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 content¹. 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 bandwidth³. 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 measurement⁶. 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 directly⁷, while no-reference methods assign an arbitrary score to an image regardless of context⁸. 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 images⁹.

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 information¹⁰. 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 metrics¹¹. 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

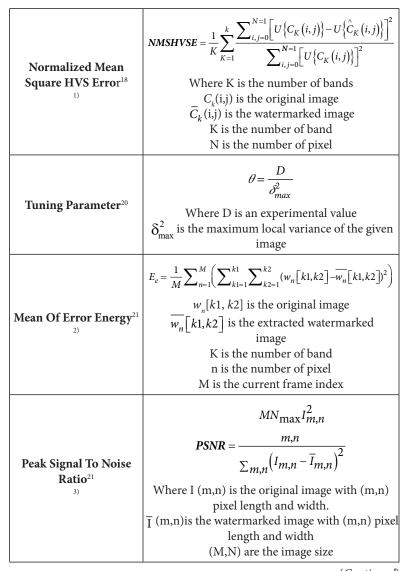
In this paper we addressed the issue of performance evaluation of information hiding methods; the visual degradation of the images has to be taken into account. A variety of commonly used distortion metrics are listed for the researchers for new algorithm development and to compare the results of the 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 <i>v</i> _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	$\mathbf{TDR} = \frac{N_c}{N_t}$ N_c - number of correctly extracted watermark bit N_t - Total number of watermark bits	
Estimation Error ¹³	$EE = Q_C(q_f) - Q_E(q_f)$ $q_f \text{ is the quality factor}$ $Q_c - \text{ Calculated Quality}$ $Q_E - \text{ Estimated Quality}$	
Watson Just Noticeable Difference ¹³	$\mathbf{G}(\mathbf{i}, q_f) = \begin{cases} V_{JND}(\mathbf{i}, q_f + 10) - V_{JND}(\mathbf{i}, q_f) \\ 0 \end{cases}$ $V_{JND} \text{ the JND value calculated between the corresponding DWT blocks} \\ q_f \text{ is the "Quality Factor"} \end{cases}$	
Minkowsky Measurement ¹⁶	$M_{\lambda} = \frac{1}{k} \sum_{k=1}^{k} \left\{ \frac{1}{N^2} \sum_{i,j=1}^{N} \left C_k(i,j) - \overline{C}_k(i,j) \right ^{\gamma}$ $C_k(i,j) \text{ is the original image}$ $\overline{C}_k(i,j) \text{ is the watermarked image}$	

⁽Continued)

	It is number of hand		
	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.		
	<i>len</i> is the length of the watermark sequence		
Image Content	$Complexity = \sum_{i=1}^{n} \left(N_i * 2^i \right)$		
Complexity ¹⁷	i=current quad tree decomposition level		
	n=highest decomposition level N= no. of quad tree decomposition nodes on level i.		
	no. or quad tree decomposition nodes on level i.		
Czekanowski Distance ¹⁸	$CD = \frac{1}{N^{2}} \sum_{i,j=0}^{N-1} \left(1 - \frac{2\sum_{k=1}^{k} \min\left(C_{k}(i,j), C_{k}(i,j)\right)}{\sum_{k=1}^{k} \left(C_{k}(i,j) + C_{k}(i,j)\right)} \right)$		
	C_k (i,j) is the original image		
	$C_k^{}$ (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	$AC = 1 - \frac{1}{N^2} \sum_{i,j=1}^{N} \frac{2}{\pi} COS^{-1} \frac{\left\langle C(i,j), \hat{C}(i,j) \right\rangle}{\left\ C(i,j) \right\ \left\ \hat{C}(i,j) \right\ }$		
	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		



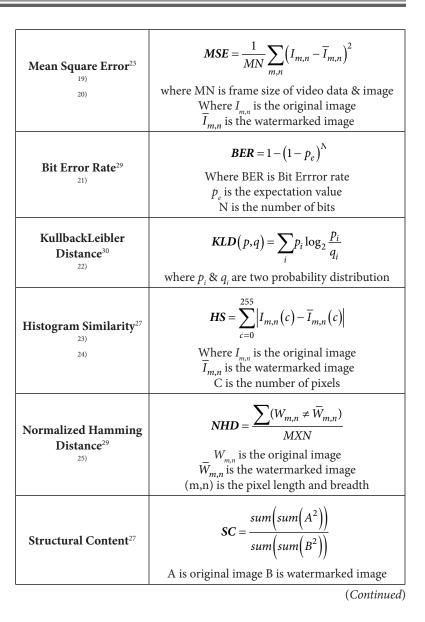


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Hausdorff Distance ²² 4)	$H_{d} = e(p, A) = min_{v_{ieA}^{A}d(p, v_{i}^{A})}$ Where d is Euclidian distance v_{i}^{A} is the i th vertex of object A p is the block of an image		$MS = \left(\frac{1}{n_w} \sum_{j=1}^{n_w} LMSDM(a_j, b_j)^3\right)^{\frac{1}{3}}$ $n_w \text{ is the number of local windows of the meshes.}$ $a_j \text{ is the local window of A corresponding to the window of B}$
Root Mean Square Error ²² ⁵⁾	$RMS = \left(\sum_{i=1}^{n} \left\ v_i^A - v_i^B \right\ ^2 \right)^{1/2}$ 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.	Minkowski Sum ²²	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)
	$GL(v) = v - \frac{\sum_{i \in n(v)} l_i^{-1} v_i}{\sum_{i \in n(v)} l_i^{-1}}$	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
Geometric Laplacian Measures ²²	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.	6) Strength Of Measure (of an image) ²⁵ 7)	$\rho = \frac{\sum_{i=1}^{N} w_i \overline{w}_i}{\sqrt{\sum_{i=1}^{N} w_i} \sqrt{\sum_{i=1}^{N} \overline{w}_i}}$ N is number of pixels in watermark, w_i is original watermark, \overline{w}_i is extracted watermark.
	$aRMS(A,B) + (1-\alpha) \left(\sum_{i=1}^{n} \left\ GL(v_i^A) - GL(v_i^B) \right\ ^2 \right)^{\frac{1}{2}}$ 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. $\alpha = 0.5$	LSE Metric(M) ¹⁵ ⁸⁾	$M = X - g^*X $ $g^*X \text{ represents convoluting (non causally filtering)}$ $X = \text{Its Image X which is supposed to have I rows and J columns, i.e. I.J (pixels height & width) where M is of the same size with X and has nonnegative elements.}$

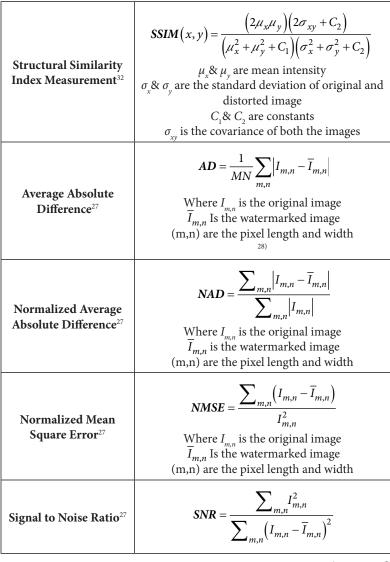
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9)	17)	
10)	$\begin{pmatrix} 18 \end{pmatrix}$	
11)	$MD(x_k, y_k) = \left(\sum_{i=1}^{a^2} \frac{\left(u_{i,k} - v_{i,k}\right)^2}{\tilde{\lambda}_i}\right) \frac{1}{2}$	
12)	$MD(x_k, y_k) = \sum \frac{1}{2} \frac{1}{2}$	
13)	$\begin{pmatrix} i=1 \end{pmatrix}^2$	
14)	$x_k \otimes y_k$ is the block coefficients, $u_{i,k} \otimes v_{i,k}$ is the	
15)	KLT coefficients of block	
Mahalanobis Distance ¹⁵	$\hat{\lambda}_i$ is used to weigh the distance along the eigenvector	
Complexity ¹⁷	$Complexity = \sum_{i=1}^{n} \left(N^{i} X 2^{i} \right)$ where, <i>i</i> is the current quad-tree decomposition level; <i>n</i> is the highest decomposition level; <i>N_i</i> is the number of quad-tree decomposition nodes on level <i>i</i> .	
Masked Peak Signal To Noise Ratio ²⁷	MPSNR = $10 \log_{10} \frac{255^2}{E^2}$ Where E is the computed distortion.	
	where E is the computed distortion.	
Picture Quality Scale ²⁸	$PQS = b_0 + \sum_{j=1}^{J} b_j Z_j$ 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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Mutual Information ²⁹ 26) 27)	$MI(X,Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log\left(\frac{p(x,y)}{p_1(x) + p_{2(x)}}\right)$ $p(x,y) \text{ is the joint probability distribution function of X and Y,}$ $p1(x), p2(x) \text{ are the marginal probability distribution functions of X and Y}$	
Maximum Difference ²⁷	$MD = max_{m,n} \left I_{m,n} - \overline{I}_{m,n} \right $ Where $I_{m,n}$ is the original image $\overline{I}_{m,n}$ 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	
$\mathbf{Q} = \frac{4\sigma I_{M,N}}{\left(\sigma_I^2 - \sigma_w^2\right) \left[(I)^2 + (W)^2 \right]}$ Where $\sigma_I^2 = \frac{1}{N-1} \sum_{i=1}^N (I-\overline{I}), \sigma_W^2 = \frac{1}{N-1} \sum_{i=1}^N (W-\overline{W})$ $\sigma = \frac{1}{N-1} \sum_{i=1}^N (W-\overline{W}) (I-\overline{I})$ And I and W are original and test image sign respectively		



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Image Fidelity ²⁷	Where $I_{m,n}$ is the original image $\overline{I}_{m,n}$ is the watermarked image (m,n) are the pixel length and width $IF = 1 - \frac{\sum_{m,n} (I_{m,n} - \overline{I}_{m,n})^2}{\sum_{m,n} I_{m,n}^2}$ Where $I_{m,n}$ is the original image $\overline{I}_{m,n}$ is the vatermarked image (m,n) are the pixel length and width $\sum_{m,n} (\nabla^2 I_{m,n} - \nabla^2 \overline{I}_{m,n})^2$	Weighted Peak Signal To Noise Ratio ³⁵	$WPSNR = 20 \log 10 \left(\frac{255}{NVF \times \sqrt{MSE}} \right)$ $NVF = NORM \left(\frac{1}{1 \times \delta_{block}^2} \right)$ 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_{block}^2 is local variance of any image block
Laplacian Mean Square Error ²⁷	$LMSE = \frac{\sum_{m,n} (\nabla^2 I_{m,n} - \nabla^2 I_{m,n})^2}{\sum_{m,n} (\nabla^2 I_{m,n})^2}$ Where $I_{m,n}$ is the original image $\overline{I}_{m,n}$ is the watermarked image (m,n) are the pixel length and width	Normalized Cross. Correlation ²⁷	$NC = \frac{\sum_{m,n} I_{m,n} \overline{I}_{m,n}}{\sum_{m,n} I_{m,n}^2}$ Where $I_{m,n}$ is the original image $\overline{I}_{m,n}$ Is the watermarked image
Visual Signal To Noise Ratio ³³	$VSNR = 20 \log_{10} \left(\frac{C(I)}{a d_{pc} + (1 - a) \frac{d_{gp}}{\sqrt{2}}} \right)$ where α is the relative contribution of each distance d_{pc} is distortion contrast d_{gp} is global precedence	Correlation Quality ²⁷	$CQ = \frac{\sum_{m,n} I_{m,n} \overline{I}_{m,n}}{\sum_{m,n} I_{m,n}}$ Where $I_{m,n}$ is the original image $\overline{I}_{m,n}$ Is the watermarked image (m,n) are the pixel length and width
Noise Quality Measure ³⁴	$NQM(dB) = 10\log_{10}\left(\frac{\sum_{m,n} I'_{m,n}}{\sum_{m,n} (I'_{m,n} - I_{m,n})}\right)$ Where $I_{m,n}$ is the Original Image $I'_{m,n}$ is the Watermarked Image	Correlation Factor ²⁷	$CF = \frac{\sum_{m,n} (W_{m,n} * \overline{W}_{m,n})}{\sum_{m,n} (W_{m,n}^2 * \overline{W}_{m,n}^2)}$ Where $W_{m,n}$ is the original image $\overline{W}_{m,n}$ is the watermarked image (m,n) are the pixel length and width

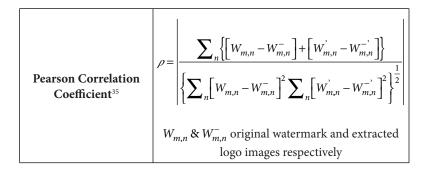
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Hellinger Distance ³⁷	$HD = \frac{1}{2} \int \left(\sqrt{\overline{P}} - \sqrt{P} \right)^2 d\lambda$ p^ the context probability mass function. of the distorted image, p the probability mass function of the original image, <i>Ep</i> is the expectation with respect to <i>p</i>		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 $MAD = 1 - \frac{1}{N^2} \sum_{m=1}^{N} (\frac{2}{\pi} cos^{-1} \frac{(C_{m,n}, \overline{C}_{m,n})}{ C_{m,n} }$
Sigma to Error Ratio ²⁷	$SER = \frac{\sigma_b^2}{\frac{1}{P} \sum (I_{m,n} - \overline{I}_{m,n})}$ Where $I_{m,n}$ is the original image $\overline{I}_{m,n}$ is the watermarked image	Mean of Angle Difference ³⁷	$N^{2} \sum_{m,n=1}^{\infty} \langle \pi^{coc} C_{m,n} \overline{C}_{m,n} $ Where $C_{m,n}$ is the Original Image $\overline{C}_{m,n}$ Is the Watermarked Image N is the number of pixels
Global Sigma Signal To Noise Ratio ²⁷	$GSSNR = \frac{\sum_{b} \sigma_{b}^{2}}{\sum_{b} (\sigma_{b-\overline{\sigma}\overline{b}})^{2}}$ 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	Pratt Edge Measure ³⁷ 29) 30)	$PEM = \frac{1}{\max\{n_d, n_t\}} \sum_{i=1}^{n_d} \frac{1}{1 + ad_i^2}$ 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>i</i> th detected edge pixel. The factor max{n _d ,n _t } penalizes the number of false alarm edges or conversely missing edges.
Sigma Signal To Noise Ratio ²⁷	(m,n) are the pixel length and width, b block of p pixels of original and watermarked image $SSNR = \frac{1}{P} \sum_{b} SSNR_{b}$ $SSNR_{b} = 10 \log \frac{\sigma_{b}^{2}}{(\sigma_{b} - \sigma_{b})^{2}}$ $\sigma_{b} = \sqrt{\frac{1}{P} \sum_{b} I_{m,n}^{2} - \left(\frac{1}{P} \sum_{b} I_{m,n}\right)^{2}}$	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.



Spectra of Spectral Measures ²⁶	$\Gamma_{x}(u,v) = \sum_{m,n=0}^{N-1} C_{k}(m,n) \exp\left[-2\pi i m \frac{u}{N}\right] \exp\left[-2\pi i n \frac{u}{N}\right]$ $C_{k}(m,n) \text{ is the original image}$ N is number of watermarked bits $(u,v) \text{ denotes the point}$ $\frac{u}{n} \text{ denotes the block point of an image}$	
Texture Sensitivity ¹⁷	$M_T(l,i,j) = \operatorname{var}\{I_{LL}\left(X + \left[\frac{i}{2^{L_e - i}}\right]\right)\left(y + \left[\frac{j}{2^{L_{e+1}}}\right]\right)\}$ $I_{LL} \text{ is the sub band of an image block}$ $Where x \text{ and } y \text{ are two points}$ $(l,i,j) \text{ are the coordinates of a selected DWT}$ $Coefficient$ $I \text{ is the level to compute the distances between two images}$ $L_e = \text{uniform quantization of the color}$ $Space between the two images(original and watermarked images)$	
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	$WDR = 10 \log \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} \left[I(i,j) - X_{W}(i,j) \right]^{2}}{\sum_{i=1}^{N} \sum_{j=1}^{N} I(i,j)^{2}}$ Where N is the vertices of the image I(i,j) is the original image $X_{W}(i,j)$ is the watermarked image	

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