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Smart Solution For Citizen's Road Safety From Potholes

Rohaan Khan[1], Uzma Khan[2], Saniya Manchekar[3], Er. Farida Attar[4]

[123]Final year student, Department of I.T, M.H. Saboo Siddik College of Engineering
[4]Assistant Professor, Department of I.T, M.H. Saboo Siddik College of Engineering

Abstract — *In developing countries like India, the most relevant problem related to roads are indigenous potholes or deteriorated pavements occurring naturally or due to human action. One of the major reason for these potholes are poor construction or pavements of roads as the asphalt used to pave the roads are insufficient or are of lower quality . This leads to pavements distress resulting in occurrence of potholes on the roads posing a risk to vehicles safety such as truck accident or traffic disturbance. The general solution for fixing potholes depends upon reporting the pothole to the concerned authority involved in the construction and maintenance of road. The overall procedure of identifying the pothole and informing the authorities can be tedious and generally include a large span of time. To ease the process of getting potholes fixed in favor of general public, there are many smart solution suggested by different authors which comprises of pothole detection system based on image processing techniques, dedicated hardware equipment and custom software. In this paper, we have studied and discussed different paper of authors for pothole detection and perform a comparative study for suggesting the best available approach by highlighting the proposed method of the authors by summarizing their work.*

Keywords- *Image processing, Accelerometer, Sensors, Stereo Vision, Sampling.*

I. INTRODUCTION

Potholes are road pavement defects mainly caused by depression on road surface or asphalt pavement where continuous traffic had removed the disturbed pieces of asphalt which are ejected from the surface to form surface gaps or minor holes on the road surface. These potholes are major concerns when it comes to road safety as the most fatal problem associated with road accident. It is estimated by U.S Department of Transportation that in the year 2014, 32,675 people died in motor vehicle traffic crashes in America [1]. Whereas in Europe in the same year, 25,700 people died on the road and almost 200,000 people involved in the accident suffered life changing injuries [2]. In both the cases pothole being the major cause of the mishap. Potholes occur due to many factors. Formation of potholes requires presence of two main factors at the same time i.e. water and traffic. Water being the main activator, after it leaks into the road surface it creates depression between underneath particles of pavement causing fatigue of the road surface. This process leads to forming of cracks on the road surface formally known as crocodile pattern cracking. Eventually the continuous traffic on the road causes these cracks to expand and bits or chunks of pavements gradually work loose due to these expanding cracks and form depression or uneven surface to form a pothole [3].

Figure 1. Crocodile pattern cracking

Potholes vary in different sizes ranging in cm to several feet in width. Potholes of small sizes mainly create small bumps for vehicles passing by, but large potholes are of grave concerns on roads where vehicles travel at a faster speed causing accidents. Potholes are formed in one of the scenarios mentioned below [3]:

1. If the paved asphalt is of inappropriate thickness, leading to faster deterioration of the road surface.
2. If proper drainage is not provided on rain clogged roads resulting in road surface absorbing much larger volume of water, than it can handle.
3. Pavement defects and cracks formed during rainy season if left unchecked and improper maintenance.

Solutions to fixing pothole in general include survey by government authority of the roads targeting locality where case of road fatality are usually higher. This is most likely true in cases of highways where fixing potholes are first priority for the authorities. Nevertheless, this approach is marred by financial priority or may include political bias involving fixing of potholes in upmarket locations and neglecting destitute localities.

One approach is citizen reporting potholes to concerned authority which may include government agency or department responsible for fixing potholes in their localities and may require a participant to call on the helpline or lodging complaint through letter or online. The problem associated with this approach mainly revolves around general participation of public which is unreliable and may be not the most effective in most cases.

As shown in studies [1], [2] there is a significant amount of improvement required in processes involving fixing potholes. Some of the solutions proposed involve pothole detection system based on image processing techniques which works around an image of a pothole taken from a device [4]. This system focuses on accuracy parameter where main goal is to maximize the accuracy of pothole detection through available techniques [4]. Another Solution involves [5] a dedicated device (android smartphone) where the inbuilt accelerometers are optimized to use them in detecting incoming potholes. In [5] a whole system is proposed which help user through a smartphone device that is travelling in a vehicle to become aware of incoming potholes.

The following chapter provides a brief summary and comparison of techniques used in detection of pothole and suggests the best possible techniques and system as solution to fixing the problem of pothole.

II. METHODOLOGY

A. Detection and Counting Of Pothole Using Image Processing Techniques

In [4] image processing techniques are leveraged where pothole images are processed in series of steps which include detection, identification and segmentation. This process is proved to be highly successful in achieving maximum accuracy which is the goal of the process. Performance measure are used to compare the image processing techniques where image segmentation being the final stage of whole process, is used as basis for comparison of parameter in different image processing techniques. The performance measure includes average of accuracy, specificity, sensitivity and compute time. Compute time is proved to be a major hindrance for processing images as high quality images are required for better results but may increase the overall computing duration hence additional steps are undertaken to lower the compute times in all comparison techniques. The initial phase of the approach involves partial steps which focus on lowering the overall size of the image and processing only useful areas neglecting unusable components of the input image. These steps are termed as image preprocessing where a series of task are performed on the raw input image thus making it compatible for further processing in future phases of the approach.

First task of image preprocessing involves image resizing where a raw image is resized in a fixed image format with dimension [200px, 200px]. The dimension ensures that the image is of appropriate size for further processing and also reduces size of the image which in turn lowers the computational time for the overall process. Next task include grayscale conversion where the RGB of image is reduced to include only black and white to eliminate unusable component and highlight target subject (pothole). Succeeding steps involves applying median filter to reduce overall noise in the image resulting in smoother image and applying DoG (Difference of Gaussian) filters. DoG filters is applied to detect the edges of the highlighted pothole and reduce extra noise that may be present in the resulting image. This concludes the image preprocessing phase.

The next phase deals with image segmentation where pothole image area is separated from non-pothole road area from the pothole image. Here the author has taken into account different image segmentation technique for processing the image and compare them based on performance measure and suggested the best overall techniques. The evaluated techniques include combination of Canny edge detection method and DoG filters [6], Thresholding technique based in Otsu Method [6], Fuzzy C-Mean based image clustering technique and K-Mean based image clustering technique [6]. The Evaluation yielded result which is compared and of all the K-Mean based technique is found to be better overall against all other methods. It has the highest overall score in average sensitivity, lower compute times but fall short of average accuracy where it yielded lower score against canny edge detection method. Thus in conclusion [4] suggested K-mean clustering based image segmentation for its lower compute time and edge detection based segmentation was preferred for its accuracy and specificity.

B. Image Processing-based Pothole Detecting System For Driving Environment

An automatic pothole detection system based on image processing through a camera is suggested in [8]. This approach focuses on three main characteristics of a pothole the dark region, rugged texture and the round shape, as opposed to evaluating different techniques in [4], [8] discusses 3 approaches for pothole detection, one [9] where a 3-axis accelerometer is setup on a car and alert about the pothole when the car passes over the pavement defect and the sensor reacting to it. But has a backdrop as the system require the car to go over the pothole where in real time system cannot estimate the potholes which are not encountered by the car hence accuracy of the system takes a hit despite costing less. The second approach [10] involves a laser sensor embed on the car which scan the road environment to detecting the depth of potholes rendering higher accuracy but includes higher cost and slower processing times. [8] Suggest an image processing based camera sensor system focusing on main characteristics of potholes where the principle of parallel processing is emphasized using super pixel, wavelet energy field and differential. Super pixels are used to cluster similar pixel of the grayscale image and outlines the clustered pixels. Since the dark region of the pothole includes similar dark pixel the superpixel outline the darker region segmenting the structure of pothole from the rest of the image. The wavelet energy field highlights the texture of the image. Superpixel clusters all pixels in the image into cells. The wavelet field is then used to differentiate between the cells of pothole and the rest of the image. The differential method is used to congregate the similar pavement of asphalts and separating the rugged texture extracted from wavelet field to form a better segmented image. The three frames formed during three processes, where the third differential based frame is subtracted from the first two to form the better distinguishable highlighted image. The pothole is then detected from the three intersection methods. The final accuracy achieved from this approach is approximately 93.06% applied on 1920x1080px based video downgraded to 800x200 pixels images having 38137 frames collectively.

C. Real Time Pothole Detection Using Android Smartphones With Accelerometers

It proposed an automated pothole detection system as a service layer which can be integrated into a car navigation system where sensor data was collected voluntarily from the user smartphone and evaluated to detect pothole. The proposed system targets data collected from smartphone's accelerometer and leverages the accelerometers data processing for a less resource intensive approach for pothole detection [5] suggests though modern smartphone have high processing power and modern CPU architecture, but the approach for pothole detection should not be resource intensive and rather focus on user responsiveness. This approach involves collecting initial test data from accelerometer sensor using a modified lynx collar device. The device from which initial data is extracted is based on Tmote Mini sensor node with Texas Instruments micro-controller MSP430F1611 and Analog Devices 3-axis accelerometer ADXL335. ManOS are used as setup software for collecting raw acceleration data at sampling rate of 100 MHz [11].
RoadMic Pothole Detection technique is utilized for extraction of test data. Using the acquired data events are recognized when an accelerometer in a car encounter a pothole. For this, four algorithms are tested that classify the measurements as the values exceeding specific thresholds to identify the type of the potholes (Large or small) that the accelerometer can encounter. Z-THRESH algorithm is evaluated on the data which requires virtual reorientation of accelerometer hence the procedure becomes lengthy since assumption is to be made in every estimation, as accelerometer is assumed to be in 3-Dimensional space. The Z-DIFF algorithm is utilized where virtual orientation is eliminated and accelerometer is setup in a fixed placement making the procedure simpler. The next algorithm STDEV (Z) involves standard deviation of vertical axis acceleration. However determining of window sizes of time and threshold level for tuning of the selected algorithms are still a problem. This problem is solved by developing an algorithm termed as G-ZERO by the authors. This algorithm is conceived on basis of two conclusions one where data tuples consisting of evaluation of data can be acquired when car is entering or exiting pothole and the other where the data tuples can be analyzed without requiring information of Z-axis position of accelerometer. After complete evaluation of all dataset with all the mentioned algorithms Z-DIFF yielded near perfect result giving 92% accuracy in all test scenario(large and small potholes, gaps, clusters etc.), where STDEV(Z) coming second yielded 81% and Z-THRESH on third spot with 78% accuracy and self-developed algorithm G-ZERO with Lowest accuracy of 73%. Thus in conclusion the proposed system achieved higher accuracy when accelerometer have controlled placement eliminating determination of Z-Axis, and can recognize nearly all categories of potholes.

D. An Efficient Algorithm For Pothole Detection Using Stereo Vision

Unlike the use of an image sensor or accelerometer sensor, [12] proposes a pothole detection system based on a stereo vision camera. [12] argues though camera sensor are cheap they capture less information and require intensive processing to reveal greater details and are vulnerable to environmental parameters such as light condition, where an accelerometer sensor requires, the vehicle to be driven into the pothole which may cause damage.
In [12] the authors suggest use of stereo vision camera can overcome the difficulties as it is not vulnerable to environmental condition and can capture finer details without the need for the vehicle to encounter any danger. Stereo vision methods capture 3D measurements of the subject thus size and depth information van be determined by stereo vision approach without the need of high cost laser scanners. However one difficulty in using stereo vision is generating disparity maps with high accuracy. To tackle this authors have implemented a self-developed disparity calculation algorithm. This algorithm include three steps matching cost computation, search range recalculation and, disparity enhancement. First step involves calculating cost volume of each pixel for finding the overall cost function. This is done by generating a controlled search range. When a road encounter obstacle, this information is relay on the image. Hence this obstacle will create a disparity between current pixel and the pixels in the lower line. By exploring this disparity we can generate a smaller search range of disparity values. This result in a lower ambiguity and much faster and accurate calculations as compared to evaluating exhaustive search ranges using advanced search algorithms. After disparity calculations the coordinates are then converted to world coordinates system (x, y, z). Now surface fitting algorithm is

utilized and the point which corresponds lower than road surface can be considered pothole. Now the point cloud which belongs to the pothole can be selected by using threshold of value 0.04m on the Euclidean distance between each point and the surface. After pothole 3D points are determine, the identical pixel in disparity maps are segmented and then a component labeling algorithm is used to labeled pothole areas on the road. This data is used to calculate pothole's volume on the point cloud formed on the disparity map. The results of this approach yield higher positive when region of interest (ROI) is defined in front of the vehicle where region of interest is the portion where the stereo vision camera captures its input.

E. Real-Time Pothole Detection on TMS320C6678 DSP.

This paper proposed the solution for pothole detection which is implemented for TMS320C6678SoC. The proposed algorithm is based on [12] but is further tweaked to achieve higher detection accuracy. The proposed system uses the concept of sampling which requires prior knowledge of the road surface. Sampling algorithm uses prior knowledge of point distribution and randomness. The data sampling uses the grid of points which is a strong computational solution and is helpful in detecting the pothole. The algorithm is also using data sampling techniques like RANSAC, Random Grid. In this paper the pothole detection system achieves real-time performance with 145fps and 100images with a resolution of 1050x600 pixels. The performance of the system can be improved by using parallelization of the code. These include OpenMP, OpenCL, OpenMPI and OpenEM. OpenMPI algorithm uses the concept of fork-join which means that several "worker" threads are forked before the parallel region by the "master" thread and jointed after. It also uses the concept of pothole detection and clustering and is based on the concept that we can detect the pothole by considering one point which has disparity value lower than actually predicted mode. [13] It focusses on minimizing the computational complexity in generating the disparity map and detection algorithms. Hence sampling algorithms like RANSAC and Random grid is incorporated to for making the disparity map easier and filter out the noise of depth map of the road. The prior knowledge that the sampling techniques leverage aims to improve the detection rate of pothole based on the assumption that a corresponding pothole may appear in multiple frame if prior sampling is provided to disparity calculation algorithm. This increases the positive hit of surface fitting algorithm where point cloud (indication of potholes) are more accurately labeled on the depth map of the road which in turned is correctly labeled on the final result yielding much higher accuracy in controlled environment.

III. DISCUSSION

Comparison of different approaches of pothole detection by major researcher and authors

Table 1. Comparison of different approaches of pothole detection

SR. NO.	AUTHOR	DETECTION METHODS	METHODOLOGY	ALGORITHM USED	EFFICIENCY
1	Zhen Zhang, Xiao Ai, C. K. Chan and Naim Dahnoun [12]	Stereo Vision based	Extracting 3D information using computer vision	Disparity Calculation Algorithm,	75%
2	Aliaksei Mikhailiuk ; Naim Dahnoun [13]	Comparing Disparity values	Prior knowledge of road surface, OpenMp Api, RANSOM, Random grid	Sampling Algorithm	98% with 1050x600 pixels
3	Vigneshwar.K ; B. Hema Kumar [4]	Image processing→ Canny edge detection, thresholding,	Difference of gaussian-filtering & Clustering based img. segmentation	K-means, Fuzzy c-means	90-95%
4	Artis Mednis, Girts Strazdins, Reinholds Zviedris, Georgijs Kanonirs, Leo Selavo [5]	3 axis acceleration sensor, laser sensor, camera sensor	Event detection Z-thresh, standard deviation of vertical axis acceleration	Grayscale image processing algorithm, superpixel	83-90%

IV. CONCLUSION

The aim of the paper is to survey best available approaches for solving the problem of pothole and suggest the most appropriate for global scale implementation. From the surveyed paper majority of the approaches focuses on pothole detection using combination of hardware like camera image sensor, stereo vision camera and software such as image processing libraries along with the use of mathematical algorithm like sampling algorithms (random grids, RANSACS)

Z-DIFF algorithm. The best available approach [12] is found to be use of Stereo vision camera approach where sampling algorithms are utilized and results are based on comparing the disparity value generated on a disparity map. This approach [12] yielded a near perfect 98% accuracy in results when evaluated. Another low cost implementation [5] that is suggested is the use of accelerometer based smartphone where disparity in its sensor data and its standard deviation is used to detect pothole when the smartphone is setup is a controlled placement inside a vehicle and the Z-DIFF algorithm is used to determine the disparity in accelerometer 2-D orientation. This approach [5] gives result close to 92% in a test drive where a smartphone is setup in a vehicle driven on pothole loaded road.

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