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Ultrasonic Leak Detection Using MEMS Sensors For Industrial Pneumatic Pipeline Monitoring

Bijoy Laxmi Koley[1*], Anupam Kumar Biswas[2], Moloy Mukherjee[3], Surajit Batabyal[4], Subhadra Deb Roy[5], Subhasish Debroy[6], Saradindu Mondal[7]

[*1]Department of Electrical Engineering, Dr. B. C. Roy Engineering College, Durgapur, West Bengal.
Email ID: bijoylaxmi.koley@bcrec.ac.in

[2]Department of Civil Engineering, Dr. B. C. Roy Engineering College, Durgapur, West Bengal.
Email ID: anupam.biswas@bcrec.ac.in

[3]Department of Electronics & Communication Engineering, Dr. B.C. Roy Engineering College, Durgapur, West Bengal.
Email ID: moloy.mukherjee@bcrec.ac.in

[4]Department of Electronics & Communication Engineering, Dr. B.C. Roy Engineering College, Durgapur, West Bengal.
Email ID: surajit.batabyal@bcrec.ac.in

[5]Department of Electronics & Communication Engineering, Dr. B.C. Roy Engineering College, Durgapur, West Bengal.
Email ID: subhadra.debroy@bcrec.ac.in

[6]Bachelor of Computer Application, Dr. B.C. Roy Academy of Professional Courses, Durgapur, West Bengal.
Email ID: subhasish.debroy@bcrec.ac.in

[7]Department of Electrical Engineering, Dr. B.C. Roy Engineering College, Durgapur, West Bengal.
Email ID: saradindu.mondal@bcrec.ac.in

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ABSTRACT

This study presents an ultrasonic leak detection system for industrial pneumatic pipelines utilizing MEMS-based sensors. The system incorporates a conical horn (electronic gun) design to enhance signal focusing and improve detection sensitivity. Controlled experiments were conducted using six leak diameters (1–6 mm) and six pressure levels (5–30 PSI). Fast Fourier Transform (FFT) analysis was employed for feature extraction, improving the system's robustness over conventional CWT-based methods. The CNN model achieved 90% accuracy for binary leak detection, while a reduced feature-based model maintained 88.9% accuracy with improved computational efficiency. Results indicate higher detection accuracy for larger leaks at elevated pressures, while small leaks at low pressures posed greater challenges. The integration of the conical horn significantly enhanced signal clarity, particularly in detecting minor leaks. The proposed system's effective balance of accuracy, sensitivity, and computational efficiency makes it suitable for real-time industrial monitoring applications.

Keywords: *Ultrasonic Leak Detection Using MEMS Sensors for Industrial Pneumatic Pipeline Monitoring*

1. INTRODUCTION

Leak detection in industrial pneumatic pipelines is crucial to prevent energy losses, equipment failures, and operational downtime. Studies indicate that undetected leaks in compressed air systems can account for 20–30% of total energy losses in industrial plants, resulting in significant financial and productivity impacts. Additionally, pipeline leaks may cause pressure drops that reduce the efficiency of pneumatic tools and machinery, further contributing to operational inefficiencies.

Various techniques have been explored for leak detection, including acoustic emission analysis, infrared thermography, and gas-sniffing sensors. Ultrasonic detection has emerged as a preferred method due to its ability to identify leaks from a distance and under noisy industrial conditions. However, traditional ultrasonic methods face limitations in detecting low-pressure leaks and small-diameter openings.

In this study, MEMS-based ultrasonic sensors are employed to improve detection sensitivity and provide real-time monitoring capabilities. To further enhance detection efficiency, a conical horn (electronic gun) design was introduced to