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Economical instrumentation utilising ultrasonic guided waves on threaded steel with a usb oscilloscope: A review

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ABSTRACT

Guided ultrasonic wave is a diagnostic method that utilizes high frequency wave propagation to analyze the physical condition of a material in real-time. This research aims to develop economical instrumentation using guided ultrasonic waves on threaded steel with the help of a USB oscilloscope. Threaded steel, which is used as reinforcement in construction structures, often develops cracks that affect its strength and reliability. Therefore, there is a need for an efficient evaluation method to identify the condition of this material. The system developed in this study overcomes measurement challenges at high frequencies, such as significant noise and complex propagation modes, by utilizing narrow bandwidth signals. The performance of the system is evaluated through analysis of signal to noise ratio, averaging effect, filtration, and initial gain. The results show that techniques such as averaging, bandpass filtration, and gain using a pre-amplifier successfully improve measurement accuracy and reliability despite the limitations of USB oscilloscopes in signal capture quality. These findings provide a reliable low-cost instrumentation for monitoring and physical characterization of threaded steel in civil engineering applications.

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1. INTRODUCTION

A building structure comprises a set of components that constitute a building. Building structures typically comprise foundations, floors, walls, columns, beams, and roofs. Every section of the construction undoubtedly possesses a framework [1, 2]. This framework is typically a metal structured to enhance the building's stability. In the domain of construction, it is essential to assess and regulate the quality of building materials. An assessment of material quality is required to ascertain the viability of utilising these materials [3, 4].

Steel thread is one of the materials utilised in the construction of constructions. Screw steel is a type of concrete reinforcing steel engineered to enhance adhesion and mitigate the longitudinal displacement of steel rods within concrete [5, 6]. In construction, it is typical for threaded steel components to exhibit cracks. Consequently, equipment technology is required to provide quality analysis data regarding the material's physical state [7].

Ultrasonic wave propagation can be employed to ascertain the physical condition of a substance. The physical status of embedded structures, such as threaded steel reinforcement, can be monitored in real time [8, 9]. This analysis necessitates two locations at each extremity of the threaded steel reinforcing frame, which serves as both the propagation medium and the material under examination for its physical state [10].

This research examines an economical instrumentation equipment for high-frequency physical state characterisation of threaded steel. The employed system is predicated on a USB oscilloscope. The difficulty of employing high frequencies lies in the presence of several propagation modes and significant dispersion. This study necessitates a narrow frequency bandwidth signal. Performance is evaluated using signal-to-noise ratio (SNR), mean effect, filtration, and pre-amplification.

2. THEORITICAL REVIEW

2.1. Threaded Steel

Threaded steel is an essential material in infrastructure building. Threaded steel serves as reinforcement in foundations, poles, and several other structural components. Threaded steel is a material that enhances concrete adhesion, is lightweight, and possesses high tensile strength. The mechanical property of threaded steel that influences the measurement outcomes is its Young's modulus. Hooke's law asserts that elastic deformation is directly proportional to the ratio of stress to strain:

$$\frac{Tegangan}{Regangan} = Modulus\ elastisitas \tag{1}$$

Stress is defined as the force applied per unit area, whereas strain is the ratio of change in length. Young's modulus, denoted as Y, is the ratio of stress to strain:

$$Y = \frac{F/A}{\Delta l/l_0} = \frac{F}{A}\frac{l_0}{l} \tag{2}$$

where:
Y : Young's modulus (N/m²)
A : Area (m²)
l_0 : Length (m)
Δl : Length change (m)
F : Force (N)

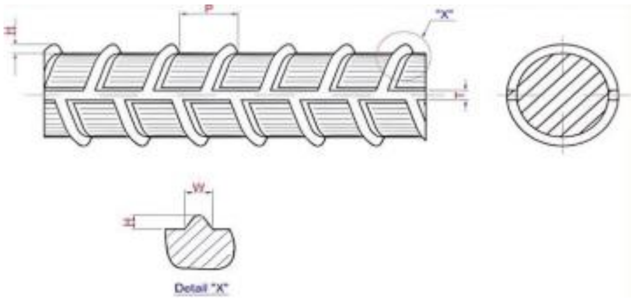


Figure 1. Threaded Steel.

2.2. Utilisation of Ultrasonic Waves

Ultrasonic waves are defined as waves with a frequency exceeding 20 kHz. Guided ultrasonic waves are high-frequency waves employed to ascertain the properties of the propagation medium. Guided ultrasonic waves travel at an identical velocity in all directions within a homogeneous isotropic medium. The velocity of ultrasonic wave propagation is influenced by the wave's frequency. The equation for wave propagation velocity is as follows:

$$v = f\lambda$$

where:
v : Propagation velocity (m/s)
f : Frequency (Hz)
λ : Wavelength (m)

Guided ultrasonic waves can investigate extensive structural volumes from a singular transducer position. This ability arises from guided ultrasonic waves travelling with comparatively little attenuation. Guided ultrasonic waves can be employed to examine structures that are challenging to reach, such as embedded threaded steel reinforcements and insulated pipes.

Bandwidth refers to the range of frequency coverage defined by the upper and lower cut-off frequencies employed. Bandwidth is influenced by factors including the kind of transmission medium, transmission distance, and level of interference. Transmission media exhibit varying bandwidths; for instance, fibre optic bandwidth surpasses that of copper wire. The transmission distance (length of the propagation medium) influences bandwidth; a greater distance results in reduced bandwidth. Interference from external devices and magnetic fields also impacts bandwidth. The waveform's repetition rate is anticipated to exhibit high precision; hence, a narrower bandwidth yields superior outcomes.

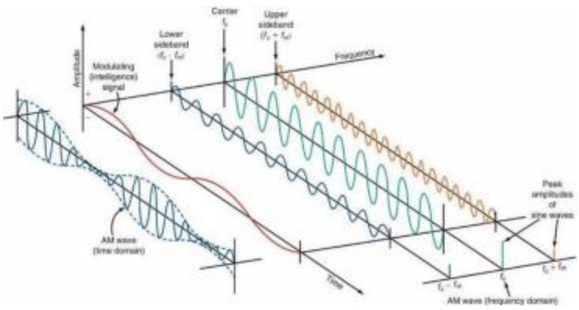


Figure 2. Bandwith.

2.3. Universal Serial Bus Oscilloscope

An oscilloscope is an electronic measurement device that visualises electrical impulses for analysis and examination. The oscilloscope serves to analyse the waveforms of electrical signals regarding amplitude, distortion, period, pulse width, frequency, and phase difference. A USB oscilloscope is an oscilloscope that measures working frequency without external interference, with results displayed on a computer. The benefits of a USB oscilloscope encompass: compact dimensions, convenient for transport.

The PC display is larger, allowing for clearer visibility of the waveforms. This oscilloscope is devoid of a monitor, resulting in a reduced price. The PC interface facilitates the processing and editing of files. Users have the capability to create custom programs for oscilloscope control. Figure 3 illustrates the USB oscilloscope.

Figure 3. USB oscilloscope.

3. RESEARCH METHODS

A literature review on economical instrumentation of threaded steel was performed to examine the material's physical condition. Research on this material is necessary since threaded steel is the most crucial component in the construction of building structures. Substantial structures necessitate oversight and regulation due to their considerable dimensions and mass. The study involved analysing the measurement waves obtained from the guided ultrasonic waves propagating through the threaded steel. The threaded steel possesses a Young's modulus of 210 GPa. The results were analysed considering noise, the effects of averaging, filtering, and pre-amplification. Figure 4 illustrates the collection of tools and materials.

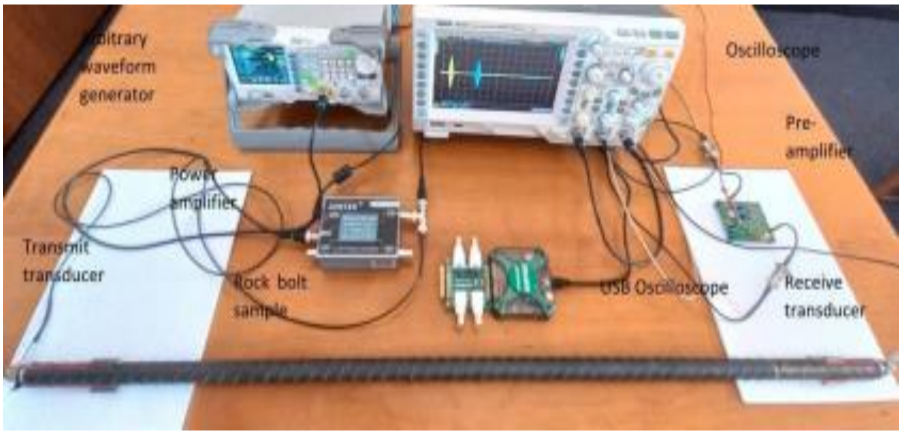
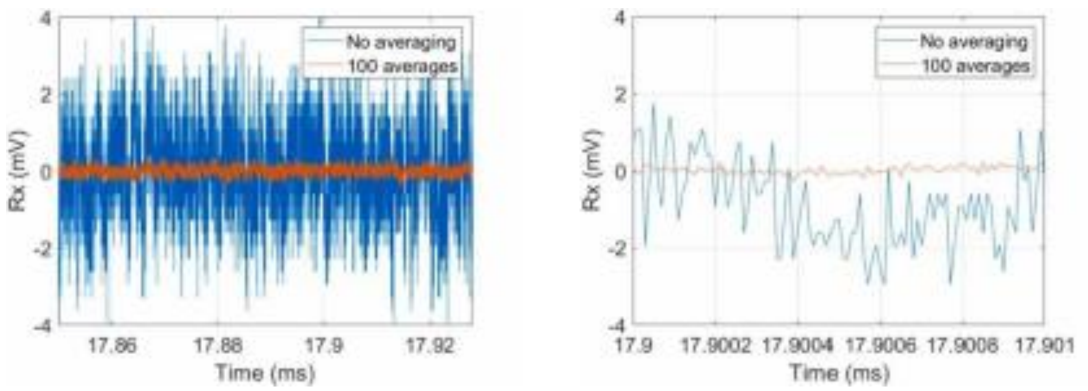


Figure 4. Collection of instruments and resources.

4. RESULTS AND DISCUSSIONS

4.1. Excited signal interference on USB oscilloscope

The disruption or noise in the signal can be seen in Figures 5 (a) and 5 (b). Measurements using a USB oscilloscope indicate significant noise levels. The sampling rate employed in this investigation is 100,000,000 samples per second (100 MSa/s). The USB oscilloscope caught merely 8192 samples over two channels. The wavelength is diminished, resulting in a reduced resolution of the acquired frequency following the application of the fast Fourier transform. Measurements were conducted subsequent to the connection and activation of the excitation signal and power amplifier. It is essential to ensure that ultrasonic energy does not persist; hence, noise is monitored over extended time intervals following the application of stimulation. The response occurs over a reduced timeframe, and the digitisation levels of both oscilloscopes are presented on the enlarged noise display. Averaging can diminish the root mean square (RMS) of the noise. It is evident that 100 Averaging diminishes the RMS of the noise by approximately tenfold the anticipated amount.

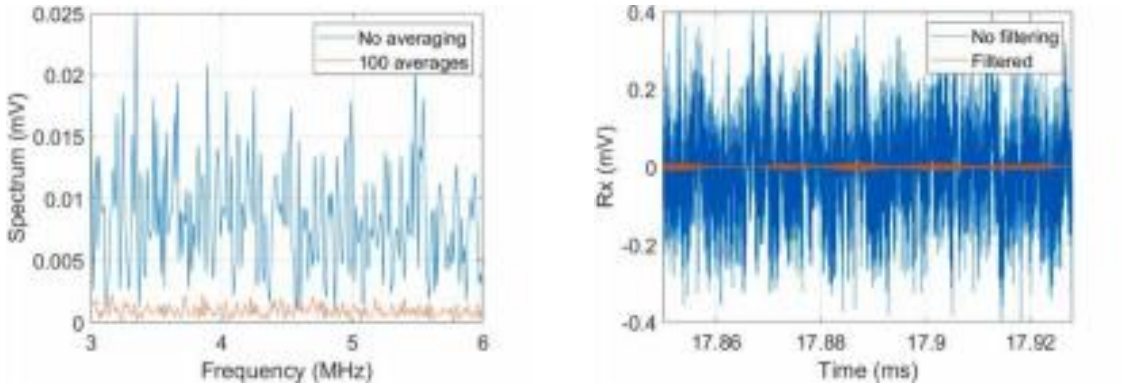


(a) (b)

Figure 5. Graphs of (a) USB oscilloscope noise visualisation and (b) magnified noise visualisation.

4.2. Noise Frequency and Filtration

The noise frequency and the impact of bandpass filtering on the noise are illustrated in Figures 6 (a) and 6 (b). The Fast Fourier Transform is employed to assess the spectra of the noise signal within the specified frequency range. The significant noise level of the USB oscilloscope is influenced by the averaging effect. The noise is allocated across the specified frequency range. The origin of this noise is thought to be the power amplifier, as the noise signal peak vanishes when the amplifier is deactivated. The noise signal peak exceeds the USB oscilloscope peak, rendering this noise peak unreadable by the USB oscilloscope. Utilising a 200-cycle signal concentrates energy within a bandwidth of approximately 100 kHz. Noise outside this frequency range can be disregarded, and only the bandwidth needs to be considered.



(a) (b)

Figure 6. Graphs of (a) noise frequency (b) impact of bandpass filtering.

Bandpass filtering involves transforming the signal into the frequency domain, with a frequency range of 4.875 MHz to 4.975 MHz, with a central frequency of 4.925 MHz, followed by a conversion back to the time domain. Bandpass filtering substantially influences noise (Figure 6 (b)). The RMS values of the noise signals (Figures 5 (a) to 6 (b)), illustrating the efficacy of averaging and bandpass filtering in diminishing noise within the measurements. Filtering is very efficient for signals acquired with a USB oscilloscope. Post-filtering, the noise inside the signal acquired by the USB oscilloscope increases. Additional noise level attenuation can be attained by increasing the number of averages, although this would prolong the measurement duration.

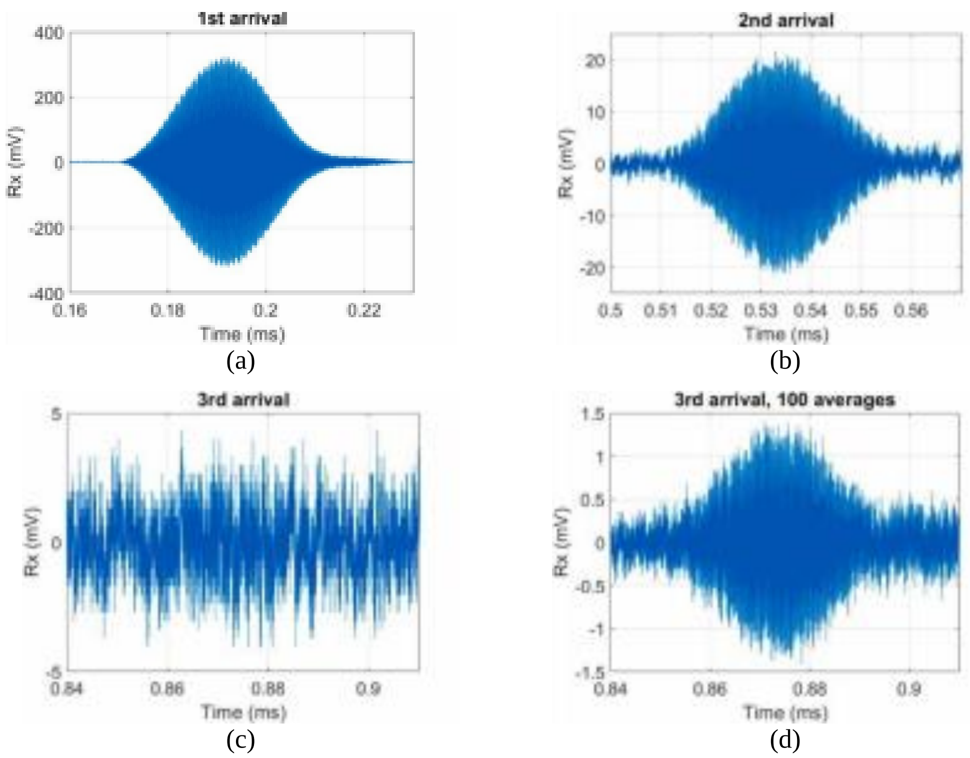


Figure 7. Graphs of (a) first arrival (b) second arrival (c) third arrival (d) third arrival with an average of 100.

Figure 7 (c) illustrates the elevated noise levels of the USB oscilloscope, which complicate the measurement of tiny signals. The significant noise is especially apparent in the image at the third arrival. The utilisation of 100 averaged measures renders the third arrival discernible. Figure 7 (d) illustrates the substantial impact of averaging.

4.3. Impact of Amplification and Impedance Matching

The RMS values of the signal and noise from these measurements are presented in Table 1. Measurements were conducted prior to and subsequent to the incorporation of pre-amplification. Figure 8 (a) illustrates the third reflection, captured with a USB oscilloscope devoid of the pre-amplifier. This measurement was conducted with an average of 100, and noise is distinctly observable in the data obtained from the USB oscilloscope. The noise is markedly diminished by eliminating frequencies outside the 4.875 – 4.975 MHz spectrum. Noise measurements (long after stimulation) were conducted using an oscilloscope without a pre-amplifier, as illustrated in Figure 8 (c). Figure 8 (b) illustrates the third arrival measurement utilising the pre-amplifier. The pre-amplifier's gain is around 31.5 dB, equating to a gain factor of 38, relative to the absence of a pre-amplifier.

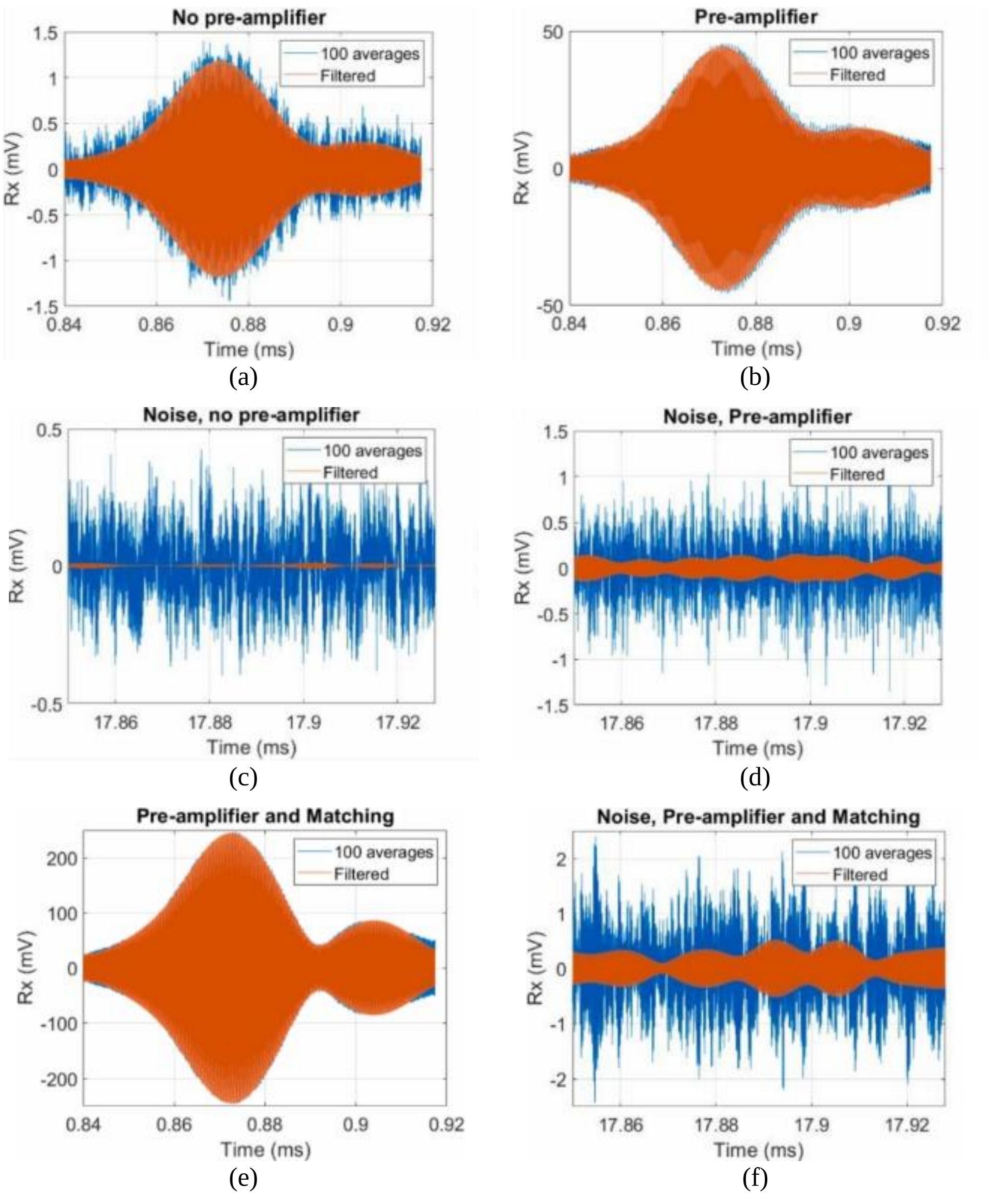


Figure 8. Graphs of (a) signal without pre-amplifier, (b) signal with pre-amplifier, (c) noise without pre-amplifier, (d) noise with pre-amplifier, (e) pre-amplifier and matching without noise, and (f) noise, pre-amplifier, and matching.

The incorporation of electrical impedance matching enhances the signal amplitude. Measurements using a USB oscilloscope indicated a comparable enhancement in signal with the incorporation of impedance matching; however, the noise level did not rise proportionately, leading to an improved SNR. The impact of amplification and impedance matching is illustrated in figures 8 (a) to 8 (f).

The measurement waveform of threaded steel, utilising the specified apparatus, is influenced by pre-amplifiers, filters, and impedance matching. The SNR on the USB oscilloscope is observable refer to Table 1.

Table 1. SNR utilising USB oscilloscope.

Variation		RMS signal (V)	RMS noise (V)	SNR
Unfiltered	Absence of a pre-amplifier	8.4×10^{-4}	8.4×10^{-4}	5.06×10^{1}
Unfiltered	Pre-amplifier	3.15×10^{-2}	2.98×10^{-4}	1.12×10^{4}
Unfiltered	Pre-amplifier and impedance matching	0.174	7.14×10^{-4}	5.99×10^{4}
Refined	Absence of a pre-amplifier	8.4×10^{-4}	5.08×10^{-6}	2.73×10^{4}
Refined	Pre-amplifier	3.15×10^{-2}	1.09×10^{-4}	8.39×10^{4}
Refined	Pre-amplifier and impedance matching	0.174	3.36×10^{-4}	2.71×10^{5}

RMS is the average value in the presence of noise. RMS is described as the method for calculating the average power output over an extended duration. The RMS can be lowered by averaging many values. RMS quantifies the mean noise, hence affecting the SNR. The SNR is the root mean square level given in decibels. Table 2 presents the RMS values obtained from a USB oscilloscope employing various averaging and bandpass filters.

Table 2. RMS value.

Median	RMS noise
1	1161.1
100	122.2
100 and bandpass filter	3.93

5. CONCLUSION

The test results from the USB oscilloscope revealed inadequate performance regarding noise and sample capture quality. Nonetheless, these constraints can be adeptly mitigated by the application of techniques such as averaging to diminish noise, filtering to eradicate undesirable frequencies, and employing pre-amplifiers to enhance the signal prior to processing. These enhancements can augment the overall precision and dependability of the measurements.

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