Some Studies on Quality Metrics for Information Hiding

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Abstract

Information hiding is popular technique to deal with copyright fraud and uncontrollable distribution of multimedia content but developers and researchers yet to get a standardized way regarding performance evaluation of information hiding schemes. This paper deals with the essential quality metrics which are used to measure and monitor the impairments of data caused by information hiding. Preferably, quality metrics should have the skill to emphasize the advantages and the weaknesses of the hiding method under test and allow for easy and efficient method. It is helpful for researchers in order to accurately predict the results and to score in new algorithm development as well as to compare different information hiding algorithms altogether on a perceptual quality viewpoint.

Keywords: Copyright, Impairments, Information Hiding, Performance Evaluation, Perceptual Quality, Quality Metrics

1. Introduction

Proliferations of digital data and different multimedia processing tools have produced the problem of copyright fraud and uncontrollable distribution of multimedia content[1]. To sort out this problem, information hiding technology has been adapted as a prospective tool to achieve copyright protection, ownership trace, authentication etc.[2]. The technique embeds invisible/visible information into a host signal without affecting channel bandwidth[3]. Measurement of visual quality is of critical importance in data hiding because quality is a key determinant for data reception and transmission control. There are basically two classes of objective quality or distortion assessment approaches. The first are mathematically defined which measures Mean Squared Error (MSE), Peak Signal to Noise Ratio (PSNR), Root Mean Squared Error (RMSE) etc. The second class of measurement methods considers Human Visual System (HVS) characteristics in an attempt to incorporate perceptual quality measures[4,5]. The most commonly used mathematically measurements are comprised of two main types - first one is the subjective measurement while the other is the objective measurement[6]. These metrics use the original object as a reference to compare it with

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the impaired object. Objective measurement can be further divided into two classes: Full-reference and no-reference. Full-reference measures compare a test image to some known standard directly[7], while no-reference methods assign an arbitrary score to an image regardless of context[8]. Quality assessment aims to quantify these distortions in a perceptually consistent manner. As the end user for such images is usually a human, qualitative assessment should be centered on human visual perception. The goal of quality assessment, then, is to automate this process of assigning objective human visual system based quality scores to images[9].

The paper organizes the quality metrics in Section 2 and draws the conclusion in Section 3.

2. Quality Metrics

Imperceptibility means that the supposed quality of the host signal should not be distorted by the existence of the information[10]. Developers and researchers of information hiding system need a standard metric to measure the quality of impaired signal compared with the original signal. Thus it is required to have a list of most popular subjective and objective quality metrics[11]. These measured metrics are all based on the difference distortion between the original signals and undistorted or the modified signal. Here we present the list of metrics with mathematical expression in Table 1.

3. Conclusion

In this paper we addressed the issue of performance evaluation of information hiding methods; the visual degradation of the images has to be taken into account. A variety of commonly used distortion metrics are listed for the researchers for new algorithm development and to compare the results of the earlier algorithms.

Table 1. The list of Quality Metrics

Name of the Metrics	Mathematical expression
Quadratic Error Metric[12]	$Q_F(x)=x^T Ax+2b^T x+c$ where x is any point in 3-d space a,b,c are constants
Quadratic Error With Respect To Vertex v_i[12]	$\sum_{j}^{N_{v_i}} Q_{F_j}(x) = \left(\sum_{j}^{N_{v_i}} A_j, \sum_{j}^{N_{v_i}} b_j, \sum_{j}^{N_{v_i}} c_j\right)$ where $Q_{F_j} = (A_j, b_j, c_j)$ The quadratic error of x with respect to v_i is the sum of the squared distance from a point x to all the planes adjacent to v_i.
True Detection Rate[13]	$\textbf{TDR} = \frac{N_c}{N_t}$ N_c – number of correctly extracted watermark bits N_t – Total number of watermark bits
Estimation Error[13]	$EE = Q_C(q_f) - Q_E(q_f)$ q_f is the quality factor Q_c – Calculated Quality Q_E – Estimated Quality
Watson Just Noticeable Difference[13]	$\mathbf{G}(i,q_f) = \begin{cases} V_{JND}(i,q_f+10) - V_{JND}(i,q_f) \\ 0 \end{cases}$ V_{JND} the JND value calculated between the corresponding DWT blocks q_f is the "Quality Factor"
Minkowsky Measurement[16]	$M_\lambda = \frac{1}{k}\sum_{k=1}^{k}\{\frac{1}{N^2}\sum_{i,j=1}^{N}\left\|C_k(i,j) - \bar{C}_k(i,j)\right\|^{\gamma}$ C_k (i,j) is the original image $\bar{C}_k$ (i,j) is the watermarked image

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	k is number of band γ corresponds to Mean Absolute Error N is the number of pixels
WSEGS[17]	$W_{segs} = \left[\frac{Redundency * len}{\sum A_{wb}}\right]$ The watermark bit assignment, $A_{wb} = [a1, a2, a3]$, where $a1$, $a2$ and $a3$ are the number of the water mark bits. *len* is the length of the watermark sequence
Image Content Complexity[17]	$\boldsymbol{Complexity} = \sum_{i=1}^{n} \left(N_i * 2^i\right)$ i=current quad tree decomposition level n=highest decomposition level N= no. of quad tree decomposition nodes on level i.
Czekanowski Distance[18]	$\boldsymbol{CD} = \frac{1}{N^2} \sum_{i,j=0}^{N-1} \left(1 - \frac{2\sum_{k=1}^{k} \min\left(C_k(i,j), \hat{C}_k(i,j)\right)}{\sum_{k=1}^{k}\left(C_k(i,j) + \hat{C}_k(i,j)\right)} \right)$ C_k (i,j) is the original image $\hat{C}_k$ (i,j) is the watermarked image K is the number of bands N is the number of pixel
Angular Correlation[18]	$\boldsymbol{AC} = 1 - \frac{1}{N^2} \sum_{i,j=1}^{N} \frac{2}{\pi} COS^{-1} \frac{\langle C(i,j), \hat{C}(i,j) \rangle}{\lVert C(i,j) \rVert \lVert \hat{C}(i,j) \rVert}$ where C(i,j) is original image $\hat{C}$(I,j)is the watermarked image (i,j) are the pixel length and breadth N is the number of bit

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Normalized Mean Square HVS Error[18] 1)	$\boldsymbol{NMSHVSE} = \frac{1}{K} \sum_{K=1}^{k} \frac{\sum_{i,j=0}^{N-1} \left[U\{C_K(i,j)\} - U\{\hat{C}_K(i,j)\} \right]^2}{\sum_{i,j=0}^{N-1} \left[U\{C_K(i,j)\} \right]^2}$ Where K is the number of bands C_k(i,j) is the original image $\bar{C}_k$ (i,j) is the watermarked image K is the number of band N is the number of pixel
Tuning Parameter[20]	$\theta = \frac{D}{\delta_{max}^2}$ Where D is an experimental value δ^2_{max} is the maximum local variance of the given image
Mean Of Error Energy[21] 2)	$E_e = \frac{1}{M} \sum_{n=1}^{M} \left(\sum_{k1=1}^{k1} \sum_{k2=1}^{k2} (w_n[k1,k2] - \overline{w_n}[k1,k2])^2 \right)$ $w_n[k1, k2]$ is the original image $\overline{w_n}[k1,k2]$ is the extracted watermarked image K is the number of band n is the number of pixel M is the current frame index
Peak Signal To Noise Ratio[21] 3)	$\boldsymbol{PSNR} = \frac{MN_{\max} I^2_{m,n} \; m,n}{\sum_{m,n}\left(I_{m,n} - \bar{I}_{m,n}\right)^2}$ Where I (m,n) is the original image with (m,n) pixel length and width. $\bar{I}$ (m,n)is the watermarked image with (m,n) pixel length and width (M,N) are the image size

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Hausdorff Distance[22] 4)	$H_d = e(p,A) = min_{v_{i \in A}^{A}} d(p, v_i^A)$ Where d is Euclidian distance v_i^A is the i th vertex of object A p is the block of an image
Root Mean Square Error[22] 5)	$RMS = (\sum_{i=1}^{n} \left\| v_i^A - v_i^B \right\|^2)^{1/2}$ Where n is the number of vertices of the meshes v_i^B is the vertex of B corresponding to the vertex v_i^A of A.
Geometric Laplacian Measures[22]	$GL(v) = v - \frac{\sum_{i \in n(v)} l_i^{-1} v_i}{\sum_{i \in n(v)} l_i^{-1}}$ $n(v)$ is the set of indices of the neighbors of **v** l_i^{-1} is the Euclidean distance from to **v** to v_i GL(v) represents the difference Vector between **v** and its new position after a Laplacian smoothing step. $\alpha RMS(A,B) + (1-\alpha)\left(\sum_{i=1}^{n} \left\| GL(v_i^A) - GL(v_i^B) \right\|^2\right)^{\frac{1}{2}}$ Where n is the number of vertices of the meshes and v_i^B is the vertex of B corresponding to the vertex v_i^A of A. α=0.5
Minkowski Sum[22]	$MS = (\frac{1}{n_w} \sum_{j=1}^{n_w} LMSDM(a_j, b_j)^3)^{\frac{1}{3}}$ n_w is the number of local windows of the meshes. a_j is the local window of A corresponding to the window of B b_j is the local window of B corresponding to the window of A. LSDM=Local Mesh Structural Distortion Measure (This measures the distance between two mesh local windows a_j and b_j to introduce the concept of structural similarity in 2D images)
Strain Field Based Measure (Perceptual Distance)[22]	$SF = \frac{1}{S} \sum w_i W_i$ w_i are weight W_i is the strain energy associated to each triangle. S = Total area of the triangular faces
6) **Strength Of Measure (of an image)**[25] 7)	$\rho = \frac{\sum_{i=1}^{N} w_i \overline{w}_l}{\sqrt{\sum_{i=1}^{N} w_i}\sqrt{\sum_{i=1}^{N} \overline{w}_i}}$ N is number of pixels in watermark, w_i is original watermark, $\overline{w}_i$ is extracted watermark.
LSE Metric(M)[15] 8)	$M = \| X - g^* X \|$ g*X represents convoluting (non causally filtering) X = Its Image X which is supposed to have I rows and J columns, i.e. I.J (pixels height & width) where M is of the same size with X and has nonnegative elements.

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9) 10) 11) 12) 13) 14) 15) **Mahalanobis Distance**[15]	17) 18) $$MD(x_k,y_k)=\left(\sum_{i=1}^{a^2}\frac{\left(u_{i,k}-v_{i,k}\right)^2}{\breve{\lambda}_i}\right)\frac{1}{2}$$ x_k & y_k is the block coefficients, $u_{i,k}$ & $v_{i,k}$ is the KLT coefficients of block $\widehat{\lambda}_i$ is used to weigh the distance along the eigenvector
Complexity[17]	$$\textbf{Complexity}=\sum_{i=1}^{n}\left(N^i X2^i\right)$$ where, i is the current quad-tree decomposition level; n is the highest decomposition level; N_i is the number of quad-tree decomposition nodes on level i.
Masked Peak Signal To Noise Ratio[27]	$$\mathrm{MPSNR}=10\log_{10}\frac{255^2}{E^2}$$ Where E is the computed distortion.
Picture Quality Scale[28]	$$PQS=b_0+\sum_{j=1}^{J}b_jZ_j$$ PQS quality metric as a linear combination of principal components Zj where the bj are the partial regression coefficients & J is the block coefficients of an image.
Perceptually Based Metric[22]	$$M_{fit}=\frac{1}{2\pi}\int_{a+bM}^{\infty}e^{-\frac{t^2}{2}}dt$$ where M is the perceptually-based metric used, a and b are the parameters estimated by a nonlinear least-squares data fitting. where $e^{-\left(\frac{t^2}{2}\right)}$ is the estimated value of block image

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Mean Square Error[23] 19) 20)	$$\boldsymbol{MSE}=\frac{1}{MN}\sum_{m,n}\left(I_{m,n}-\bar{I}_{m,n}\right)^2$$ where MN is frame size of video data & image Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ is the watermarked image
Bit Error Rate[29] 21)	$$\boldsymbol{BER}=1-\left(1-p_e\right)^{\Lambda}$$ Where BER is Bit Errror rate p_e is the expectation value N is the number of bits
KullbackLeibler Distance[30] 22)	$$\boldsymbol{KLD}\left(p,q\right)=\sum_i p_i\log_2\frac{p_i}{q_i}$$ where p_i & q_i are two probability distribution
Histogram Similarity[27] 23) 24)	$$\boldsymbol{HS}=\sum_{c=0}^{255}\left\|I_{m,n}(c)-\bar{I}_{m,n}(c)\right\|$$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ is the watermarked image C is the number of pixels
Normalized Hamming Distance[29] 25)	$$\boldsymbol{NHD}=\frac{\sum(W_{m,n}\neq\bar{W}_{m,n})}{MXN}$$ $W_{m,n}$ is the original image $\bar{W}_{m,n}$ is the watermarked image (m,n) is the pixel length and breadth
Structural Content[27]	$$\boldsymbol{SC}=\frac{sum\left(sum\left(A^2\right)\right)}{sum\left(sum\left(B^2\right)\right)}$$ A is original image B is watermarked image

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Mutual Information[29] 26) 27)	$$MI(X,Y)=\sum_{y\in Y}\sum_{x\in X}p(x,y)\log\left(\frac{p(x,y)}{p_1(x)+p_{2(x)}}\right)$$ $p(x, y)$ is the joint probability distribution function of X and Y, p1(x), p2(x) are the marginal probability distribution functions of X and Y
Maximum Difference[27]	$$MD = max_{m,n}\left\|I_{m,n}-\bar{I}_{m,n}\right\|$$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ Is the watermarked image (m,n) are the pixel length and width.
Adaptive Peak Signal To Noise Ratio[20]	$$APSNR = 10\log_{10}\frac{\left[Y_{0,max}(K)-Y_{0,min}(K)\right]^2}{M_{se}\times NVF^2}$$ Where NVF is the Noise Visibility Function M_{se} is the Mean Square Error Y is the level, k is the band
Universal Image Quality Index[31]	$$Q=\frac{4\sigma I_{M,N}}{\left(\sigma_I^2-\sigma_w^2\right)\left[(I)^2+(W)^2\right]}$$ Where $$\sigma_I^2=\frac{1}{N-1}\sum_{i=1}^{N}\left(I-\bar{I}\right),\sigma_W^2=\frac{1}{N-1}\sum_{i=1}^{N}\left(W-\bar{W}\right)$$ $$\sigma=\frac{1}{N-1}\sum_{i=1}^{N}\left(W-\bar{W}\right)\left(I-\bar{I}\right)$$ And I and W are original and test image signal respectively

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Structural Similarity Index Measurement[32]	$$SSIM(x,y)=\frac{\left(2\mu_x\mu_y\right)\left(2\sigma_{xy}+C_2\right)}{\left(\mu_x^2+\mu_y^2+C_1\right)\left(\sigma_x^2+\sigma_y^2+C_2\right)}$$ μ_x & μ_y are mean intensity σ_x & σ_y are the standard deviation of original and distorted image C_1 & C_2 are constants σ_{xy} is the covariance of both the images
Average Absolute Difference[27]	$$AD=\frac{1}{MN}\sum_{m,n}\left\|I_{m,n}-\bar{I}_{m,n}\right\|$$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ Is the watermarked image (m,n) are the pixel length and width 28)
Normalized Average Absolute Difference[27]	$$NAD=\frac{\sum_{m,n}\left\|I_{m,n}-\bar{I}_{m,n}\right\|}{\sum_{m,n}\left\|I_{m,n}\right\|}$$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ is the watermarked image (m,n) are the pixel length and width
Normalized Mean Square Error[27]	$$NMSE=\frac{\sum_{m,n}\left(I_{m,n}-\bar{I}_{m,n}\right)}{I_{m,n}^2}$$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ Is the watermarked image (m,n) are the pixel length and width
Signal to Noise Ratio[27]	$$SNR=\frac{\sum_{m,n}I_{m,n}^2}{\sum_{m,n}\left(I_{m,n}-\bar{I}_{m,n}\right)^2}$$

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	Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ is the watermarked image (m,n) are the pixel length and width
Image Fidelity[27]	$\boldsymbol{IF} = 1 - \frac{\sum_{m,n}(I_{m,n} - \bar{I}_{m,n})^2}{\sum_{m,n} I^2_{m,n}}$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ is the watermarked image (m,n) are the pixel length and width
Laplacian Mean Square Error[27]	$\boldsymbol{LMSE} = \frac{\sum_{m,n}(\nabla^2 I_{m,n} - \nabla^2 \bar{I}_{m,n})^2}{\sum_{m,n}(\nabla^2 I_{m,n})^2}$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ is the watermarked image (m,n) are the pixel length and width
Visual Signal To Noise Ratio[33]	$\boldsymbol{VSNR} = 20\log_{10}\left(\frac{C(I)}{\alpha d_{pc} + (1-\alpha)\frac{d_{gp}}{\sqrt{2}}}\right)$ where α is the relative contribution of each distance d_{pc} is distortion contrast d_{gp} is global precedence
Noise Quality Measure[34]	$\boldsymbol{NQM}(dB) = 10\log_{10}\left(\frac{\sum_{m,n} I'_{m,n}}{\sum_{m,n}(I'_{m,n} - I_{m,n})}\right)$ Where $I_{m,n}$ is the Original Image $I'_{m,n}$ is the Watermarked Image

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Weighted Peak Signal To Noise Ratio[35]	$\boldsymbol{WPSNR} = 20\log 10\left(\frac{255}{NVF \times \sqrt{MSE}}\right)$ $\boldsymbol{NVF} = NORM\left(\frac{1}{1 \times \delta^2_{block}}\right)$ Where 255 are the range of pixel values NVF (Noise visibility function) is the optimal substitution is obtained by dynamic programming strategy to get the good image quality MSE is the Mean Square Error δ^2_{block} is local variance of any image block
Normalized Cross. Correlation[27]	$\boldsymbol{NC} = \frac{\sum_{m,n} I_{m,n}\bar{I}_{m,n}}{\sum_{m,n} I^2_{m,n}}$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ Is the watermarked image (m,n) are the pixel length and width
Correlation Quality[27]	$\boldsymbol{CQ} = \frac{\sum_{m,n} I_{m,n}\bar{I}_{m,n}}{\sum_{m,n} I_{m,n}}$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ Is the watermarked image (m,n) are the pixel length and width
Correlation Factor[27]	$\boldsymbol{CF} = \frac{\sum_{m,n}(W_{m,n} * \bar{W}_{m,n})}{\sum_{m,n}\left(W^2_{m,n} * \bar{W}^2_{m,n}\right)}$ Where $W_{m,n}$ is the original image $\bar{W}_{m,n}$ is the watermarked image (m,n) are the pixel length and width

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Hellinger Distance[37]	$$HD = \frac{1}{2}\int\left(\sqrt{\hat{P}} - \sqrt{P}\right)^2 d\lambda$$ p^ the context probability mass function. of the distorted image, p the probability mass function of the original image, *Ep* is the expectation with respect to *p*
Sigma to Error Ratio[27]	$$SER = \frac{\sigma_b^2}{\frac{1}{P}\sum\left(I_{m,n} - \bar{I}_{m,n}\right)}$$ Where $I_{m,n}$ is the original image $\bar{I}_{m,n}$ is the watermarked image (m,n) are the pixel length and width b block of p pixels of original and watermarked image
Global Sigma Signal To Noise Ratio[27]	$$GSSNR = \frac{\sum_b \sigma_b^2}{\sum_b\left(\sigma_{b-\bar{\sigma}b}\right)^2}$$ Where $\sigma_{b=}\sqrt{\frac{1}{P}\sum_b I_{m,n}^2 - \left(\frac{1}{P}\sum_b I_{m,n}\right)^2}$ Where $I_{m,n}$ is the original image (m,n) are the pixel length and width, b block of p pixels of original and watermarked image
Sigma Signal To Noise Ratio[27]	$$SSNR = \frac{1}{P}\sum_b SSNR_b$$ $$SSNR_b = 10\log_{10}\frac{\sigma_b^2}{\left(\sigma_{b-\bar{\sigma}_b}\right)^2}$$ $$\sigma_{b=}\sqrt{\frac{1}{P}\sum_b I_{m,n}^2 - \left(\frac{1}{P}\sum_b I_{m,n}\right)^2}$$

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	Where $I_{m,n}$ is the original image (m,n) are the pixel length and width b block of p pixels of original and watermarked image
Mean of Angle Difference [37]	$$MAD = 1 - \frac{1}{N^2}\sum_{m,n=1}^{N}\left(\frac{2}{\pi}cos^{-1}\frac{\left(C_{m,n},\bar{C}_{m,n}\right)}{\left\|C_{m,n}\right\|\left\|\bar{C}_{m,n}\right\|}\right.$$ Where $C_{m,n}$ is the Original Image $\bar{C}_{m.n}$ Is the Watermarked Image N is the number of pixels
Pratt Edge Measure[37] 29) 30)	$$PEM = \frac{1}{\max\left\{n_d,n_t\right\}}\sum_{i=1}^{n_d}\frac{1}{1+ad_i^2}$$ Where n_d is the number of detected n_t is the ground-truth edge points d_i is the distance to the closest edge candidate for the i^{th} detected edge pixel. The factor $\max\{n_d,n_t\}$ penalizes the number of false alarm edges or conversely missing edges.
Gaussian Psychometric Function[14]	$$GPF = \frac{1}{2\pi}\int_{a+bR}^{\infty} e^{-\left(\frac{t^2}{2}\right)}dt$$ where and are the parameters to be estimated by fitting the objective metric values to the subjective data R is the objective metric used to measure the visual distortions where $e^{-\left(\frac{t^2}{2}\right)}$ is the estimated value of block image.

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Spectra of Spectral Measures [26]	$\Gamma_x(u,v) = \sum_{m,n=0}^{N-1} C_k(m,n) \exp\left[-2\pi i m \frac{u}{N}\right] \exp\left[-2\pi i n \frac{u}{N}\right]$ C_k (m,n) is the original image N is number of watermarked bits (u,v)denotes the point $\frac{u}{n}$ denotes the block point of an image
Texture Sensitivity[17]	$M_T(l,i,j) = \text{var}\{I_{LL}\left(X + \left[\frac{i}{2^{L_e-1}}\right]\right)\left(y + \left[\frac{j}{2^{L_{e-1}}}\right]\right)\}$ I_{LL} is the sub band of an image block Where x and y are two points (l,*i*, *j*) are the coordinates of a selected DWT Coefficient i is the level to compute the distances between two images L_e=uniform quantization of the color space between the two images(original and watermarked images)
Strength Of Measure[25]	$\rho = \frac{\sum_{i=1}^{N} W_i \overline{W}_i}{\sqrt{\sum_{i=1}^{N} W_i} \sqrt{\sum_{i=1}^{N} \overline{W}_i}}$ N is number of pixels in watermark W_i is original image $\overline{W}_i$ is the extracted watermarked image
Watermark To Document Ratio[36]	$\boldsymbol{WDR} = 10\log \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\left[I(i,j) - X_W(i,j)\right]^2}{\sum_{i=1}^{N}\sum_{j=1}^{N} I(i,j)^2}$ Where N is the vertices of the image I(i , j) is the original image X_w (i,j) is the watermarked image
Pearson Correlation Coefficient[35]	$\rho = \left\| \frac{\sum_n \left\{\left[W_{m,n} - W^{-}_{m,n}\right] + \left[W'_{m,n} - W^{-'}_{m,n}\right]\right\}}{\left\{\sum_n \left[W_{m,n} - W^{-}_{m,n}\right]^2 \sum_n \left[W'_{m,n} - W^{-'}_{m,n}\right]^2\right\}^{\frac{1}{2}}} \right\|$ $W_{m,n}$ & $W^{-}_{m,n}$ original watermark and extracted logo images respectively

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