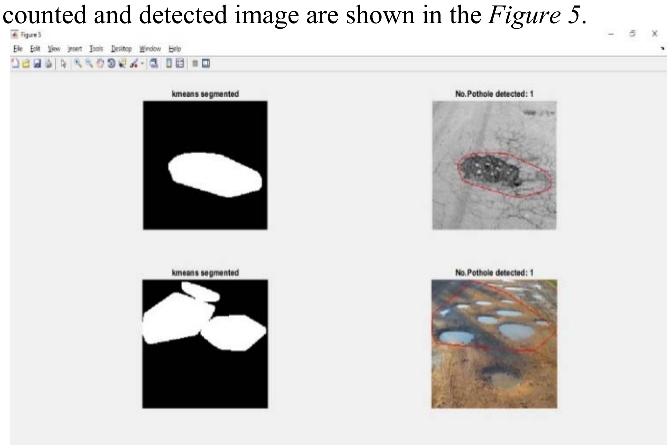

Figure 5

F. *Fuzzy C-Means segmented and pothole detected image sample*

The Fuzzy C-means based segmented image and the pothole counted and detected image are shown in *Figure 6*.

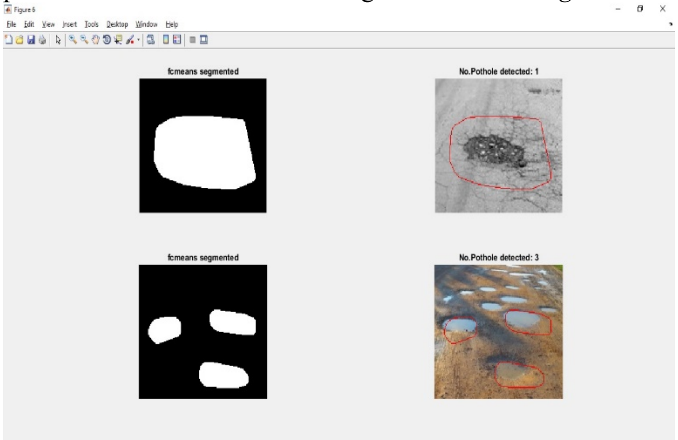

Figure 6

Comparison of different performance measures of the image segmentation techniques listed in Table I.

TABLE I. COMPARNG PERFORMANCE MEASURES

No. of samples	**Image segmentation technique**	**Performance Measures**			
		Average of Accuracy (Acc)	***Average of Sensitivity (Se)***	***Average of Specificity (Sp)***	***Compute time (s)***
20	Thresholding	80.6090	64.0402	83.0482	2.0476
20	Edge detection	90.1943	67.3474	93.1151	0.4950
20	K-Means clustering	82.4790	87.1834	82.2017	0.2766
20	Fuzzy C-Means clustering	82.4629	71.3947	83.6494	1.1028

The edge segmentation and k-means performs well in single pothole cases, refer *Figure 4*, *Figure 5* and TABLE I. For multiple pothole detection edge segmentation was better compared to K-Means, since K-Means was able to detects pothole with incorrect count, refer *Figure 6*. Moreover, K-Means is preferred for faster computation and better sensitivity, refer TABLE I.

VII. CONCLUSION

The Identification of different image processing techniques for pothole detection was done by comparing performance measures for different image segmentation techniques. The K-Means clustering based segmentation was preferred for its fastest computing time and edge detection based segmentation is preferred for its specificity, refer TABLE I. This work can be implemented in future for different automated application. My future work could be implementing these image segmentation techniques using hybrid classifiers like neural network and fuzzy rule base and to develop a standalone product for pothole detection.

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