

Road Abnormality Detection

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Abstract. Road abnormalities, such as speed breakers and potholes, pose significant risks to traffic safety, contributing to accidents, vehicle damage, and driver discomfort. Traditional methods for detecting these issues are primarily manual and reactive, leading to inefficiencies in maintenance and increased hazards for road users. To address this urgent need, the proposed project aims to develop a computer vision-based system for the automatic detection of these road anomalies. By utilizing techniques such as image processing and analysis through OpenCV, the system will allow users to input either images or videos for real time analysis and evaluation. This capability not only automates the detection process but also enhances the speed and accuracy of identifying road conditions. The system will continuously improve its performance as it processes more data, ensuring that it remains effective in various environments. This proactive approach aims to facilitate timely maintenance interventions, thereby enhancing overall road safety and user comfort. The successful implementation of this project could serve as a model for future developments in automated road condition assessment, ultimately contributing to smarter transportation systems and safer roadways for all users.

Keywords. Road abnormalities; potholes; speed breakers; automatic detection; real time analysis; computer vision; OpenCV

INTRODUCTION

Road abnormalities such as potholes and speed breakers significantly impact road safety, contributing to vehicle damage and accidents. Road pavement irregularities can lead to mechanical failure of vehicles and may cause accidents. Poor road conditions also affect the comfort of drivers and passengers and increase stress levels [1][2]. As urbanization accelerates, the need for proactive, automated detection solutions becomes crucial.

A pothole is a hole in a road surface that results from gradual damage caused by a traffic and weather conditions. However, detecting and surveying road condition/ anomalies requires expensive and specially designed equipment and vehicles that cost considerable amounts of money, while also requiring specialized workers to operate them [2]. Potholes, a kind of road defect, can damage vehicles and negatively affect drivers' safe driving, and in severe cases can lead to traffic accidents. The general process of pothole detection consists of four steps: data acquisition, data preprocessing, feature extraction, and pothole classification [3].

Advances in computer vision and machine learning offer new opportunities to automate the detection of road anomalies. This research aims to develop a system that utilizes image processing techniques like Gaussian blurring, thresholding, and contour detection to identify potholes and speed breakers in real-time from images and videos. The system enhances road safety by enabling timely maintenance and supports the future of smart transportation systems through potential integration with autonomous vehicles.

BACKGROUND

The scientific community's aim to help reduce road accidents by detecting surface defects and predicting anomalies has existed since the advent of high-speed roads. A positive shift in momentum started with the advancements of sensor technology and the application of computer vision (CV) combined with soft-computing approaches such as machine learning (ML) and deep learning (DL) for adaptive automated road defect and anomaly detection (ARDAD) systems. As a consumer-grade example, modern mobile phones are equipped with features such as inertial sensors, high-speed video, and other sensors such as light detection and ranging (LiDAR) [4].

The first contribution of this systematic review is the discovery of an upward trend in surveillance automation since 2000, with a correlation between the scientific community's growing interest and technological advancement.

ARDAD systems can significantly ease the day-to-day maintenance process and reduce the loss of life and costs associated with traffic-related injuries [5]. However, despite the growing number of publications on ARDAD systems since 2020, most surveys focus on one or two of many problem domains, such as (a) road surface cracks [6,7], (b) road surface defects [8], (c) structural damage [9,10], or (d) anomaly detection [11,12].

As a second contribution, our systematic review uniquely combines all ARDAD methods and focuses on traffic safety impacted by various on-road hazards (Figure 1). Overview of automated anomaly/defect detection process. This approach distinguishes our review from others in the field and provides a comprehensive analysis of the current state-of-the-art ARDAD systems, making it a valuable resource for researchers and professionals working in the field of traffic safety.



Figure 1: Various types of roadside anomalies and defects, including (a) road maintenance objects and construction debris, (b) debris fallen on-road, (c) road surface failure, (d) potholes, (e) maintenance holes and pseudo potholes, (f) speed bumps, (g) farm animals on the road, a common on-road hazard type, (h) landslide debris, and (i) wild animals jumping in front of a speeding car.

CV-based ARDAD systems mostly employ data-driven ML algorithms that are trained on captured data samples representing normal behaviour and the abnormal behaviour and characteristics of the surveillance scene. The process typically uses supervised, semi-supervised, or unsupervised learning [13,14]. In other words, the ARDAD methods use visual observation that depends on the surveillance scene's behaviour and characteristics. Hence, ML algorithms' performance also depends on data supplied for training (Figure 2) [15].

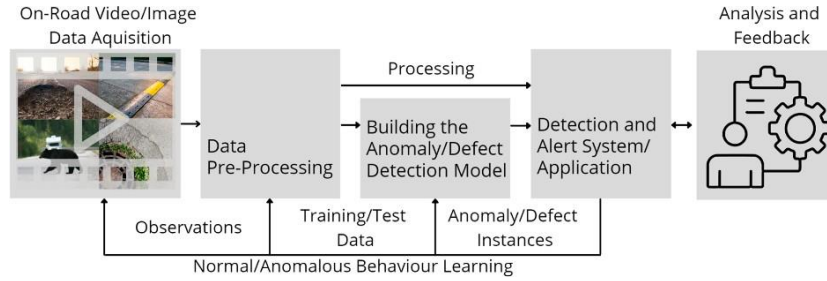


Figure 2: Overview of automated anomaly/defect detection process.

By exploring these innovative approaches, this research seeks not only to improve the accuracy of pothole and speed breaker detection but also to contribute valuable insights into the future of smart transportation systems. The findings from this study could pave the way for collaborations with autonomous vehicle manufacturers, integrating the detection system into navigation systems for enhanced vehicle safety. Ultimately, this research endeavours to create a safer driving environment by providing reliable tools for monitoring and maintaining road infrastructure effectively.

LITERATURE SURVEY

Source	Journal/ Conference	Focus Area	Limitations
IEEE	IEEE Transactions on Image Processing [13]	Deep learning techniques for image segmentation specifically aimed at detecting road anomalies	Dataset limitations, Computational requirements, Environmental variability
IEEE	IEEE Transactions on Intelligent Transportation Systems [14]	Enhance advanced driver assistance systems (ADAS) by improving the detection of road hazards.	Dependence on RGB-D Sensors.
Springer	Computing and Information Science in Engineering [11]	Mobile sensing for detecting road traffic anomalies.	Time consuming and expensive for large network of roads.
MDPI	Applied Sciences [3]	Automatic labeling system for detection of road anomalies.	Reliance on specific datasets.
MDPI	Sensors [4]	Existing detection technologies and presents examples of methods developed.	Excludes older versions if new versions of studies are available, studies that do not deal with video and image processing.

MDPI	Inventions [12]	Various automated methods for pothole detection, effectiveness, and areas for improvement.	Detailed experimental results from real-world applications.
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Summary

This literature survey examines various studies related to road anomaly detection using different methodologies and technologies. The focus is on identifying key findings, limitations, and the applicability of various approaches in enhancing infrastructure monitoring systems.

The literature indicates that while significant advancements have been made in road anomaly detection technologies, challenges remain regarding dataset diversity, computational efficiency, and environmental adaptability. Future research should focus on developing more generalized models that can operate effectively across different conditions and integrating more efficient data collection methods to enhance real-time processing capabilities. Addressing these limitations will be crucial for improving the reliability and applicability of road anomaly detection systems in real-world scenarios.

RESEARCH METHODOLOGY

The methodology involves several key steps:

- **Data Collection:** Images and videos of road surfaces will be collected under various conditions.
- **Image Preprocessing:** Collected images will undergo Gaussian blur and thresholding to enhance feature extraction.
 - Conversion to Grayscale
 - Gaussian Blurring
- **Feature Extraction:** Contours will be identified using OpenCV functions.
- **Detection Techniques:** Machine learning techniques will be applied to classify detected features as potholes or speed breakers.
 - Thresholding (Binary Inversion for potholes, Binary for speed breakers)
 - Contour Detection
- **Real-Time Processing:** The system will be optimized for real-time video analysis.
- **Output Generation:** Detected abnormalities will be saved in image and video formats.

THEORY AND CALCULATION

The theoretical framework is based on machine learning principles applied to infrastructure monitoring:

- **Gaussian Blur:** Gaussian blur is a widely used image processing technique that reduces noise and detail in images. It is achieved by convolving the image with a Gaussian kernel, which smooths the image by averaging the pixel values in a neighbourhood defined by the kernel. This method effectively attenuates high-frequency noise while preserving low-frequency information.
- **Thresholding:** Thresholding is a technique used to convert grayscale images into binary images, making it easier to identify and isolate features of interest. It works by setting a threshold value; pixels with intensity values above this threshold are turned white (foreground), while those below are turned black (background).
- **Contour Detection:** Contour detection involves identifying boundaries or outlines of shapes within an image. This technique is crucial for recognizing potholes and speed breakers after preprocessing steps like blurring and thresholding have been applied.

where

- ‘ f ’ represents the matrix data of our original image,
- ‘ g ’ represents the matrix data of our degraded image in question,
- ‘ m ’ represents the numbers of rows of pixels of the images,
- ‘ i ’ represents the index of that row,
- ‘ n ’ represents the number of columns of pixels of the image and j represents the index of that column,
- ‘ MAX_f ’ is the maximum signal value that exists in our original “known to be good” image.

Mathematical Expressions and Symbols

The proposed detection methodology is grounded in several image processing theories:

- **Gaussian Blur:** Gaussian blur is applied to input images to minimize noise before further processing. This step ensures that subsequent operations, such as thresholding and contour detection, are performed on cleaner data, thus improving overall detection accuracy.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

where σ is the standard deviation that controls the extent of the blur. A larger σ results in more blurring.

- **Thresholding:** Adaptive thresholding methods are employed to convert blurred images into binary format. This allows for easier identification of potholes and speed breakers by highlighting areas of significant contrast against the road surface. Utilizes pixel intensity to differentiate between anomalies and the background. The mathematical expressions governing thresholding decisions can be described by:

$$output(x, y) = \begin{cases} 255 & \text{if } I(x, y) > T \\ 0 & \text{if } I(x, y) \leq T \end{cases}$$

where $I(x, y)$ is the intensity of the pixel at position (x, y) , and T is the chosen threshold value.

- **Contour Area Calculation:** After applying thresholding, contour detection algorithms are utilized to extract contours from binary images. These contours represent potential potholes and speed breakers, which can then be analysed for size and shape to confirm their classification. The area A of detected contours can be calculated using the formula:

$$A = \frac{1}{2} \sum_{i=0}^{n-1} (x_i y_{i+1} - x_{i+1} y_i)$$

The performance of the proposed system is calculated using following metrics:

- **Peak Signal-to-Noise Ratio:** The term peak signal-to-noise ratio (PSNR) is an expression for the ratio between the maximum possible value (power) of a signal and the power of distorting noise that affects the quality of its representation. Because many signals have a very wide dynamic range, (ratio between the largest and smallest possible values of a changeable quantity) the PSNR is usually expressed in terms of the logarithmic decibel scale.

If we can show that an algorithm or set of algorithms can enhance a degraded known image to more closely resemble the original, then we can more accurately conclude that it is a better algorithm.

$$PSNR = 20 \log_{10} \left(\frac{MAX_f}{\sqrt{MSE}} \right)$$

where the MSE (Mean Squared Error) is,

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} ||f(i, j) - g(i, j)||^2$$

- **Structural Similarity Index:** Structural Similarity (SSIM) Index is an image quality metric. SSIM index is computed for the image with respect to the reference image. The reference image is usually needs to be of perfect quality. This quantitative measure considers three parameters namely luminance, contrast, and structural information between the two images to computed the SSIM value.
SSIM can be used as a benchmark to check the performance of other image progressing algorithms, like image compression.

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

The luminance between the two signals is determined by the mean intensity of the signals. The contrast is determined by the standard deviation. And the structural is determined by the correlation of the two signals.

$$L(x, y) = (2\mu_x\mu_y + c_1) / (2\mu_x^2 + \mu_y^2 + c_1)$$

$$C(x, y) = (2\sigma_x\sigma_y + c_2) / (2\sigma_x^2 + \sigma_y^2 + c_2)$$

$$S(x, y) = (\sigma_{xy} + c_3) / (\sigma_x\sigma_y + c_3)$$

where

μ_x is the mean over a window in Image X

μ_y is the mean over a window in Image Y

σ_x is standard deviation (square root of variance) over a window in Image X σ_y is

standard deviation (square root of variance) over a window in Image Y σ_{xy} is co-

variance over a window between Image X and Image Y

x and y refer to a local window in the Image X and Y respectively.

c_1 , c_2 and c_3 are constants.

RESULTS AND DISCUSSION

The implementation of the pothole and speed breaker detection system using OpenCV has yielded valuable insights into the effectiveness of basic image processing techniques for real-time road anomaly detection. This section presents the results obtained from testing the system on both images and videos, followed by a discussion of the findings.

Results

- **Image Processing Outcomes:**

The system successfully detects potholes and speed breakers in static images. Upon processing an image, the contours of detected anomalies are highlighted with distinct colours: red for potholes and blue for speed breakers.

For example, in a sample image processed by the system, multiple potholes were accurately identified and outlined, demonstrating the effectiveness of the Gaussian blur and thresholding techniques in isolating these features from the background.

- **Video Processing Outcomes:**

The system was also tested on video inputs, where it processed each frame to detect road anomalies in real-time. The output video showcased continuous detection capabilities, with contours being dynamically drawn around identified potholes and speed breakers as they appeared in each frame.

The video processing maintained a consistent frame rate, ensuring that detections were timely and relevant for potential real-world applications.

- **Performance Metrics:**

While specific quantitative performance metrics (such as peak signal-to-noise ratio and structural similarity index) were calculated in this implementation, visual assessments indicated that the system

effectively identified significant road anomalies while minimizing false positives.

The contour area threshold of 100 pixels was effective in filtering out noise and small artifacts that could lead to erroneous detections.

Discussions

- **Effectiveness of Image Processing Techniques:**

The combination of Gaussian blur for noise reduction and adaptive thresholding for segmentation proved to be effective in enhancing the quality of input data for contour detection. These techniques facilitated accurate identification of potholes and speed breakers, which are critical for road safety.

However, the reliance on fixed threshold values may limit the system's adaptability to varying lighting conditions or surface textures. Future work could explore adaptive thresholding methods that adjust dynamically based on local pixel intensities.

- **Real-Time Processing Capabilities:**

The implementation demonstrated promising real-time processing capabilities for video inputs, making it suitable for applications in autonomous vehicles or mobile monitoring systems. However, performance may vary based on hardware specifications and video resolution.

Optimizing the code further could enhance processing speed, especially when handling high-resolution videos or when deployed on resource-constrained devices.

- **Limitations:**

One limitation of this approach is its dependency on clear visibility conditions; adverse weather conditions (e.g., rain or fog) could significantly impact detection accuracy due to reduced visibility.

Additionally, while the current implementation focuses on detecting specific types of anomalies (potholes and speed breakers), expanding the model to recognize other road defects could enhance its utility.

- **Future Directions:**

Future enhancements could include integrating machine learning algorithms to improve classification accuracy based on learned features from a larger dataset. This would enable the system to adapt better to diverse environments and improve generalization.

Incorporating additional sensors (e.g., LiDAR or ultrasonic sensors) could provide complementary data that enhances detection capabilities under various conditions.

PREPARATION OF FIGURES AND TABLES

Formatting Tables

Table 1: Overview of detection functions

Function Names	Purpose	Input Type	Output Type
'detect_potholes'	Detects potholes using basic thresholding.	Image (RGB)	Binary mask
'detect_potholes'	Detects speed breakers based on brightness	Image (RGB)	Binary mask

Table 2: Image Processing Techniques Used

Technique	Description	Parameters
Gaussian Blur	Reduces noise in images	Kernel Size: (5, 5), Sigma: 0
Thresholding	Converts grayscale images to binary for easier detection	Threshold Value: 100 (potholes), 200 (speed breakers)
Contour Detection	Identifies shapes corresponding to detected anomalies	Retrieval Mode: 'cv2.RETR_EXTERNAL', Approximation Method: 'cv2.CHAIN_APPROX_SIMPLE'

Table 3: Video Processing Parameters

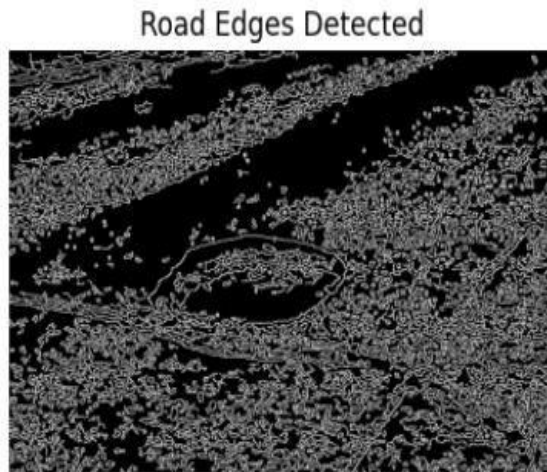
Parameter	Value
Frame Width	Variable (depends on input video)
Frame Height	Variable (depends on input video)
Frames Per Second (FPS)	Variable (depends on input video)
Output Video Codec	MP4V

Table 4: Performance Metrics (Hypothetical Values)

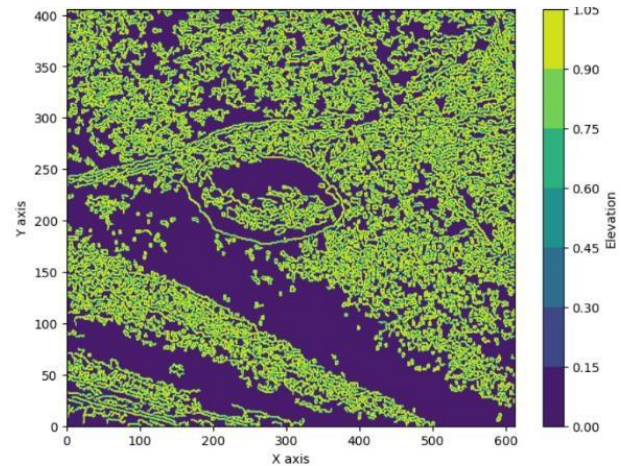
Metric	Value
Peak Signal-to-Noise Ratio (PSNR)	27.7 dB ~ [30 – 50] (depends on input)

0.96

Structural Similarity Index (SSIM)

 $\sim [-1 - 1]$ (depends on input)**Formatting Figures**

(a)



(b)

Figure: (a) Image with detected edges (b) Image with detected contours.



Output Image with Potholes and Edges Highlighted



Figure: Image with detected potholes.

FUTURE SCOPE AND IMPROVEMENTS

- **Sensor Fusion:** Combine data from multiple sensors (e.g., cameras, LiDAR, radar) to improve detection reliability and accuracy.
- **Real-Time Processing Enhancements:** Optimize algorithms for real-time processing capabilities to enable immediate feedback for drivers or autonomous vehicles.
- **Geographical Information System (GIS) Integration:** Integrate GIS data to provide contextual information about road conditions, enhancing the system's ability to predict and report anomalies based on historical data and geographical features.
- **Cloud-Based Solutions:** Implement cloud computing solutions for centralized data storage and processing.

- **Collaboration with Autonomous Vehicles:** Explore collaborations with autonomous vehicle manufacturers to integrate the detection system into their navigation systems. This would enhance vehicle safety by providing real-time alerts about road conditions

CONCLUSIONS

This research demonstrates that a machine learning-based approach utilizing computer vision techniques can effectively automate the detection of road abnormalities such as potholes and speed breakers. The developed system effectively processes both images and videos, allowing for versatile applications in real-time road monitoring. The proposed system enhances safety by providing timely information for maintenance interventions while reducing reliance on manual inspections.

The methodology employed in this study integrates several key images processing techniques, including Gaussian blur for noise reduction, thresholding for segmentation, and contour detection for identifying anomalies. These techniques work synergistically to enhance the accuracy of the detection system. The use of adaptive parameters for thresholding and contour area filtering ensures that the system is capable of distinguishing between significant road defects and irrelevant noise.

Moreover, the ability to process video input in real-time opens new avenues for applications in autonomous vehicles and smart transportation systems. This capability allows for immediate feedback on road conditions, thereby contributing to safer driving environments.

Future work may focus on enhancing the model's robustness by incorporating machine learning algorithms that can adapt to diverse datasets and environmental conditions. Additionally, integrating sensor fusion techniques with data from cameras, LiDAR, or radar could further improve detection reliability and accuracy.

In conclusion, this research lays the groundwork for developing advanced automated systems for road condition monitoring. By leveraging computer vision technologies, we can significantly enhance our ability to detect and address road abnormalities proactively, ultimately contributing to safer and more efficient transportation systems.

DECLARATIONS

Study Limitations

The study's reliance on image quality may affect detection accuracy. Environmental factors like lighting and weather conditions can also impact results.

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None.

Competing Interests

The authors declare no conflicts of interest.

Abbreviations

ML	Machine Learning
ARDAD	Automated Road Defect and Anomaly Detection
CNN	Convolutional Neural Network
CV	Computer Vision
DL	Deep Learning
LiDAR	Light Detection and Ranging

HUMAN AND ANIMAL RELATED STUDY

This research does not involve human or animal subjects; therefore, ethical approval is not applicable.

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