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Simulation of Image Transmission using BPSK over an AWGN Channel with Performance Evaluation via PSNR and SSIM Report

Aim and Objective

The aim of this experiment is to simulate the transmission of a grayscale image through an Additive White Gaussian Noise (AWGN) channel using Binary Phase Shift Keying (BPSK) modulation, and to evaluate the quality of the reconstructed images at different noise levels using objective image quality metrics such as PSNR and SSIM. The objective is to understand how noise in the channel affects image quality and to demonstrate the effectiveness of BPSK in preserving the information content of images under varying signal-to-noise ratios.

Theory

In digital communication, BPSK is one of the simplest and most robust modulation schemes, where binary data is mapped to two distinct phase states, represented by +1 and –1. When the signal passes through a channel, it is corrupted by random noise. The AWGN model is commonly used to represent this noise, as it introduces random variations with a Gaussian distribution across all frequencies.

To assess the fidelity of the reconstructed images, two widely used quality measures are considered. The first is the Peak Signal-to-Noise Ratio (PSNR), which quantifies the pixel-level distortion between the reference and reconstructed image. A higher PSNR value indicates better image quality. The second is the Structural Similarity Index (SSIM), which compares the structural and perceptual similarity between two images, with a value of 1 representing a perfect match. Together, these metrics provide both numerical and perceptual insights into the effects of noise on image transmission.

Methodology

A standard grayscale image, the “Cameraman” image of size 256×256 pixels, was chosen as the test reference.

Original

The pixels of this image were converted into binary bits, and these bits were modulated using BPSK. The modulated signal was then passed through an AWGN channel at different values of signal-to-noise ratio (SNR), ranging from 0 dB to 20 dB. At the receiver, the noisy signal was demodulated through hard decision decoding, and the bits were reassembled into pixels to reconstruct the received image.

For each reconstructed image, both PSNR and SSIM values were computed with respect to the original reference image. To visualize the results, the received images at the lowest SNR (0 dB) and highest SNR (20 dB) were displayed, along with plots of SNR versus PSNR and SNR versus SSIM.

CODE:

```
clc; clear; close all;
rng(1);                         % repeatable results


%% 1) Load grayscale image (original reference)
img = imread('cameraman.tif');          % built-in
img = imresize(img,[256 256]);          % standard size
ref = img;                      % keep ORIGINAL for all comparisons
figure, imshow(ref), title('Original');


%% 2) Bits from image (8 bits per pixel, MSB-first)
pix = double(ref(:));           % 0..255 as double
bits = de2bi(pix, 8, 'left-msb');       % Npix x 8
tx_bits = bits(:);              % column bitstream (0/1)


%% 3) BPSK mapping (0->-1, 1->+1) and enforce double column
tx_syms = 2*double(tx_bits) - 1;        % ±1
tx_syms = tx_syms(:);                   % column vector
```

```
%% 4) Sweep SNR and evaluate
SNRdB = 0:5:20;
psnr_vals = zeros(size(SNRdB));
ssim_vals = zeros(size(SNRdB));

for k = 1:numel(SNRdB)
    snrdb = SNRdB(k);

    % AWGN on symbols (SNR measured vs signal power)
    rx_syms = awgn(tx_syms, snrdb, 'measured');

    % BPSK hard decision
    rx_bits = rx_syms > 0;              % logical column

    % Rebuild pixels from bits (MSB-first to match de2bi)
    rx_bits_mat = reshape(rx_bits, [], 8);              % Npix x 8
    rx_pix = bi2de(rx_bits_mat, 'left-msb');            % 0..255 (double)
    rx_img = uint8(reshape(rx_pix, size(ref)));       % image

    % Quality vs ORIGINAL
    psnr_vals(k) = psnr(rx_img, ref);
    ssim_vals(k) = ssim(rx_img, ref);

    % Show worst/best cases
```

```
        if snrdb==min(SNRdB) || snrdb==max(SNRdB)

        figure, imshow(rx_img), title(sprintf('Received (SNR = %d dB)', snrdb));

        end

end

%% 5) Plot

figure; plot(SNRdB, psnr_vals, '-o','LineWidth',2);

xlabel('SNR (dB)'); ylabel('PSNR (dB)'); title('SNR vs PSNR'); grid on;

 figure; plot(SNRdB, ssim_vals, '-s','LineWidth',2);

xlabel('SNR (dB)'); ylabel('SSIM'); title('SNR vs SSIM'); grid on;
```

Results

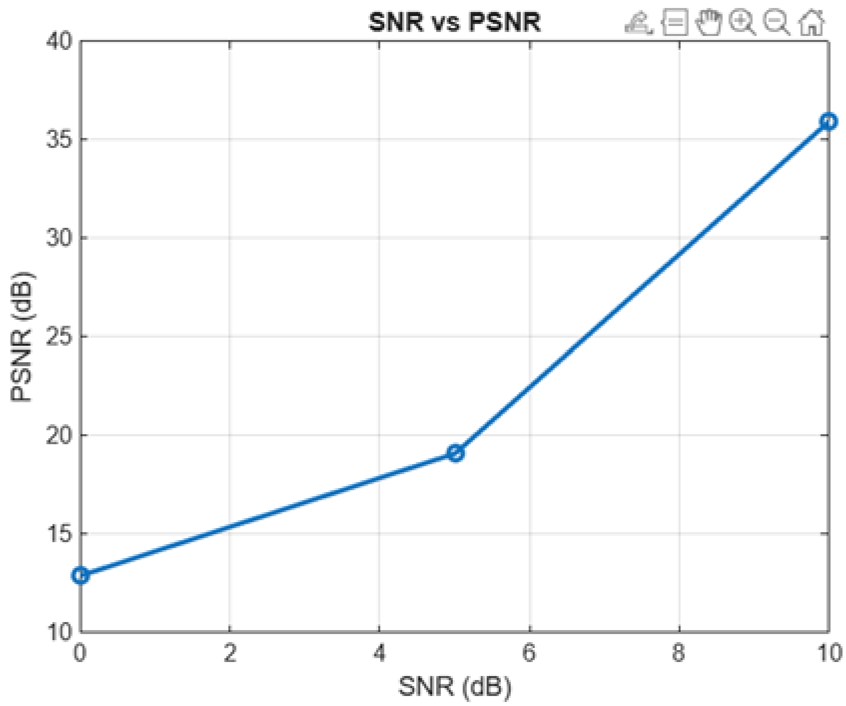
At very low SNR values such as 0 dB, the effect of noise on the reconstructed image is highly visible. The image appears strongly degraded, with noticeable distortions and loss of detail.

Received (SNR = 0 dB)

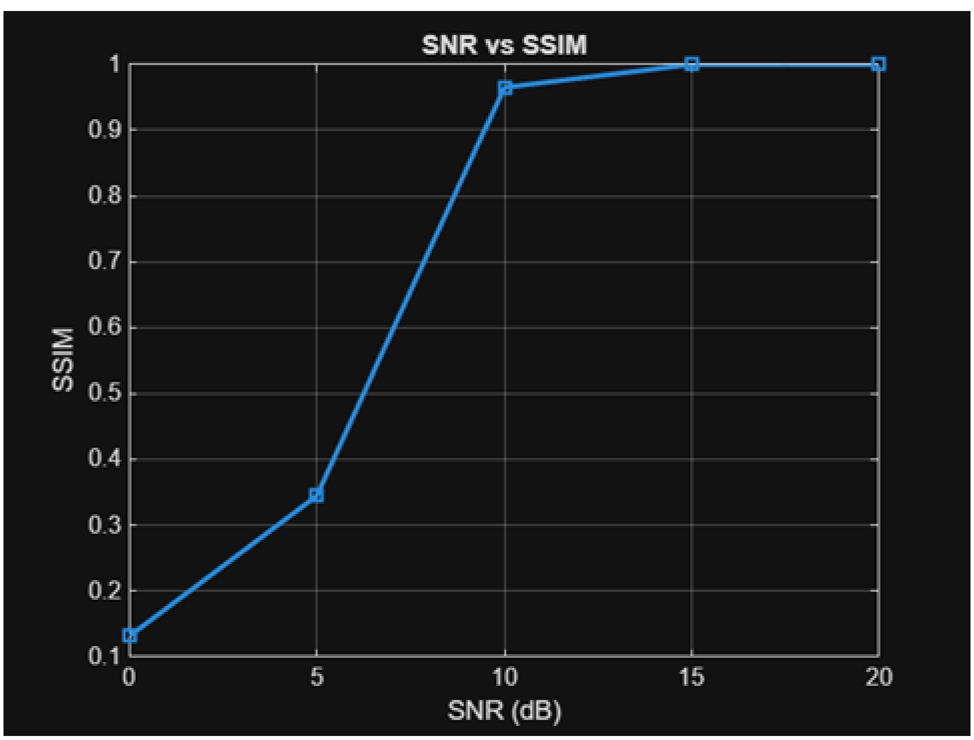
At higher SNR levels such as 20 dB, the reconstructed image closely resembles the original, with very little visible distortion.

Received (SNR = 20 dB)

The plots of PSNR and SSIM confirm this observation. As SNR increases, the PSNR values rise steadily, indicating improved pixel-level fidelity.



Similarly, the SSIM values also increase with SNR and approach values close to 1 at higher SNRs, indicating strong structural similarity to the reference image.



Conclusion

The experiment clearly demonstrates the impact of channel noise on image transmission and recovery. At low SNR values, noise dominates the transmitted signal, resulting in poor-quality images with low PSNR and SSIM scores. As the SNR increases, the effect of noise diminishes, and the reconstructed images become almost identical to the original. This confirms the robustness of BPSK modulation in transmitting images under noisy conditions and also highlights the usefulness of PSNR and SSIM as objective quality metrics.