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Review of Crack Detection System for Industrial Pipe

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Abstract
Industrial pipes play a critical role in various sectors, and their structural integrity is essential for safe and efficient operation. Over time, cracks may develop due to stress, corrosion, fatigue, or environmental factors, potentially leading to failures if not detected early. This paper presents a Python-based real-time crack detection system for industrial pipes, utilizing advanced image processing and machine learning techniques. The system supports both static image analysis and live webcam feed inspection, enabling flexible and continuous monitoring. Key functionalities include (1) crack detection using Canny edge detection and adaptive thresholding, (2) support for TensorFlow-based machine learning models for complex pattern recognition, (3) adjustable detection parameters for sensitivity tuning, and (4) statistical analysis of crack dimensions such as area.
In addition to its detection capabilities, the system offers advanced visualization features, including split-screen comparisons, crack overlays, and severity-based highlighting. Built using Python with libraries such as OpenCV, TensorFlow, and CustomTkinter, the framework provides a modern, user-friendly interface and is scalable for integration into industrial monitoring setups. By enabling real-time condition assessment and facilitating early maintenance actions, the system significantly enhances the safety, reliability, and longevity of industrial piping infrastructure.

KEYWORDS: Crack detection, Industrial Pipe Inspection, Image Processing.

I. INTRODUCTION

Industrial pipes play a crucial role in various sectors, ensuring the seamless transportation of fluids and gases. However, over time, these structures are prone to deterioration due to factors such as pressure variations, environmental conditions, and material fatigue, leading to the formation of cracks. Early detection and accurate assessment of these cracks are essential to prevent structural failures, minimize maintenance costs, and ensure operational safety. Traditional inspection methods rely on manual visual assessments, which can be time-consuming, inconsistent, and prone to errors. To address these limitations, image processing techniques combined with Python-based automation provide an effective solution for crack detection and analysis, enhancing accuracy and efficiency.

This paper aims to develop an advanced crack detection system for industrial pipes using Python-based image processing. Our system systematically identifies cracks through edge detection and adaptive thresholding techniques, and optionally supports machine learning-based detection for complex damage patterns. It allows for crack dimension measurement, including length, width, and area, and provides severity assessment and location mapping. While depth or volume estimation is not implemented, the system provides percentage crack coverage on the pipe surface. Additionally, it supports basic crack pattern analysis through visual overlays, offering a detailed understanding of structural vulnerabilities. By integrating these key features, our approach provides a comprehensive tool for assessing the health of industrial pipes, facilitating proactive maintenance and ensuring long-term structural integrity.

Beyond mere detection, our approach emphasizes a deeper structural analysis by providing real-time detection, statistical analysis, and visualization. Through quantitative measurements and advanced data representation, engineers can make informed decisions regarding maintenance, repair, or replacement strategies. The system's scalability allows seamless integration with existing monitoring frameworks, enabling continuous inspection and real-time condition assessment. Ultimately, this paper contributes to enhancing the resilience and longevity of industrial pipes, ensuring their reliability and safety in demanding operational environments.

II. LITERATURE REVIEW

1] Golewski, Grzegorz Ludwik. In this paper, the author provides an in-depth review of issues related to the formation and development of damage and cracking in the structure of concrete composites. It focuses on the causes of crack initiation and characterises their basic types. An overview of the most commonly used methods for detecting and analysing the shape of microcracks and diagnosing the trajectory of their propagation is also presented.

2] Chakraborty, Joyraj, Andrzej Katunin, et al. In this paper, the four-point bending test on the benchmark RC structure was used as a test of the quality and sensitivity of the embedded sensors. It allowed assessment of whether any cracking and propagation that occurs with the embedded sensors can be detected. Various methods are used for the analysis of the ultrasonic signals. By determining the feature from the ultrasonic signals, the changes in the whole structure are evaluated. The structural degradation of the RC benchmark structure was tested using various non-destructive testing methods to obtain a comprehensive decision about structural condition. It is shown that the ultrasonic sensors can detect a crack with a probability of detection of 100%, also before it is visible by the naked eye and other techniques, even if the damage is not in the direct path of the ultrasonic wave.

3] Kim, Jung Jin, Ah-Ram Kim, et al. In this paper, the author uses an image analysis technique using deep learning to detect cracks and analyse characteristics (e.g., length, and width) in images for small-scale facilities. Three stages of the image processing pipeline are proposed to obtain crack detection and its characteristics. In the first and second stages, two-dimensional convolutional neural networks are used for crack image detection (e.g., classification and segmentation). Based on convolution neural networks for the detection, hierarchical feature learning architecture is applied into our deep learning network. After deep learning-based detection, in the third stage, thinning and tracking algorithms are applied to analyze length and width of the crack in the image.

4] Momeni, Hamed, Sina Basereh, et al. In this paper, using video processing methods, a methodology is developed to track crack formation. In this regard, robust principal component analysis is employed to detect new crack propagation. The experimental test data of RC shear walls are used to assess the implemented methodology. The quasi-static cyclic load is applied to these walls, and several cameras captured the video of walls' behavior. Taking advantage of the phase-based motion processing method, a video stabilization is implemented to enhance the accuracy of the crack detection step. Propagation of cracks is monitored by calculating Gini coefficients for each frame. The results show that monitoring this coefficient can indicate new crack formations.

5] Giri, Paritosh, and Sergey Kharkovsky. In this paper, the author uses an efficient noncontact method of the detection of such cracks in concrete using a measurement system with a laser displacement sensor (LDS) is presented. The proposed system consists of an LDS mounted on the scanner performing a raster scan. During the scanning process, the system gives the reading of displacement value from the sensor head to the laser spot on the target surface of the specimen. The proof of concept is given by testing with two different concrete specimens, namely, a concrete slab with a 0.7-mm-width through crack and a cylindrical concrete specimen with multiple cracks on the surface caused by loading effect. It is shown that a characteristic response of crack as a sharp distortion of the displacement reading occurs when the laser spot crosses the crack.

6] Zhao, Zhiyong, Bo Chen, et al. In this paper, a comprehensive site crack status monitoring system was constructed in a roller compacted concrete (RCC) gravity dam during the construction period, by combining acoustic emission (AE), micro-seismic (MS), cross-hole acoustic wave detection (CAWD), crack gauge and strain gauge techniques; this system was used to investigate crack development problems that may occur under varying construction conditions. Through knocking location tests, the acoustic wave transmission rate of RCC was determined by the AE and MS system, to monitor the real-time status of micro-cracks. Moreover, the crack tip displacement, adjacent concrete strain and concrete ultrasonic velocity were captured, to monitor the propagation of macroscopic cracks. By combining the information obtained at both the micro- and macro- levels, the development trend of a crack was analysed.

7] Zhang, Lingxin, Junkai Shen, and Baijie Zhu. In this paper, the Crac Unit model based on deep learning is proposed to solve the above problems. First, crack images collected from the lab, earthquake sites, and the Internet are resized, labelled manually, and augmented to make a dataset (1200 subimages with $256 \times 256 \times 3$ resolutions in total). Then, an improved Unet-based method called CrackUnet is proposed for automated pixel-level crack detection. A new loss function named generalised dice loss is adopted to detect cracks more accurately. How the size of the dataset and the depth of the model affect the training time, detecting accuracy, and speed is researched.

8] Kim, Ah-Ram, Donghyeon Kim, et al. In this paper, deep learning and image processing techniques were developed to detect cracks and analyse characteristics in images for concrete facilities. Two-stage image processing pipeline was proposed to obtain crack segmentation and its characteristics. The performance of the method was tested using various crack images with a label and the results showed over 90% of accuracy on crack classification and segmentation. Finally, the crack characteristics (length and thickness) of the crack image pictured from the field were analyzed, and the performance of the developed technique was verified by comparing the actual measured values and errors.

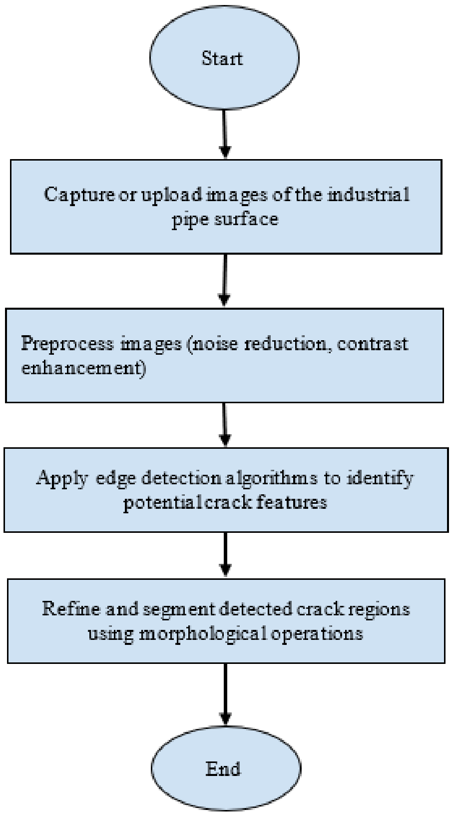
9] Mohan, Arun, and Sumathi Poobal. In this paper, the author conducted a detailed survey to identify the research challenges and the achievements till in this field. Accordingly, 50 research papers are taken related to crack detection, and those research papers are reviewed. Based on the review, analysis is provided based on the image processing techniques, objectives, accuracy level, error level, and the image data sets. Finally, we present the various research issues which can be useful for the researchers to accomplish further research on crack detection.

10] Golding, Vaughn Peter, Zahra Gharineiat, et al. In this paper, the author proposes a deep learning (DL)-based autonomous crack detection method using the convolutional neural network (CNN) technique. To improve the CNN classification performance for enhanced pixel segmentation, 40,000 RGB images were processed before training a pretrained VGG16 architecture to create different CNN models. The chosen methods (grayscale, thresholding, and edge detection) have been used in image processing (IP) for crack detection, but not in DL. The study found that the grayscale models (F1 score for 10 epochs: 99.331%, 20 epochs: 99.549%) had a similar performance to the RGB models (F1 score for 10 epochs: 99.432%, 20 epochs: 99.533%), with the performance increasing at a greater rate with more training (grayscale: +2 TP, +11 TN images; RGB: +2 TP, +4 TN images). The thresholding and edge-detection models had reduced performance compared to the RGB models (20-epoch F1 score to RGB: thresholding −0.723%, edge detection −0.402%).

III. METHODOLOGY

The proposed crack detection system for industrial pipes utilizes Python-based image processing to accurately identify and analyze cracks. The system begins by acquiring images of the pipe surface, followed by preprocessing steps such as noise reduction and contrast enhancement to improve detection accuracy. Edge detection algorithms are then applied to identify cracks, while morphological operations refine and segment the detected regions. The extracted data is visualized, providing engineers with actionable insights for maintenance and repair, ensuring infrastructure safety and longevity.

FLOW CHART



IV. SYSTEM REQUIREMENT

HARDWARE REQUIREMENT

Web Camera

SOFTWARE REQUIREMENT

Python Software IDE

MODULES USED

- Open CV
- TensorFlow
- CustomTkinter

V. CONCLUSION

In conclusion, our Python-based image processing system provides an advanced and efficient solution for crack detection and analysis in industrial pipes. By automating the inspection process, the system accurately identifies cracks, analyzes crack patterns based on angles. These quantitative insights enhance the precision of structural assessments, enabling proactive maintenance and reducing the risk of failures. Additionally, the integration of data visualization techniques ensures clear interpretation of findings, supporting informed decision-making for repair and reinforcement strategies. With its scalability and ability to integrate with existing monitoring systems, this paper significantly improves industrial pipe maintenance, enhancing safety, reliability, and operational efficiency in various industries.

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