4. PERFORMANCE PARAMETERS

1. **Correlation Coefficient (CC)**

   The robustness performance of watermark extraction is evaluated by normalized correlation coefficient, $r$, of the extracted watermark $A$ and the original watermark $B$ [36].

   $$\gamma = \frac{\sum_{m} \sum_{n} (A(m,n) - \bar{A})(B(m,n) - \bar{B})}{\sqrt{\left(\sum_{m} \sum_{n} (A(m,n) - \bar{A})^2\right) \left(\sum_{m} \sum_{n} (B(m,n) - \bar{B})^2\right)}}$$

   Where $A$ and $B$ respectively, the normalized original and watermark image by subtracting its corresponding means value. The magnitude range of $r$ is $[0, 1]$, and the unity holds if the extracted image perfectly matches the original one.

   We use correlation coefficient to compare original image ($A$) and the watermarked image ($A_w$), and also for comparing original watermark $W$ and the retrieved watermark.

2. **Peak Signal to Noise Ratio (PSNR)**

   The imperceptibility of a watermark is measured by the watermarked image quality in terms of Peak-Signal-to-Noise Ratio (PSNR) (in dB). Most common difference measure between tow images is the mean square error. The mean square error measure is popular because it correlates reasonably with subjective visual tests and it is mathematically tractable.

   Consider a discrete image $A(m, n)$ for $m=1,2,\ldots,M$ and $n=1,2,\ldots,N$, which is regarded as a reference image. Consider a second image $\hat{A}(m, n)$, of the same spatial dimension as $A(m, n)$, that is to be compared to the reference image.

   We use PSNR to determine the difference between original image $A (m, n)$ and the watermarked image $\hat{A} (m, n)$.

3. **Mean Square Error (MSE)**
Under the assumption that $A(m, n)$ and $\tilde{A}(m, n)$ represent samples of a stochastic process, Mean Square Error (MSE) is given as

$$E_{\text{MSE}} = E\left( |A(m, n) - \tilde{A}(m, n)|^2 \right)$$

Where $E(\cdot)$ is the expectation operator.

The normalized Mean Square Error

$$E_{\text{NMSE}} = \frac{E\left( |A(m, n) - \tilde{A}(m, n)|^2 \right)}{E\left( |A(m, n)|^2 \right)}$$

Normalized mean square error for deterministic image arrays is defined as

$$E_{\text{NLSE}} = \frac{\sum_{m} \sum_{n} |A(m, n) - \tilde{A}(m, n)|^2}{\sum_{m} \sum_{n} |A(m, n)|^2}$$

Image error measures are often expressed as signal-to-noise ratio,

$$SNR = -10 \log_{10} \varepsilon$$

The value of mean square error should be minimum as possible and the value of peak signal to noise ratio should be maximum as possible.