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Image Enhancement Using Adjacent Cell-Based Noise Detection Method in Underwater Communication

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1. Ambient Noise

Underwater communication is crucial in various fields, including marine exploration, military operations, and environmental monitoring[1-2]. As the use of image data in these applications continues to grow, ensuring the quality of transmitted images becomes increasingly important. However, the underwater environment poses significant challenges, particularly due to background noise, which can severely degrade image quality during transmission.

Background noise in underwater communication can be categorized into natural and artificial sources, with ship noise occupying the frequency range between 10 Hz and several hundred Hz, increasing over time. Natural noise dominates at low and high frequencies, while high-frequency noise is often influenced by sea state and wind conditions[3-4]. This noise distorts images, obscuring critical details and complicating accurate interpretation. For instance, in subsea inspections or habitat monitoring, even minor noise can lead to significant misinterpretations, underscoring the need for effective noise reduction methods.

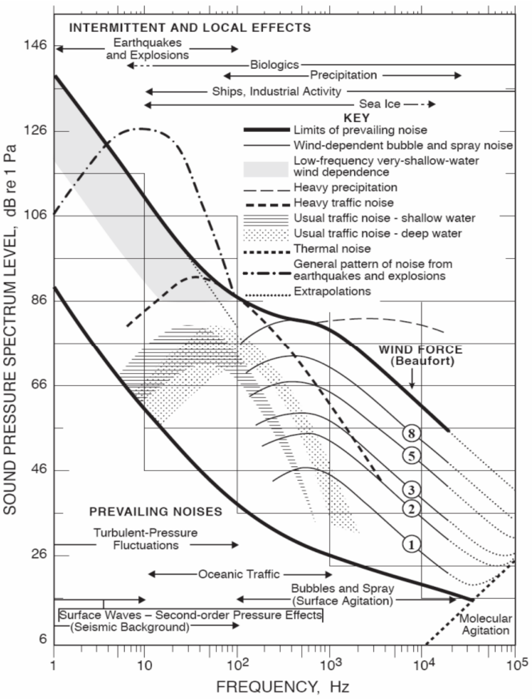

Fig. 1 The ambient noise spectra schematics by Wenz[3)] (1962)

To address these challenges, this paper proposes the Adjacent Cell-Based Noise Detection Method. This method leverages the spatial relationships between adjacent pixels to detect and remove background noise, striving to minimize noise at minimal cost. This approach efficiently removes noise without imposing significant computational demands. The findings suggest that this method could be a practical solution for enhancing image quality in underwater communication.

2. Adjacent Cell-Based Noise Detection Method

The Adjacent Cell-Based Noise Detection Method estimates Gaussian noise in images by identifying significant differences between neighbor pixels, which are often due to noise. In marine environments, noise is typically assumed to be Gaussian and mixed with the signal as white noise[5)]. To address this, we employ a method to quickly estimate the variance of Gaussian noise in images. Estimating the Gaussian standard deviation (σ), which characterizes noise distribution, is crucial for applying adaptive filtering techniques that reduce noise based on the specific level in an image[6-7)].

$$\sigma_n = \sqrt{\frac{\pi}{2} \cdot \frac{1}{6(W-2)(H-2)} \sum_{x,y} |I(x,y) * F|} \tag{1}$$

The Adjacent Cell-Based Noise Detection Method uses adaptive window sizes (3x3 to 7x7) for each pixel, calculating the difference between the central pixel and its neighbors. Pixels with differences below a threshold, based on the estimated noise level, are selected. If at least five neighbors meet this criterion, the central pixel is replaced with their mean value, preserving critical image features while reducing noise.

This method is computationally efficient, suitable for real-time processing in resource-constrained environments. Its robustness and adaptability ensure consistent performance across various image types, and its simplicity allows for easy integration into existing workflows without needing reference images, enhancing its practical application in real-world applications.

3. Experimental conditions and results

In this study, we utilized both grayscale and color versions of standard 512x512 pixel images. We systematically applied Gaussian noise with increasing standard deviations to these images. Noise estimation was performed using spatial domain techniques, and image quality was assessed using PSNR and SSIM metrics.

Table 1. Experiment result

Noised	Denoised
	
	

Our denoising algorithm significantly improved image quality at various noise levels for both grayscale and color images. The most notable gains were at higher noise levels (STD 0.2), with PSNR increases of 7.55 dB for grayscale and 6.95 dB for color images. SSIM improvements were consistent, ranging from 0.216 to 0.259 for grayscale and 0.220 to 0.235 for color images.

Table 2. Camera (grayscale) PSNR

Gaussian STD	PSNR[dB] Noised	PSNR[dB] Denoised
0.05	26.19	30.47
0.1	20.44	27.01
0.15	17.23	24.54
0.2	15.05	22.60

Table 3. Camera (grayscale) SSIM

Gaussian STD	SSIM Noisd	SSIM Denoised
0.05	0.5222	0.7812
0.1	0.2958	0.5842
0.15	0.1979	0.4516
0.2	0.1446	0.3608

Table 4. Astronaut (RGB color) PSNR

Gaussian STD	PSNR[dB] Noised	PSNR[dB] Denoised
0.05	26.50	31.32
0.1	20.70	26.98
0.15	17.43	24.24
0.2	15.22	22.17

Table 5. Astronaut (RGB color) SSIM

Gaussian STD	SSIM Noisd	SSIM Denoised
0.05	0.5702	0.7901
0.1	0.3590	0.6286
0.15	0.2574	0.5152
0.2	0.1966	0.4317

The algorithm showed slightly better performance on color images, effectively utilizing color information during denoising. As noise levels increased, improvements in PSNR and SSIM metrics became more noticeable, indicating the algorithm's effectiveness under noisy conditions.

4. Conclusion

The Adjacent Cell-Based Noise Detection Method effectively reduces background noise in underwater communication by leveraging spatial relationships between adjacent pixels. Its computational efficiency and adaptability make it ideal for real-time use, with improvements in image quality across various noise levels. Future research will explore algorithms to address other types of noise present in underwater communication environments.

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