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Road Pothole Detection

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Abstract: *Highways and roads are arguably the most used forms of transportation in our day and age and their safety and condition is very important. While Image Processing for maintenance and detection in the transportation field has gained popularity over the last half-century thanks to development in technological areas, there is still more that we can learn and apply as Image Processing is still not utilized in this field to its fullest. The aim of this study was to explain Image Processing techniques and how it can be utilized in a multitude of scenarios in highway and road maintenance. This study describes Image Processing as a whole and continues with how Image Processing is used in the detection and maintenance of the following: Potholes, Rutting of Asphalt Terrain, Pavement Cracks and Surface Roughness which are hazards when it comes to road and highways. In addition, the effectiveness of these methods is explored and evaluated through research and comparison of the methods at hand, with attention towards accuracy and precision. Results showed promising views on the usage of Image Processing in these fields, as a generally easy and cost-effective way. Results are discussed and compared individually for each part where a different scenario or method is at hand.*

Keywords: Machine Learning, Pathole, CNN, IOT

I. INTRODUCTION

Over the last few decades, it has become increasingly easier to travel to and from places as the quality of transportation has improved. In current times we have come accustomed to an exceptional level in transportation, the roads and highways used for travel come to mind. They play a major role in the connection of cities, villages and even countries and they are arguably the most used form of safe transportation. From all this usage and other natural causes comes deterioration, so for these road networks to run smoothly and safely, frequent check-ups and maintenance is important. After all, these roads and highways used every day are man-made, so they are not perfect. If left unattended these roads can develop serious hazards, which can be a nuisance and even a threat to the safety of people. For proper maintenance and detection of these hazards, which should be cost-effective and safe for the work force an automated system can be the best solution. Thus, Image Processing comes to mind. The usage of Image Processing techniques is applicable to a multitude of situations in road network maintenance and detection. For the purposes of this paper the application of these techniques is discussed in four different hazardous areas, which are potholes, rutting of asphalt terrain, pavement cracks and surface roughness. Thanks to the development of imaging technologies over the last decade, Image Processing techniques require minimal manpower and makes the maintenance and detection of such hazards an easy task, at a cost-effective rate. Therefore, Image Processing is an effective solution to current highway maintenance and hazard detection tasks.

II. THE EVALUATION OF ROADWAY SURFACES USING THE IMAGE PROCESSING METHOD

The evaluation of road surfaces conditions is an essential task for many countries, especially in countries where the roads are inspected regularly. Roads that are well maintained increase the comfort levels and safety of the road users. Due to effects such as topographic changes, human damage, thermal contraction and expansion, and ageing the roadway surfaces surfer breaks in their internal structures and on their surfaces. It is therefore important to monitor the road surfaces continuously to ensure the roads remain safe and comfortable [1]. Some of the factors taken into account when estimating the conditions include the surface degradations, the macro texture of the service, the micro texture of the service, and the adherence of the roads [2]. Results from various studies show that with optical image processing, the results of the evaluation of the road conditions have been more promising. The essay, therefore, aims to find out some of the reason why the image processing method is the best for monitoring the roadway surfaces conditions.

How the image processing method works

The image processing devices are divided into five parts; the terminal for sensing images, laser sensors for sensing distance, image processing and storage servers, the central control system, and the speed sensor [3]. According to the authors, CMOS line scan cameras collect the original images. The colour images are then transferred to gray-scale images for processing. After the images for the surfaces have been collected, they are stitched using image mosaic algorithms and then presented for processing. During the processing phase, an effective filter is used to smooth the original images. An average filter should be used for the smoothening process since if the filter is too large, the details of the cracks will be eliminated while a small filter will smooth the original images correctly.

The image processing method detects four main types of cracks, alligator, block, transverse, and longitudinal cracks [4]. According to the authors, the shape of the type of the crack is determined by calculating a shape factor. The shape factor involves calculating the average of the sub-blocks and subtracting it from the spread. The spread on the other hand is the number of pixels that are greater than the mean of the sub-blocks around the mean. The shape factors derived from the calculations are then used to determine the shape of the cracks.

Why image processing method is used

One of the main reasons why the image processing method is used id that it allows a dense acquisition of the road surface [2]. The authors argue that imaging process method has the ability to acquire the conditions for the entire road service unlike other methods like in laser method where measurements of the roadway surfaces conditions are available at every four millimetres. The image processing method is capable of providing measurements at each millimetre.

The image processing method is very useful for the traffic information system as it enables the observation of the road surface conditions that are not observable by other methods [5]. Another reason why the image processing method is widely used is due to the fact that the acquisition systems used for processing the road surface images are easier to used compared to other systems. The systems are less sensitive to movement as well as to vibrations than the other methods used to monitor the roadway surfaces.

Image processing methods also give a precise measurement of the defects detected on the road surfaces [2]. The images provide enough information and allow acquisition of the road conditions at each millimetre hence improving the measurements provided. Lastly, the image processing method also provides more contrasted images. The optical sensors used in the devices are able to provide a higher ratio between the signals and the noise hence providing images with high contrast.

The algorithm used for image processing is able to find more than one crack in the roadway surfaces as well as give numerical statistics for each crack [4]. Some of the statistical data provided by the digital images include the length and depth of the cracks. Another reason why the image processing method is better than other methods is its ability to sense noises that are not perceived as important to the human eye. The algorithm used for the method is able to detect the little noise caused by the roadway surfaces marking.

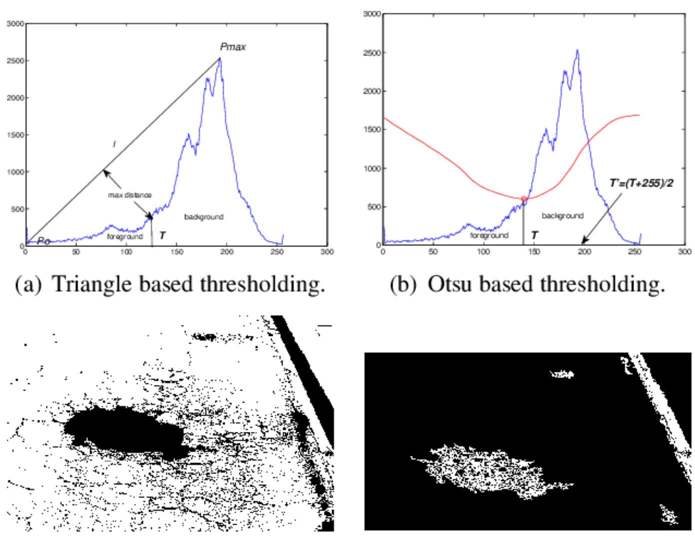
The image processing method is the best method for monitoring roadway surfaces conditions. The method is used since it allows a dense acquisition of the road surface. Imaging process method has the ability to acquire the conditions for the entire road service, unlike other methods like in laser method where measurements of the roadway surfaces conditions are available at every four millimetres. The image processing method is capable of providing measurements at each millimetre. The image processing method is very useful for the traffic information system as it enables the observation of the road surface conditions that are not observable by other methods. The algorithm used for image processing is able to find more than one crack in the roadway surfaces as well as give numerical statistics for each crack.

III. POTHOLES AND THEIR DETECTION USING IMAGE PROCESSING TECHNIQUES

Potholes are deformations that form on a road surface, which can be problematic, if the necessary road inspections are not done and they are allowed to form. They can lead to vehicle damage and even accidents if left unchecked. Before going to the process of how they can be detected using image processing, it is important to understand how they are formed. According to [6], potholes which are a bowl-shaped deformity can be caused by internal effects like pavement erosion due to water accessing it, change in climate like large amounts of rainfall and external factors such as poor manufacturing and large amounts of traffic. Figure 1 below shows an image of a pothole.

Pothole example

As can be seen from the image, these potholes can be a nuisance, as they are difficult to see when driving. So, this makes their detection an important part in maintenance and the fixing process. Thisis where image processing comes in to play. As technology has improved it has become easier to useimage processing in the detection of these potholes. However, there are steps when it comes to imageprocessing and the first can be specified as image segmentation. “Image segmentation is the crucial first step of pavement distress detection. Its accuracy and reliability are critical for subsequent potholeidentification” [7]. Knowing this, it can be said that the method or methods chosen for image segmentation are important. [8] States that there are multiple ways of performing image segmentation,which include thresholding, clustering, transform and texture methods. They continue their statementby saying that thresholding is simplest of these methods is histogram-based thresholding which usesthe assumption that an image is composed of different color or grey areas. Figure 2 below shows a comparison of two thresholding methods used on the same image of a pothole.



(a) Triangle based thresholding. (b) Otsu based thresholding.

(c) The result of binary image calculated with threshold T. (d) The result of binary image with threshold T’.

Figure 2: Two different methods image segmentation for the pothole image [8]

Retrieved from: https://theconversation.com/potholes-how-engineers-are-working-to-fill-in-the-gaps-102055

After image segmentation comes the process of identifying and counting of these potholes. This process can be a difficult one, as some potholes may not be easy to identify as others, they may haveragged edges, they may be confused for cracks and they may have water sand and other debris that fill them which makes it difficult to spot them. This is where image processing comes into great use,as even a simple method with the use of a normal camera that did not require any machine learning gives promising results in the detection of these potholes. Displayed below in Table 1 is the results of a study conducted in this manor by [9] which states that their study shows a precision of 81.8% and a recall of 74.4%. Their study also states that it presented a good method for detection of potholesin a range of 2-20 meters, by the usage of a single optical camera.

Table 1. Results of algorithm [9]

True Positives(TP)	False Positives(FP)	False Negatives(FN)	Precision (%)	Recall (%)
72	16	24	81.8	74.4

From here it is possible to see how effective image processing is regarding the detection of potholes,even with a simple method that only uses a single optical camera. Even though this is only applicableto certain situations, with improvement it could become a simple and effective way for the usage of Image processing in the detection of potholes. Finally, to apply all this information on Image processing, performance of these individual methods should be looked at, so we can determine the effectiveness, and help in the selection of method to be used. "The Identification of different image processing techniques for pothole detection was done by comparing performance measures for different image segmentation techniques" [10]. The results of their study can be found in Table 2 below.

[10] explain these results by saying that edge segmentation and k-means perform well for cases witha single pothole, whereas for multiple pothole detection edge segmentation is better compared to k- means. They add that k- means is good for fast calculations and better sensitivity.

Table 2. Comparing performance measures [10]

No. of samples	Image segmentation technique	Average of Accuracy (acc)	Average of Sensitivity (se)	Average of Specifity (sp)	ComputeTime(s)
20	Thresholding	80.6090	64.0402	83.0482	2.0476
20	Edge detection	90.1943	67.3474	93.1151	0.4950
20	K-meansclustering	82.4790	87.1834	82.2017	0.2766
20	Fuzzy C- means clustering	82.4629	71.3947	83.6494	1.1028

In summary, potholes are a dangerous hazard which have to be dealt with, but with Image processingwe have multiple methods of identifying them. With improving advancements in technology every day, detection and prevention of these potholes will become even easier, thanks to image processing.

IV. MONITORING RUTTING OF ASPHALT PAVEMENT THROUGH IMAGE PROCESSING

Rutting is a phenomenon whereby there sure surface depressions in the wheel path of the vehicles. Shearing and pavement uplifts occurs mostly along the sides of the rut. These may appear particularlyafter rains when the road surfaces are filled with water. There are two types of rutting; mix rutting and subgrade rutting. Mix rutting occurs when the subgrade does not rut but the pavement surface exhibits wheel path depressions due to compaction or mix design problems. Subgrade rutting occurswhen the subgrade exhibits wheel path depressions due to heavy loading. These may cause hydroplaning which is a hazardous condition that causes a pull towards the rutting paths.

There many methods to monitor this phenomenon and proposing new indices to relate and explain rutting resistance in asphalt pavements. The internal structure of the aggregates provides the skeletonsof the asphalt concrete and this plays a great role in the resistance of rutting. This structure can be captured using a combination of image analysis indices developed in this research, namely: number of aggregate-on-aggregate contact points, contact length/area, and contact plane orientation. These parameters are defined for both the total aggregates and for the effective load bearing aggregate structure, referred to as the 'skeleton' in this study. There is software which is designed in a study which are used to process digital images of a set of asphalt mixtures with different gradations bindercontents, type of modifications and compaction efforts and the results show the correlation between the internal structures indices and the mixture rutting performance. [11]

Figure 3: Rutting example

Rutting also occurs in hot mix asphalt (HMA) especially in summer seasons and slow moving traffic areas. Two rutting components (densification and shear disappointment) of HMA tests led in the HWT (Hamburg Wheel Tracking) gadget were controlled by Image Processing and Analysis rendition 2 (IPAS2). Results show that HMA tests under the dry HWT test can display both rutting instruments in which regularly happen in the field. Likewise, the dry HWT test shows a generally excellent R2 for a connection of creep incline with the limited and unconfined FN (flow number) test. [12]

In another study, a new approach was used to evaluate the changes in the asphalt concrete microstructure under full scale accelerated pavement test loading with a Heavy vehicle simulator of composite pavement. The methodology looked at X-beam registered tomography (CT) pictures taken when HVS trench testing. Results were utilized to distinguish the distinctions in the development of total and changes in air-void substance and circulation happening during rutting collection of rubber treated hole reviewed and polymer altered thick evaluated blends for two overlay thicknesses (64 and 114 mm). Although high air void substance for the segments built with rubber treated hole reviewed blend were relied upon to cause more densification related rutting and before disappointment identified with this densification, the genuine explanation for the prior disappointment was resolved to be essentially more prominent shear stream to the sides of the wheel-path related with the hole degree and little total size. [13]

It is significant to capture the microstructure attributes and development of asphalt blends since it is very much identified with the macroscopic asphalt execution. The X-ray Computed Tomography (CT) method is an appropriate possibility to accumulate and dissect the image information of the internal structure for materials. An advanced repeated load permanent deformation (ARLPD) test that could generally reenact the confining pressure and the temperature gradient of actual asphalts was conducted on several typical newly constructed and overlay pavement structures. CT and digital image handling methods were utilized to portray the development conduct of microstructure and damage in asphalt layers before and after testing at high temperatures. Combining the macroscopic pavement performance with microstructure evolution, the failure mechanism for different pavements and layers was finally discussed. [14]

A significant reduction in air void content of the core samples after accelerated pavement rutting test was seen as a result of the X-ray CT image processing. The highest air-void reduction was concentrated at the bottom of the OGFC layers. Permeability measurements also showed a 40%–90% reduction in permeability after APT trafficking. X-ray CT image processing of core samples tested under simulated rainfall showed that air void content reduction is concentrated in the lower part (2– 6 mm from the bottom) of the OGFC layers as a result of particle accumulation. [15]

V. PAVEMENT CRACKING DETECTION

Detection of pavement distress has a key role in the maintenance of highway and its rehabilitation because of the fact that the major distress type of all pavement distress types is surface crack. For this reason, crack detection is needed for the highway specifically maintenance of high-grade highway [16]. Also, [17] pointed out in 2018, the repeated severity of crack may cause threating environment that can disturb the highway users. So, an effectual computer algorithm has an important role in establishing analysis tools for automatic detection of crack. In addition, according to [18] for years, serious amount of work power has been spent on establishing methods to evaluate the pavement conditions equitably. The simplest method is inspecting the pavements visually and classify them by personal human experts. But this approach associates with high costs of labor and results in unreliable and inconsistent outputs. Additionally, it exposes the overseer to threatening conditions of work on highways. Under the light of the researches using the computer vision and the technologies of image processing to automate the process is very sensible. Recently, digital image processing has been extensively applied for recognition of cracking. There are so many techniques to apply image processing to detect cracks on the pavement surface. For example, [19] pointed out that in the North of Jordan area the method which is called object recognition was used to extract cracks from airborne images captured by drones. After removing thresholds and noise of images, algorithms of digital image processing were applied to recognize the existence of different types of cracks in the pavementsurface. Also, the process had capability to catch automatically the orientation and the length of the cracks that were used as input for a neural network pattern recognition function which designed for this aim. Artificial Neural Network has been used, tested and verified for extraction of cracks. Variousnumbers of hidden layers and patterns were also checked. The results showed that usage of image processing methods and neural network can recognize pavement cracks with high accuracy. Another significant example comes from [17]. It came up with a deep convolution neural network (CNN) as a detection system. To capture the pavement crack image a digital camera was used. Then, the imagescaptured by the digital camera divided into two different grid sizes, 32x32 and 64x64 and used as input to the first step deep convolution neural network. Another example can be observed in [20] it tells that 3D pavement images that collected at various highway sections by a technology which is called PaveVision3D Ultra. The collected images are used to create a dataset and one thousand imagesare selected randomly from this dataset and used as input for deep convolution neural network. Fromthe all examples it can be clearly seen that convolution neural network (CNN) plays a key role in image processing of crack detection on asphalt pavement. For this reason, concentrating on convolution neural network is essential for image processing. In [17], the methodology for crack detection and classification consists of image acquisition, image pre-processing – labeling, crack detection (using deep CNN), and crack classification steps.

Procedure of detecting pavement crack using deep convolution neural starts with the input of raw image and then images are grided by 32x32 pixels or 64x64 pixels without overlapping then CNN process works then detection of image is done as crack or non-crack and ended with calculation of network [17]. The diagram can be seen in Figure 4.

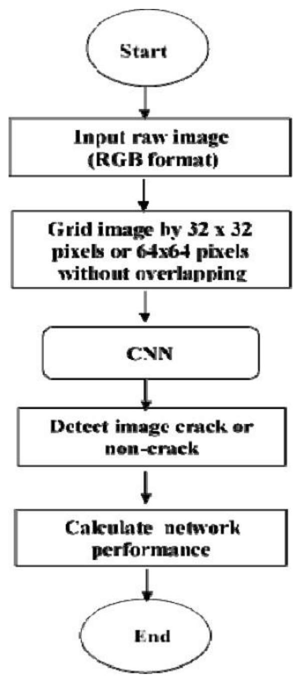


Figure 4: Procedure to detect pavement crack using deep CNN [17]

All studies in this review paper [16, 17, 18, 19, 20] have very similar methodology and their commonpoint is CNN. Deep CNN is a trainable neural network that able to broadly extract a good feature depiction for image recognition. Deep CNN architecture consists of convolution layer, pooling layerand fully connected layer [17]. The architecture of Deep CNN diagram can be seen in Figure 5.

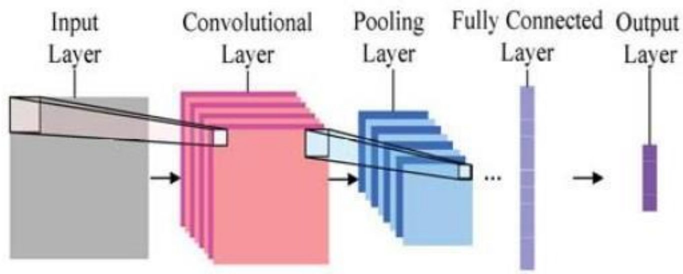


Figure 5: Architecture of deep CNN [17]

Also, the experimental results of the studies can be analyzed by looking the results' precision and accuracy percentages. According to [17] for 32x32 pixels precision 99.40 % and accuracy 99.20 % for 64x64 pixels precision 83.30 % and accuracy 87.8 %. The table can be seen in Table 3.

Table 3. Recall, precision and accuracy using 32x32 and 64x64 grid scale [17]

Grid image	Recall	Precision	Accuracy
32x32	98.00 %	99.40 %	99.20 %
64x64	83.30 %	94.60 %	87.80 %

According to [19], precision 87 % and accuracy 82.5 %. The table can be seen in Table 4.

Table 4. Sensitivity, specificity, accuracy and precision values of the performed modelling [19]

Parameter	Result %
Sensitivity	90
Specificity	60
Accuracy	82.5
Precision	87

So, the results of studies [17,19] seem quite satisfactory. Although the studies have differenttechniques when they are getting raw images like using drones or using digital cameras, the results are close each other. To criticize two result above may be the distance between the cameras and theasphalt pavement may have an impact on the results. As a result, the studies have slightly different work methodology but all of them contains convolution neural network (CNN) and it is the significantpart of the work methodology and it gives efficient percent of results.

VI. ROUGHNESS

Surface roughness evaluation is very important for transportation engineers. Roadway surfaces are representation an expression of random process, which the effects of such large irregularities as potholes must be removed and treated separately according to [21]. Pavement roughness can also bedefined as unexpected irregularities which can affect riding quality of a vehicle. Roughness does notonly affect riding quality, but also it can affect fuel consumption and maintenance cost. Which mustbe optimized by transportation engineers. Roughness can also be named as smoothness. In transportation engineering, roughness is usually shown as International Roughness Index (IRI). IRI is provides a common interval between different roughness measurements.

Image processing

In recent years, advantage of high-speed general-purpose digital computers and high defined vision systems has made image analysis easier than before. Many techniques were used to find ideal evaluation of surface roughness. Image processing technique has been used by many researchers to measure surface roughness. Recently, there are three main kinds of non-contact detecting methods:image recognition, ultrasonic and X-ray according to [22]. Surface roughness is hard to be measure.From point of view of machines image recognition-based method is practicable according to author.As it will be mentioned in applications, lasers were used to measure surface roughness as image processing. Usually lasers or laser markers were placed in vehicles. These data were collected into acomputer and software can even give a 3D visualization of road.

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Applications

This method has been tested in [23]. This method was developed by road maintenance company of Budapest to develop an own system to survey and control the roads. According to authors, this methodalso decreases the difficulties that causes by human evaluation. The system costed 74.000 EURO fornearly 2 years development which includes the system design, hardware and vehicle installation, software development and tests, project administration and institutional overhead costs. As it was mentioned earlier, system detects the laser marker points and stores the coordinates. Then calculatesthe marker coordinates by photogrammetric intersection for each marked profile. The visualization of the results is shown as 3D in Figure 6 with enlarged anomalies, the trajectory of the vehicle, longitudinal and cross sections of the investigated road segment, and isoline visualizations. In Figure7, IRI values are shown calculated for 2-meter segments were shown where laser markers were placedunder the tiers.

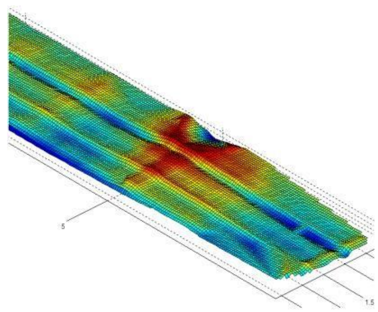


Figure 6: Perspective visualization of a road segment [23]

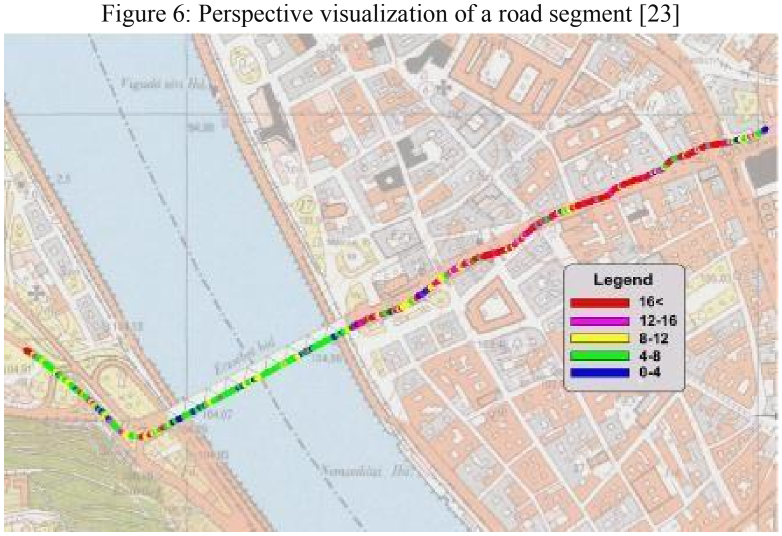


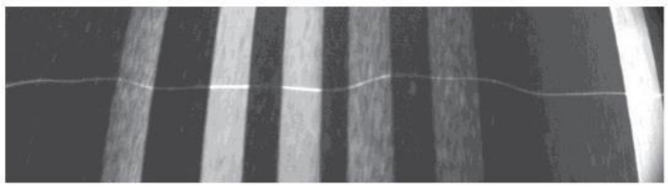
Figure 7: IRI map derived from laser markers below the tires [23]

Main purpose of this method is to develop and low-cost method to measure road roughness using system combining structure laser line and vision. Also, in this reference, comparison to other methodswere used. In Figure 8, road surface roughness measure methods were shown. In a straight edge method is shown and in b, this projects measurement instrument is shown. However, there are manyfactors that can affect this method. In this method, while measuring roughness, distribution that can be arise from other factors were also compared. Shadow disturbance and land-mark disturbance weretested to be available to observe what problems that these disturbances can cause. Another thing thatwas mentioned in report was that no qualified computers needed to do measurements of this method.In this report, authors mentioned that they use software in PC with Windows 7 operate system, 2.9GHz CPU and 2G bytes RAM, which is almost available in every house today. In Figure 9, outcomes of landmark distributed measurements are shown. As it can be observed, results of measurements areso close to each other even though disturbance was applied. Same outcomes can be observed in shadow disturbance measurement. All data are from [24].

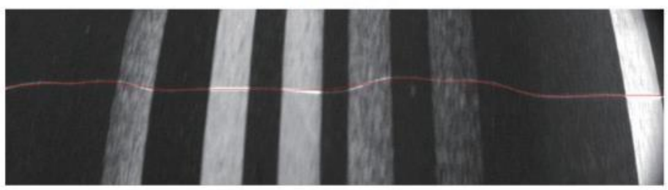
(a) straight edge measurement

(b) laser optical measurement

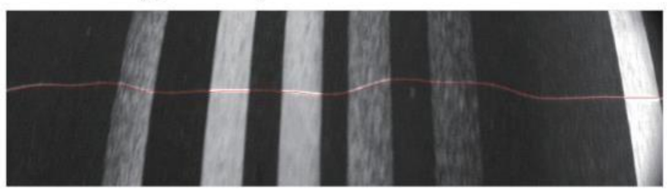
Figure 8: Road surface roughness measure methods [24]



(a) Original image



(b) Result of open curve active contour method



(c) Result of our method

Figure 9: Experimental results [24]

VII. CONCLUSION

Roadway roughness is really bad situation that a transportation engineer can face, and tests of roughness is hard in old-fashioned way. However, new applications are showing up to ease the job of engineer and to increase accuracy. For example, straight edge measurement is an old-fashioned method which is done with less accuracy since it is done by human eye but not with technology. On the other, hand in both application reports, it was mentioned that these methods were cheaper than other ways. Another thing to consider in this is how these methods can help prior detection of these defects could contribute significantly to reducing road accidents according to [25]. From the applications, it can be observed that image processing is applicable in real-life scenarios. Both applications give an applicable solution which shows that these image processing methods were ready to use if substructure is ready

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It is indeed a great pleasure and moment of immense satisfaction for us to present a project report on “Road Pothole detection” amongst a wide panorama that provided us inspiring guidance and encouragement, we take the opportunity to that thank those who gave us their indebted assistance. We wish to extend our cordial gratitude with profound thanks to our internal guide Prof. T. R. Patil for his everlasting guidance. It was his inspiration and encouragement which helped us in completing our project work. Our sincere thanks and deep gratitude to the Head of Department, Prof. R. M. Samant, and, other faculty members but also to all those individuals involved both directly and indirectly for their help in all aspects of the project. At last, but not least we express our sincere thanks to our Institute's Principal Dr. S. P. Patil, for providing us with infrastructure and technical environment

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