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Inspection of Storage Tank Bottoms and Corrosion Mapping Via Ultrasonic Testing and Signal Processing Methods

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***Abstract*— The integrity of storage tank bottom plates is critically affected by corrosion-related material loss, which poses significant risks to operational safety, environmental protection, and asset reliability. Ultrasonic testing (UT) has long been employed as a non-destructive evaluation technique for thickness measurement; however, reliable interpretation of high-density ultrasonic data remains challenging under real field conditions due to noise, surface irregularities, and complex echo patterns.**

This study presents an academically oriented framework for the inspection of storage tank bottoms using ultrasonic A-scan data combined with advanced signal processing techniques. Frequency-domain and time–frequency-domain methods, including Fast Fourier Transform (FFT), Short-Time Fourier Transform (STFT), and wavelet-based analysis, are employed to enhance signal quality and improve echo discrimination. A hybrid peak detection strategy integrating adaptive thresholding and continuous wavelet transform (CWT) is proposed to robustly identify corrosion-related reflections.

The extracted thickness data are spatially organized on two-dimensional grids and transformed into three-dimensional corrosion maps using interpolation-based reconstruction techniques. The proposed methodology demonstrates improved robustness in low signal-to-noise ratio (SNR) environments and contributes to a more objective and repeatable corrosion assessment process. The results highlight the potential of signal processing–driven UT analysis as a reliable academic and industrial tool for storage tank integrity evaluation.

***Keywords*— Ultrasonic Testing; Storage Tank Inspection; Corrosion Mapping; Signal Processing; Peak Detection; Non-Destructive Testing**

I. INTRODUCTION

Large-capacity storage tanks are widely used in petroleum, chemical, and energy industries to store hazardous and valuable fluids. Among the structural components of these tanks, bottom plates are particularly vulnerable to corrosion due to prolonged exposure to moisture, soil chemistry, differential aeration, and operational conditions. Undetected corrosion in tank bottoms can lead to leakage, environmental contamination, fire hazards, and costly unplanned shutdowns.

Non-destructive testing (NDT) techniques play a crucial role in ensuring the safe operation of storage tanks. Ultrasonic testing (UT) is one of the most commonly applied methods for bottom plate inspection because of its capability to measure remaining wall thickness with high accuracy [1]. Nevertheless, conventional UT inspections are often limited by manual interpretation, operator dependency, and insufficient spatial resolution over large inspection areas.

Recent advances in automated scanning systems have enabled the acquisition of large volumes of ultrasonic A-scan data across tank bottoms. While this data richness provides an opportunity for detailed corrosion assessment, it also introduces significant challenges related to signal interpretation, noise suppression, and reliable feature extraction [2], [3]. In particular, weak or overlapping echoes associated with localized corrosion pits may be difficult to distinguish from noise using traditional time-domain analysis.

To address these challenges, researchers have increasingly focused on applying advanced signal processing techniques to ultrasonic data. Frequency-domain, time–frequency, and multiresolution methods offer improved insight into signal characteristics and defect-related features [4]–[6]. Despite these advances, there remains a clear research gap in the integration of robust peak detection algorithms with spatial corrosion mapping for large-scale storage tank inspections.

This study aims to bridge this gap by proposing a signal processing–based UT inspection framework that emphasizes academic rigor, methodological clarity, and repeatability. The primary contributions include enhanced echo detection using hybrid peak analysis and systematic transformation of ultrasonic measurements into three-dimensional corrosion maps suitable for integrity assessment.

II. Related Work and Literature Review

Ultrasonic inspection of storage tank bottoms has been extensively studied in the context of thickness measurement and corrosion detection. Early approaches primarily relied on manual pulse-echo UT measurements conducted at discrete locations, providing limited spatial coverage [7]. While effective for local thickness evaluation, such methods often fail to capture the full corrosion distribution across large tank floors.

To overcome these limitations, automated ultrasonic scanning systems have been introduced, enabling the generation of C-scan and B-scan representations of tank bottoms [8]. These techniques allow inspectors to visualize thickness variations over extended areas; however, their effectiveness is strongly influenced by signal quality and data processing strategies.

Signal processing techniques have been widely investigated to improve UT data interpretation. FFT-based analysis has been used to examine frequency characteristics of ultrasonic signals and identify noise components [9]. STFT provides time–frequency localization, enabling the separation of overlapping echoes and transient features [10]. Wavelet transform methods, owing to their multiresolution nature, have demonstrated superior performance in detecting weak and localized defects embedded in noisy signals [11], [12].

Peak detection is a critical step in ultrasonic thickness evaluation, as it directly affects time-of-flight estimation and thickness calculation. Threshold-based methods are computationally efficient but often suffer from false detections under varying noise conditions [13]. More advanced approaches, including matched filtering and wavelet-based peak detection, have shown improved robustness in complex inspection scenarios [14], [15].

Several studies have also explored corrosion mapping and visualization techniques. Two-dimensional thickness maps are commonly generated using grid-based measurements, while three-dimensional representations provide enhanced insight into corrosion severity and distribution [16]. Interpolation methods such as inverse distance weighting and kriging have been applied to reconstruct continuous corrosion surfaces from discrete measurements [17], [18].

Despite these developments, the literature indicates that many existing studies focus either on signal processing or on spatial visualization, with limited integration of both aspects into a unified framework. This work contributes to the literature by combining advanced peak detection with systematic 3D corrosion mapping, offering a comprehensive approach to tank bottom inspection.

A comparative summary of commonly used ultrasonic signal processing techniques, including FFT, STFT, and wavelet-based approaches, is presented in **Table 1**.

Table 1. Comparison of signal processing techniques used in storage tank bottom inspection

Method	Analysis Domain	Strengths	Limitations
FFT	Frequency domain	Effective identification of dominant frequency components and electrical noise	No time localization; limited capability for transient echo analysis
STFT	Time–frequency domain	Localized analysis of overlapping echoes and non-stationary signals	Fixed window size leads to resolution trade-off
Wavelet Transform	Multi-resolution (time–scale)	High sensitivity to weak and localized corrosion echoes; robust under low SNR conditions	Higher computational cost and wavelet selection dependency

III. Methodology

The proposed methodology is based on ultrasonic A-scan data acquired from an operational storage tank bottom during routine inspection. Each measurement point consists of a time-domain ultrasonic signal representing reflections from material interfaces.

III.1 Ultrasonic Data Acquisition

Ultrasonic measurements were conducted using a conventional pulse-echo ultrasonic testing system equipped with a straight-beam longitudinal-wave transducer. The probe was operated at a nominal center frequency suitable for thin steel plate inspection, ensuring adequate penetration depth and temporal resolution. A couplant medium was applied to guarantee stable acoustic coupling between the probe and the tank bottom surface.

The tank bottom was divided into a two-dimensional inspection grid, and a single A-scan signal was recorded at each grid point. This grid-based acquisition strategy enabled systematic coverage of the inspected area and provided spatially referenced thickness information. The acquired A-scan signals represent time-domain ultrasonic waveforms containing front-wall echoes, back-wall echoes, and attenuation effects caused by corrosion-related material loss.

III.2 Signal Preprocessing

Raw ultrasonic A-scan signals obtained under field conditions are typically contaminated by electrical noise, surface roughness effects, and coupling variability. To mitigate these effects, a preprocessing stage was applied prior to feature extraction.

Band-pass filtering was employed to suppress low-frequency structural noise and high-frequency electrical interference outside the effective bandwidth of the transducer. Subsequently, amplitude normalization was performed to reduce variations caused by inconsistent coupling pressure and surface conditions. These preprocessing steps significantly improved the signal-to-noise ratio (SNR) and enhanced the visibility of corrosion-related echoes.

The characteristic ultrasonic reflections observed after preprocessing, including front-wall and back-wall echoes with varying attenuation levels, are illustrated in Fig. 1.

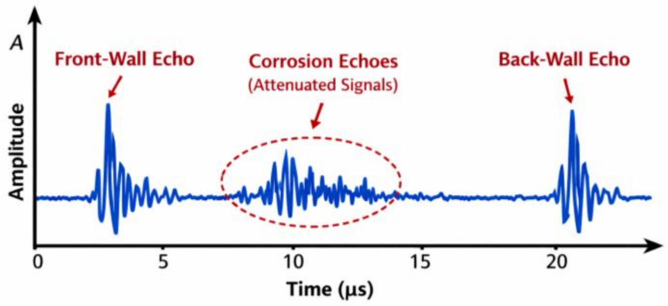

Fig. 1. Representative ultrasonic A-scan signal obtained from the storage tank bottom plate, illustrating the front-wall echo, back-wall echo, and corrosion-induced echo attenuation.

III.3 Time–Frequency Analysis

In order to capture both global and localized signal characteristics, multiple signal analysis techniques were employed. Fast Fourier Transform (FFT) analysis was used to investigate the spectral content of the ultrasonic signals and to identify dominant frequency components associated with the probe response and material properties.

However, due to the non-stationary nature of ultrasonic signals in corroded regions, time–frequency analysis was required. Short-Time Fourier Transform (STFT) was applied to provide localized frequency information, enabling the separation of overlapping echoes and transient signal components.

In addition, wavelet transform analysis was utilized due to its multi-resolution capability. Continuous wavelet transform (CWT) coefficients were examined across multiple scales to detect weak and localized echoes that may not be distinguishable using conventional frequency-domain methods. The use of wavelet-based analysis proved particularly effective in regions with low SNR caused by localized corrosion.

III.4 Peak Detection and Thickness Estimation

Accurate identification of echo positions is a critical step in ultrasonic thickness measurement. In this study, a hybrid peak detection approach was adopted to improve robustness against noise and signal distortion.

The proposed method combines adaptive thresholding with CWT-based local maxima detection. Adaptive thresholding provides computational efficiency, while wavelet-based peak detection enhances sensitivity to weak echoes embedded in noise. Detected peak positions were used to estimate the ultrasonic time-of-flight between the front-wall and back-wall echoes.

The remaining wall thickness was calculated using the time-of-flight values according to Equation (1). This approach ensures physically meaningful thickness estimation consistent with the ultrasonic wave propagation model.

$$t = \frac{v \cdot \Delta\tau}{2} \tag{1}$$

III.5 Spatial Mapping and 3D Reconstruction

The calculated thickness values were spatially organized according to the inspection grid coordinates to form two-dimensional thickness maps. To obtain continuous corrosion representations, interpolation techniques were applied to the discrete measurement data.

Interpolated thickness distributions were subsequently visualized as three-dimensional corrosion maps, providing intuitive insight into both localized pitting corrosion and generalized wall thinning. These three-dimensional representations facilitate objective assessment of corrosion severity and spatial distribution across the tank bottom.

IV. Results and Discussion

The application of the proposed methodology to real field data demonstrated improved stability and reliability in ultrasonic thickness estimation compared to conventional manual UT evaluation. The hybrid peak detection approach significantly reduced false detections in low SNR regions and enabled consistent identification of back-wall echoes.

Wavelet-assisted analysis proved particularly effective in detecting localized corrosion pits, where conventional threshold-based methods failed due to severe signal attenuation. The comparative advantages of the employed signal processing techniques are summarized in Table 1.

The generated three-dimensional corrosion maps revealed spatial patterns consistent with known corrosion mechanisms in storage tank bottoms, such as increased material loss near tank perimeters and regions exposed to moisture accumulation. Compared with traditional reporting methods based solely on numerical thickness values, the proposed visualization approach offers enhanced interpretability and supports more informed maintenance decisions.

From an academic perspective, the integration of advanced signal processing with spatial corrosion mapping contributes to a systematic framework for ultrasonic inspection of large-area structures. The results confirm that signal processing–driven analysis is essential for extracting reliable information from high-density ultrasonic datasets.

V. Conclusions

This study presented an academically oriented ultrasonic inspection framework for storage tank bottom plates, grounded in the experimental methodology and signal processing techniques developed in the associated master's thesis. By integrating time–frequency analysis, wavelet-based peak detection, and three-dimensional corrosion mapping, the proposed approach addresses key limitations of conventional ultrasonic testing practices.

The findings demonstrate that advanced signal processing techniques significantly enhance corrosion detectability under challenging field conditions characterized by low signal-to-noise ratios. Furthermore, the proposed framework reduces operator dependency and improves the repeatability of ultrasonic thickness measurements.

Future work may focus on extending the methodology through machine learning–based defect classification and automated decision support systems. Additionally, the integration of the proposed framework with robotic inspection platforms may further enhance its applicability to large-scale industrial storage tank inspections.

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