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Medical Signal Denoising Using Wavelet Transform

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Abstract
Images and videos have turned into a part of our life in the recent past. Applications now range from more general event documentation and visual communication to more serious surveillance and medicine. This has increased the huge demand for images of high accuracy and visual quality. But digital images obtained from modern cameras tend to become corrupted by noise during the process of image acquisition (digitization) and/or transmission. This type of corruption can lead to deterioration of visual quality of an image. The effectiveness of imaging sensors is influenced by a variety of factors, including conditions during the time of image capture and by sensing element quality itself. For instance, while acquiring images using a CCD camera, sensor temperatures and light intensities are significant parameters that can influence the level of noise in the acquired image. Corruption in images can also take place during transmission. Reason being the channel interference used for transmission. For instance, an image transmitted via a wireless medium could be corrupted due to lighting effects or other atmospheric interference. Image denoising is a topic which has been well researched under image processing with the main aim to enhance the visual quality of an image by removing noise from its provided noisy form. There have been a variety of techniques for image denoising designed to reduce the impact of the noise(s) caused due to any of the aforementioned sources of noise. The primary challenge is to maintain the details of the image and local geometries while eliminating the unwanted noise.
Keywords: Denoising, wavelet transform, medical, signal

INTRODUCTION

The historical use of gears dates back 12,000 years, initially employed to operate heavy cave doors and lift water in their rudimentary forms [1]. By the 15th century, gear systems were utilized in chariot wheels, and the industrial revolution of the 18th century further expanded their applications. Gears facilitate power transmission between shafts, with the smaller component referred to as the pinion and the larger as the gear, regardless of which component drives the other [9]. When the pinion acts as the driver, it results in a step-down drive characterized by low-speed output and high torque[2]. Conversely, if the gear drives the pinion, it produces a step-up drive with high speed and low torque[4]. The choice of gear drive is determined by the required speed for specific applications, exemplified by automobiles, where the first gear provides low-speed output [3].Gearboxes are integral components in nearly all machinery, facilitating the transfer of power between shafts and thereby holding a crucial role in various industries. Gears operate under high-stress conditions, which can lead to potential failures[6]. Localized faults that arise can pose significant risks during operation and may result in catastrophic breakdowns. Common issues include tooth breakage, scoring, and pitting, which are prevalent under operational stress[8]. Gear wear can occur through both adhesive and abrasive mechanisms[10]. The meshing teeth can become excessively heated, causing material from one tooth to weld onto another, resulting in adhesive wear[12]. Additionally, if abrasive particles infiltrate the gear during meshing, they can cause abrasive wear on the gear tooth surfaces[14]. Repeated loading may also lead to pitting on the mating surfaces of the gears [13]

1. REVIEW OF LITERATURE

Failures in gear systems typically arise from stresses encountered during operational conditions, such as loading, and if not identified promptly, can result in tooth breakage. Such breakage can be catastrophic, potentially damaging not only the machinery itself but also the components connected to it. Therefore, it is essential to implement Condition Monitoring (CM) effectively to prevent these failures. Gearboxes, like all machinery with moving parts, generate sound and vibration, each having a unique vibration signature that reflects its condition. The primary objective of gear CM techniques is to assess the gear's state and detect any faults. Consequently, CM plays a crucial role in averting severe breakdowns and enhancing safety. Importantly, CM does not disrupt machine operation, as vibration signals are collected via accelerometers during functioning [5]. Vibration analysis has been employed for several decades in gear CM and fault detection, garnering significant interest from researchers. The frequencies produced by a gearbox in good condition, along with modulated frequencies in the form of sidebands indicative of faults, can be differentiated through spectral analysis, allowing for the identification of 'good' versus 'faulty' gears. Compared to the early days of CM, the current landscape is considerably more cost-effective regarding the electronic equipment and software utilized. Numerous techniques exist for fault diagnosis and CM of gearboxes, with the primary aim of gathering information that reflects the gearbox's condition. These techniques may be employed individually or in combination, depending on the analytical requirements. CM can be categorized into model-based and model-free systems, the latter being referred to as signal-based systems. The model-based system necessitates a 'model' that mathematically represents the physical system, while the model-free system relies on signals for analysis [11].Model-based systems can be depicted in various formats based on the characteristics of the physical system. These representations may include physical equations, state equations for linear systems, state observers, transfer functions, neural network models, and fuzzy models. The application of model-based systems produces residual values that assess the difference between actual operating conditions and standard operating conditions. An experienced individual can qualitatively evaluate this divergence, or quantitative methods may be employed.

2. MATERIALS AND METHODS

Periodic signals produce a spectrum characterized by distinct frequency components that exhibit harmonic properties. Mechanical systems can be classified as deterministic if their attributes, such as displacement and acceleration, can be accurately forecasted over time. Kurtosis, being the fourth statistical moment of a vibration signal, is employed to identify critical peaks in the time domain, as raising the signal to the fourth power effectively enhances isolated peaks [7]. For wavelet domain denoising, numerous algorithms using wavelet transform have been proposed. The emphasis was transferred from the spatial and Fourier domain to the wavelet transform domain. It has been shown that the application of wavelets effectively eliminates noise without distorting the signal characteristics irrespective of its frequency content. Wavelet transforms have frequently been used for image denoising due to their capability of decomposing noisy signal from the image signal. The fundamental concept pertaining to the wavelet transform-based denoising is to find the wavelet decomposition of the noisy image and manage the obtained wavelet coefficients.

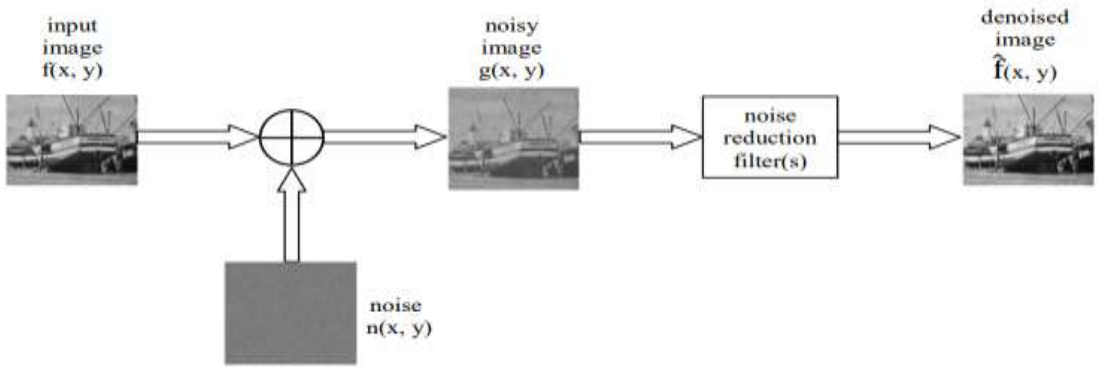

Figure 1: Image denoise process

The Wavelet Transform (WT) converts a signal into a more advantageous format. Wavelets, which are compact wave-like functions, are utilized in WT analysis.

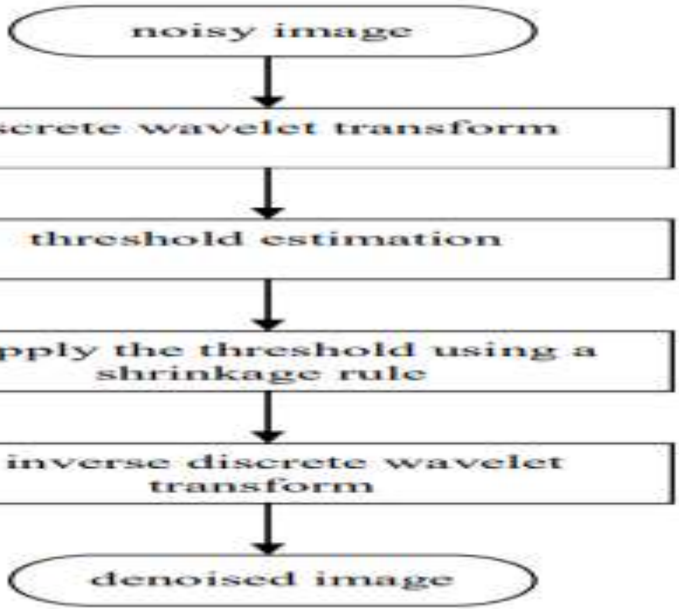

Figure 2: Main stage of WT

WT serves as an alternative to the Short Time Fourier Transform (STFT), employing a small window for high frequencies and a larger window for low frequencies, in contrast to STFT's single window approach. The Continuous Wavelet Transform (CWT) executes the transformation in a smooth and continuous manner, while the Discrete Wavelet Transform (DWT) accomplishes this in distinct steps. Although CWT provides more detailed insights into the signal, it is more time-consuming, making DWT a viable substitute.

3. RESULT

The rotary motion of a gearbox typically exhibits non-periodic characteristics, as faults and damages manifest as disturbances and impulses [15]. In vibration signals, localized and temporal variations are observed, indicating the presence of such disturbances.

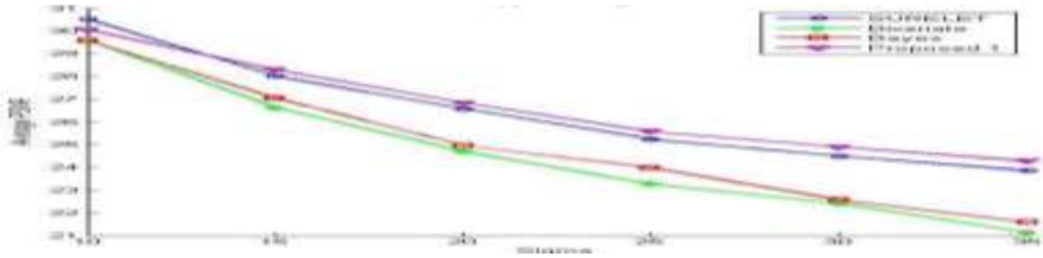

Figure 3: PSNR analysis

These disturbances lead to the emergence of certain individual frequency components that may not be identifiable in the frequency spectrum through conventional frequency analysis. Time-frequency analysis possesses the capability to detect and pinpoint frequency components that vary over time in non-stationary signals. Localized faults within gears can generate impacts that result in non-stationary vibrations; consequently, gear vibration signals demonstrate non-stationary behavior. Analyzing non-stationary signals necessitates specialized techniques that extend beyond the Fourier approach.

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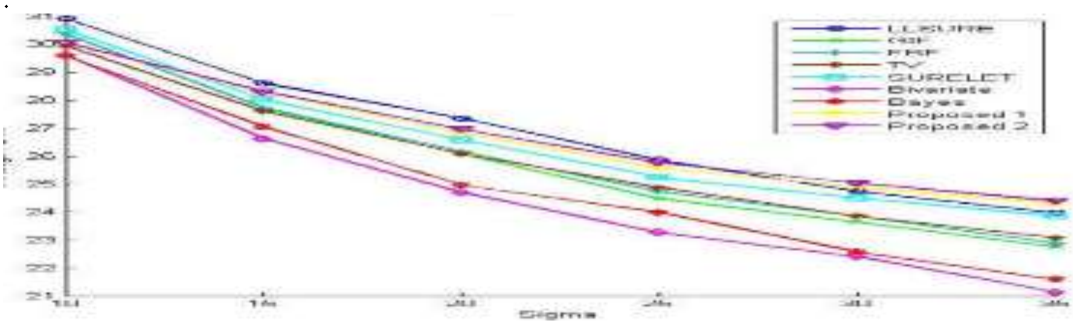

Figure 4: SNR analysis

Signals obtained from sensors and Data Acquisition (DAQ) systems often contain noise alongside the desired signals, which is problematic. The noise components can trigger resonant frequencies and obscure the necessary information. The technique of eliminating noise to extract useful information is referred to as denoising.

4. CONCLUSION

When comparing DWT with the Wavelet Packet Transform (WPT), WPT adjusts the window size based on lower and higher frequency levels, allowing for finer frequency resolution and facilitating the analysis of small frequencies, thus enhancing its utility. Wavelet-based denoising methods typically decompose the signal of interest into coefficients and subsequently reconstruct the selected coefficients to recover the original signal, effectively removing the smaller noisy coefficients through appropriate thresholding. The experimental results' quantitative and qualitative examination shows that the suggested approaches outperform wavelet transform-based methods and yield outcomes that are on par with other well-known denoising techniques.

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