Image Compression based on Non-Parametric Sampling in Noisy Environments

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Objectives

To develop a robust scheme for image compression involving:

- Creating holes in an image
- Encode and transmit the image
- Simulate a noisy channel in order to introduce errors
- Identifying and filling the holes appropriately.

System Design

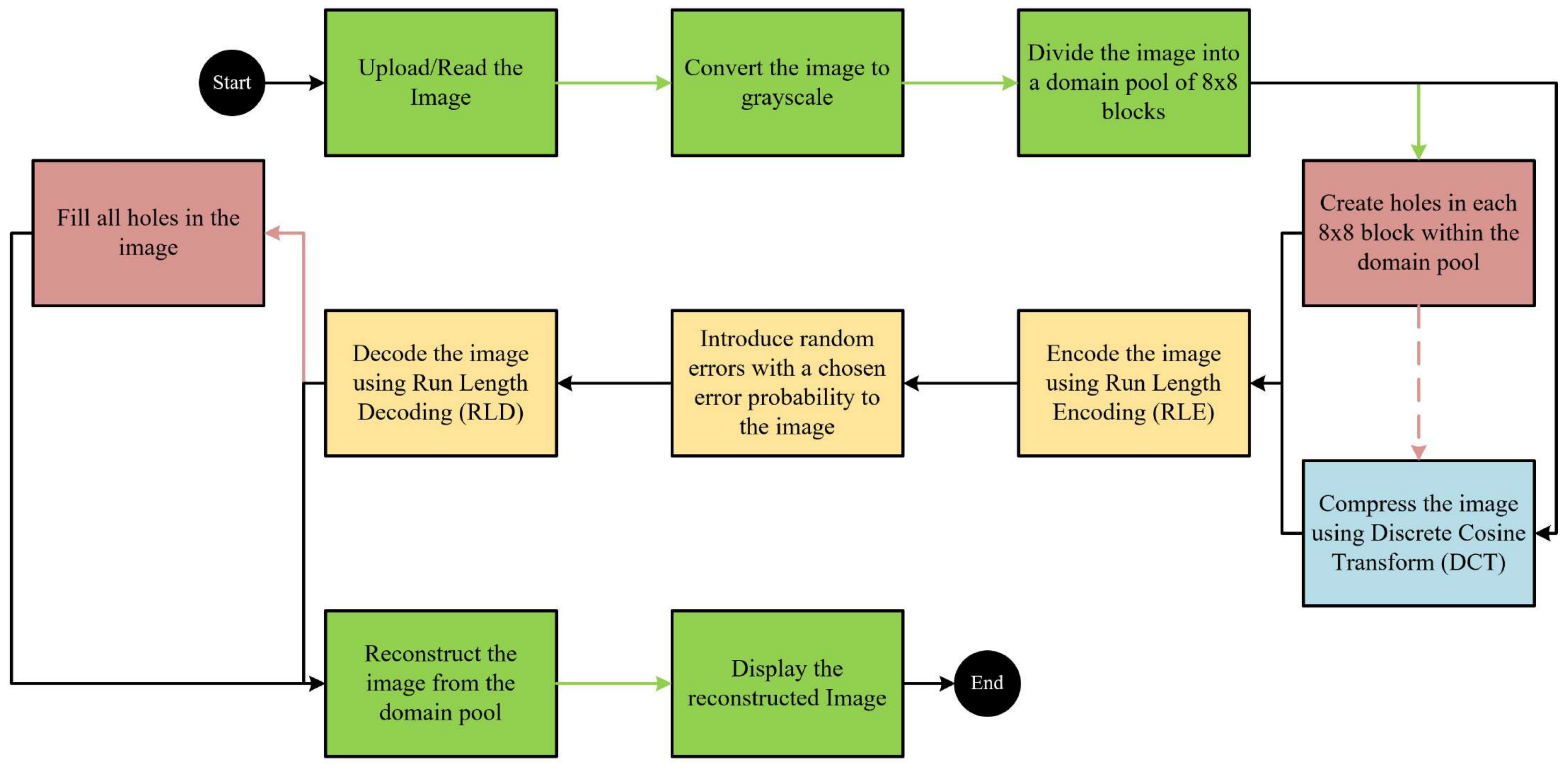


Figure 1: Image compression implementation overview

Algorithms

Algorithm 1 High-level algorithm for creating holes in `8x8` blocks

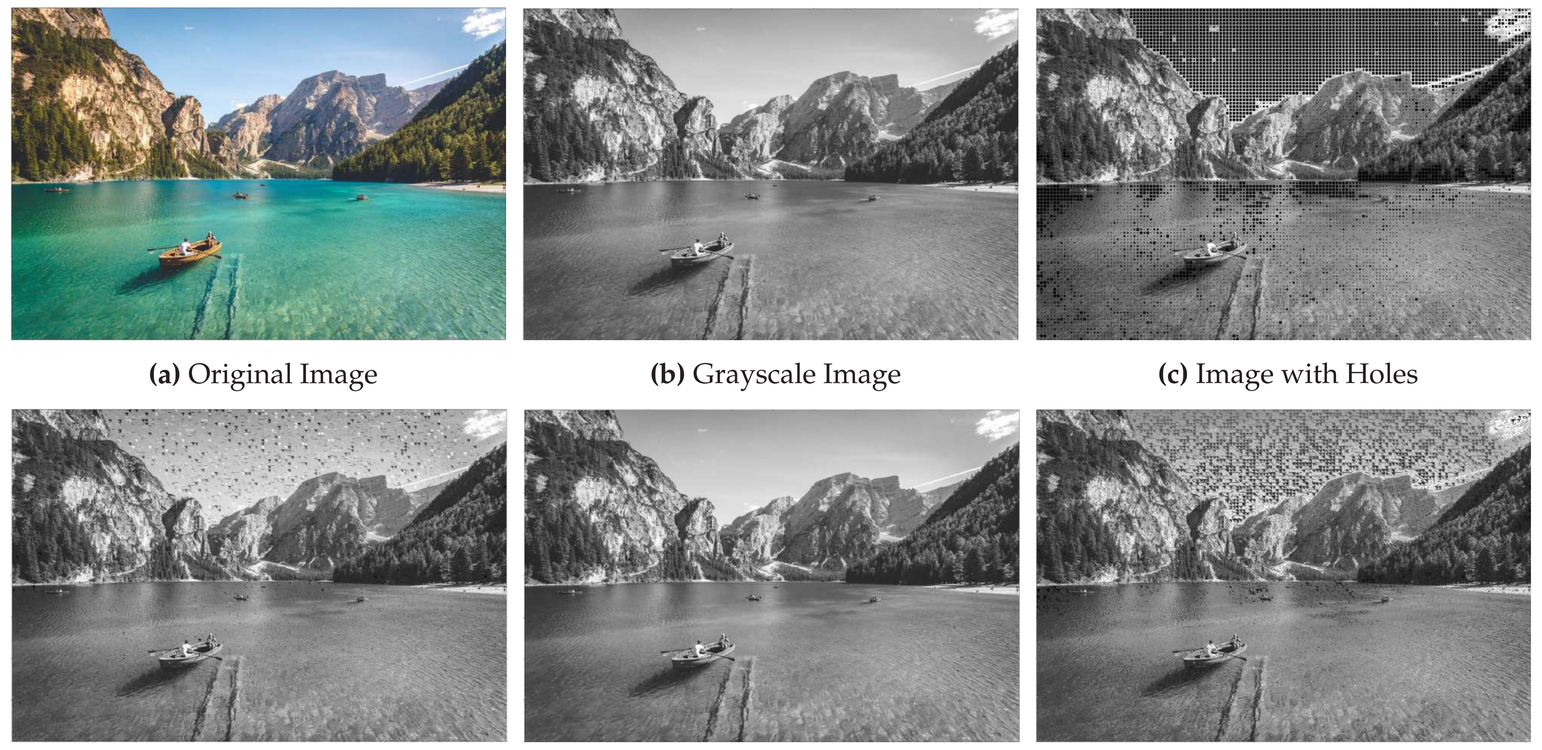
for every block in the domain pool **do**
  Set n=2
  Go to `nxn` square in `8x8` block
  Calculate average of pixels in `nxn`
  for every pixel in the `nxn` block **do**
    Check Chebyshev distance between pixels `(y[])` and average value `(x)`
  end for
  if Chebyshev distance between `x` and each value of `y[]` < 6 **then**
    Repeat for n=4
    if Chebyshev distance between `x` and each value of `y[]` < 6 **then**
      Repeat for n=6
      if Chebyshev distance between `x` and each value of `y[]` < 6 **then**
        Create hole in `6x6`
      else
        Create hole in `4x4`
      end if
    else
      Create hole in `2x2`
    end if
  else
    Move to next block in domain pool
  end if
end for

Algorithm 2 High-level algorithm for filling holes in `8x8` blocks

Set n=2
Go to `nxn` square in `8x8` block
Calculate average of pixels in `nxn`
for every pixel in the `nxn` block **do**
  Check Chebyshev distance between pixels `(y[])` and average value `(x)`
end for
if Chebyshev distance between `x` and each value of `y[]` < 6 **then**
  Repeat for n=4
  if Chebyshev distance between `x` and each value of `y[]` < 6 **then**
    Repeat for n=6
    if Chebyshev distance between `x` and each value of `y[]` < 6 **then**
      Move to top left of nxn block
      Calculate average of pixels directly:above, left & above-left. Fill pixel with average value
      Proceed from left to right and top to bottom
    else
      Fill hole in `4x4`
    end if
  else
    Fill hole in `2x2`
  end if
else
  Move to next block in domain pool
end if

Results: Processing

The figures below and to the right detail the various steps involved in the compression of the image such as: converting to grayscale; creating holes; applying the DCT transformation; and the effect of noise in the final reconstruction.

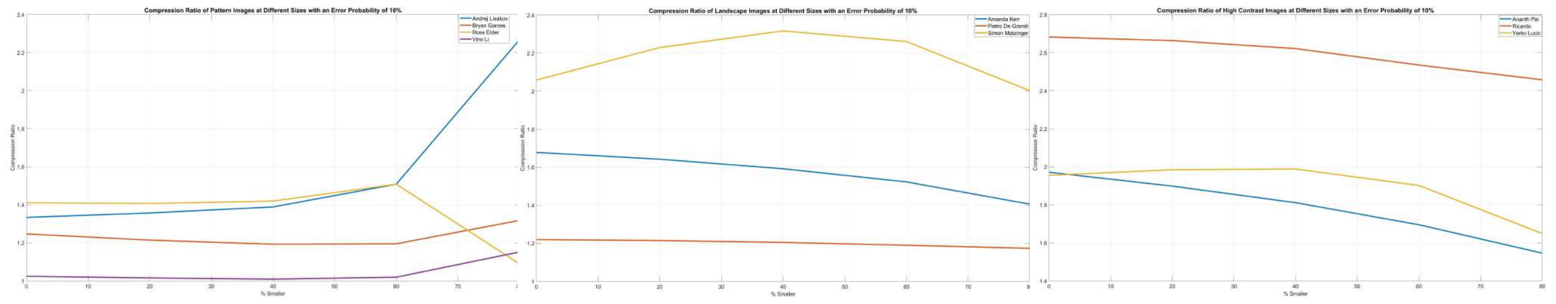


(a) Original Image (b) Grayscale Image (c) Image with Holes

(a) Bit Flip Error (50%) (b) No Errors (c) 1's Comp. Error (50%)

Results: Simulation

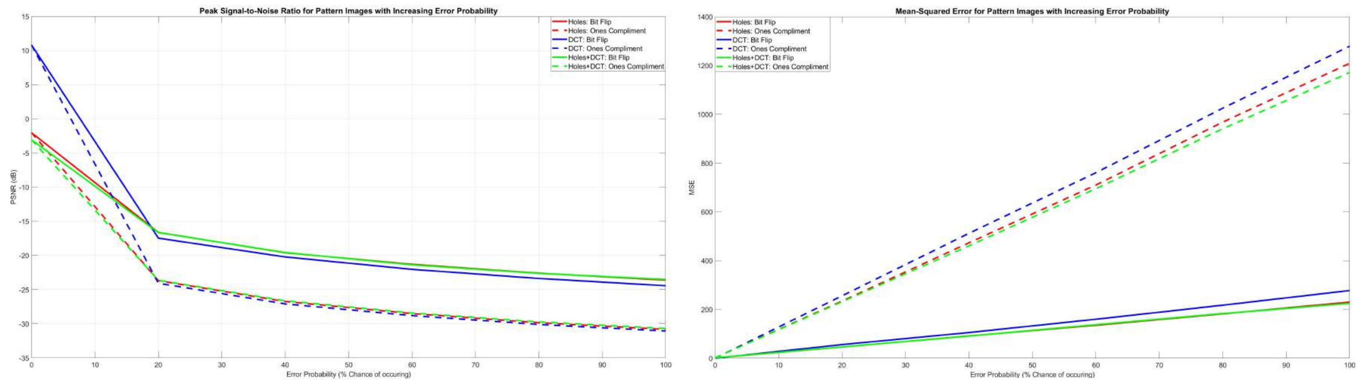
Figure 4 and the subsequent sub-figures test the created *Holes* algorithm on different images. Pattern images are chosen for the repetitive colour and smooth features; landscape images are chosen for the texture features and intense detail; high contrast images are chosen for its combination of both repetitive colour, smooth and texture features.



(a) Pattern Images (b) Landscape Images (c) High Contrast Images

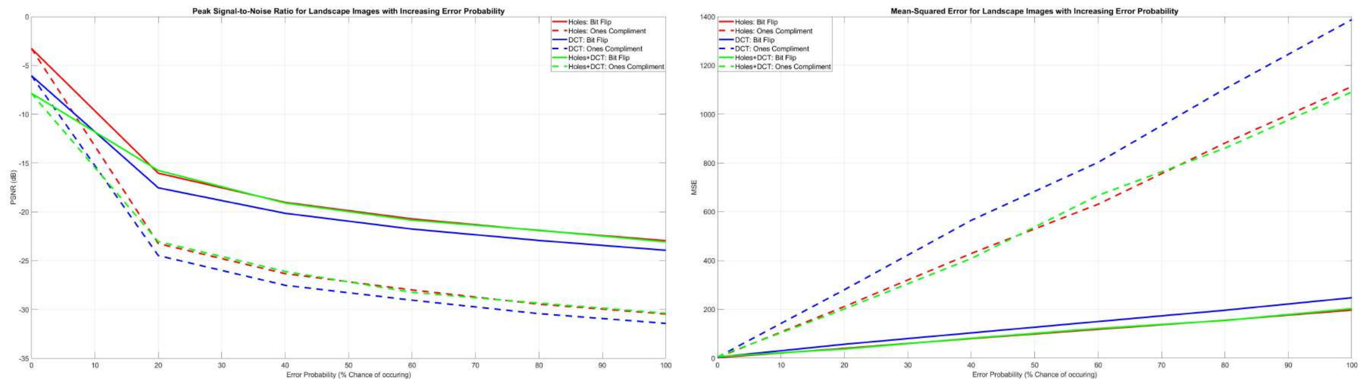
Figure 4: Compression Ratio vs Same Image at Different Sizes

An error analysis is carried out on the different image types calculating the peak signal-to-noise ratio (PSNR) and mean squared error (MSE) of the reconstructed images. The PSNR is a dimensionless number expressed on a logarithmic decibel scale, to identify the perceived errors noticeable by the human vision. The MSE is the cumulative squared error of the compressed image against the original image [1].



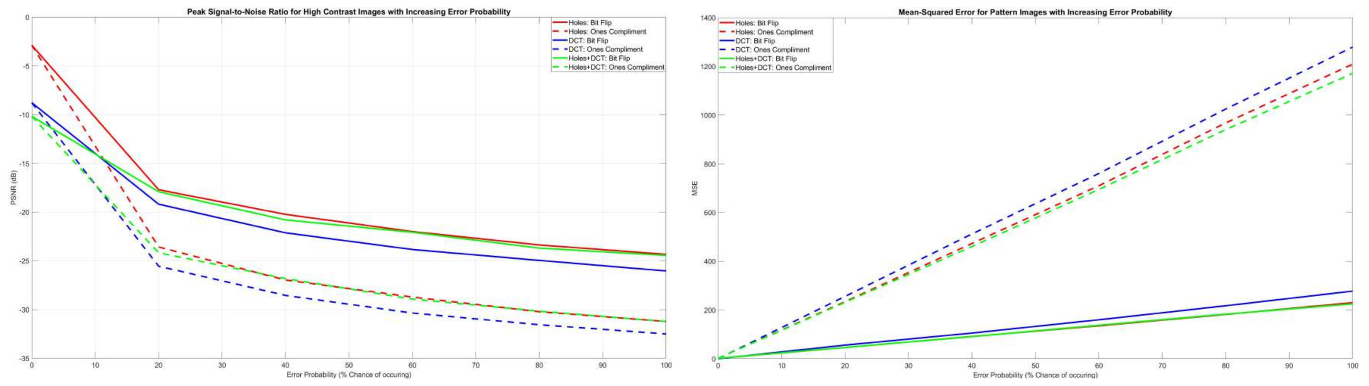
(a) PSNR for all Pattern Images (b) MSE for all Pattern Images

Figure 5: Pattern Images Error Analysis



(a) PSNR for all Landscape Images (b) MSE for all Landscape Images

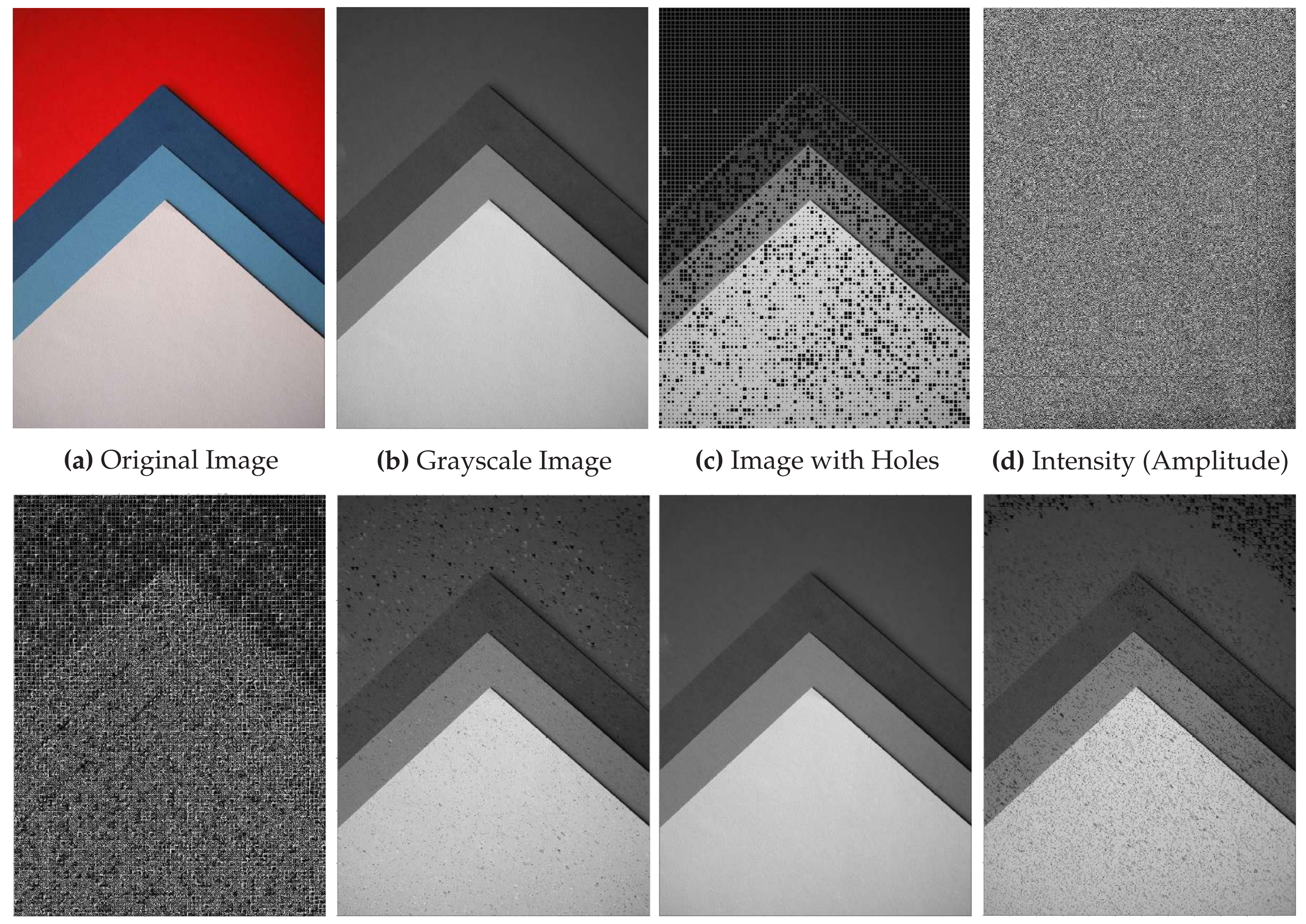
Figure 6: Landscape Images Error Analysis



(a) PSNR for all High Contrast Images (b) MSE for all High Contrast Images

Figure 7: High Contrast Images Error Analysis

Results: Processing



(a) Original Image (b) Grayscale Image (c) Image with Holes (d) Intensity (Amplitude)

(a) Quantized (b) Bit Flip Error (50%) (c) No Errors (d) 1's Comp. Error (50%)

Formulas

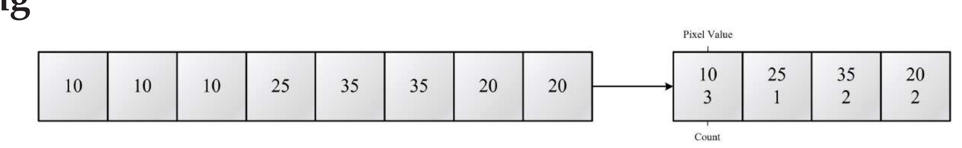
The Discrete Cosine Transform Formula

$$D(i,j) = \frac{1}{\sqrt{2N}} C(i)C(j) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} p(x,y) \cos\left[\frac{(2x+1)i\pi}{2N}\right] \cos\left[\frac{(2y+1)j\pi}{2N}\right] \qquad (1)$$

The Chebyshev Distance Formula

$$D(p,q) = \max_i(|p_i - q_i|) \qquad (2)$$

Run Length Encoding



Compression Ratio

$$CR = \frac{No.\ of\ bits\ in\ uncompressed\ image}{No.\ of\ bits\ transmitted\ after\ encoding} \qquad (3)$$

Future Work

The designed algorithm for image compression can be improved in numerous ways, including:

- Utilizing parallel computing and programming to speed up the processing time of the algorithm
- A neural network can be trained on multiple images so that holes can be created in the larger picture as opposed to smaller 8x8 blocks within the image
- A neural network trained on multiple images at different compression depths can determine the correct check value
- A trained neural network can ultimately reconstruct an image and improve detail and quality of low-quality images.

Conclusion

This project is a proof of concept that an image compression technique to both create and fill holes is possible and viable to use in noisy environments. This was proven by:

- Creating a novel holes creation algorithm
- Using an additional well known compression scheme in addition to the holes algorithm
- Simulating a simple channel and introducing random errors to the channel
- Filling of holes and successful reconstruction of original image

Overall success criteria of the algorithm:

- Achieved compression ratios of an average of: 1.303765 (Pattern); 1.6475 (Landscape); 2.0909 (High Contrast)
- Average PSNR of: $-14.111325dB$ (Pattern); $-16.7051dB$ (Landscape); $-15.7210dB$ (High Contrast)
- Average MSE of: 25.904334 (Pattern); 52.7247 (Landscape); 57.5855 (High Contrast)

Acknowledgements

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References

[1] Uthayakumar, J. et al; *A survey on data compression techniques: From the perspective of data quality, coding schemes, data type and applications*; Journal of King Saud University - Computer and Information Sciences (2018)