T1Q1.5 /88-078
November, 1988

CONTRIBUTION TO: Telecommunications Standards Committee T1
Performance Technical Subcommittee T1Q1
Wideband Program Working Group T1Q1.5

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Information Administration
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TITLE: **Compilation and Description of Candidate Video Quality Measures**

ABSTRACT

This contribution presents an annotated compilation of candidate measures of video quality. These measures or parameters can be objectively sorted for the most effective minimal set by the expert pattern recognition system previously proposed by the Institute for Telecommunication Sciences (ITS). The catalog provides a short description of each parameter and includes reference information.

INTRODUCTION

This contribution is a catalog of candidate measures for objective video quality assessment. With the large body of references in both the image processing and broadcast television areas, this catalog is not complete. The Institute will continue to maintain and update the catalog when additional candidate measures are discovered or created.

Some of the measures (or parameters) listed are digital and are measured directly from an image, while others are analog and are measured from the video signal. All of the measures are candidates for general video quality assessment. A subset of the parameters are more applicable to measuring quality of motion video. Thus, the measures are divided into two groups.

All of the measures are summarized in Table I of this report. Table II contains descriptions of general purpose video quality parameters and begins on page 5. Table III (page 21) contains measures which may be useful for assessing quality of moving scenes in addition to other aspects of quality. The tables are mutually exclusive. Measures are listed alphabetically within each table. Each table consists of three columns. The first column specifies the name of the measure. The second column provides a short description of the parameter. When available, the descriptions include information about how well the measure correlates with subjective tests. The third column gives reference numbers where information about the measure was obtained. Reference numbers are in the format [ref. no., chapter.section.subsection]. Finally, a list of references is provided on page 29 of the report.

Following work will objectively sort these measures into the most effective minimal set using the expert pattern recognition techniques proposed in earlier contributions.

Table I. Summary of Candidate Video Quality Measures

General Purpose Measures

brightness metrics (global)
brightness metrics (local)
chrominance/luminance intermodulation
chrominance nonlinear gain
chrominance nonlinear phase
chrominance to luminance delay inequality
chrominance to luminance gain inequality
color bar chart
color image fidelity measures
color metrics (global)
color metrics (local)
contrast ratio
CSF, contrast sensitivity function
CTF, contrast transfer function or contrast threshold function
cross-correlation function
DDD, detectable difference diagram
difference error or normalized difference error
differential gain
differential phase
equivalent rectangular passband measure
ghosting or echo
gray level histogram peaks
gray scale
GFP, gray-shade frequency product
GFP-log
ICS, integrated contrast sensitivity
imps, units of subjective impairment
JNDA, just-noticeable difference area
JNDA-Log
K factor
Kell factor
line time waveform distortion
luminance difference threshold
luminance nonlinearity
mean square error or normalized mean square error
modulation transfer factor
MTF, modulation transfer function
MTFA, modulation transfer function area
noise visibility function
patterns (grid and dot)
patterns (intelligibility test)
resolution (linear spacial frequency)
resolution (limiting)
resolution (suprathreshold)
RAR, resolution addressability ratio
short time waveform distortion
SNR, signal to noise ratio
SNRD, signal to noise ratio at the display
SQRI, square root integral formula

Strehl definition
SQF, subjective quality factor
vector accuracy maximum amplitude error
vector accuracy maximum phase error
visibility threshold
Weber fraction
WPSNR, ratio of the peak-to-peak luminance to the weighted rms noise

Motion Sensitive Video Quality Measures

cepstrum
critical flicker fusion frequency
cross correlation with output error
edge sharpness estimators
frequency-domain models
frequency response
histogram of error image
image entropy or information density
motion prediction errors
PQS, picture quality scale
rate distortion functions
space-domain models
spacial gratings
temporal resolution estimate
Waf-SNR

Table II. General Purpose Video Quality Measures

Table II contains 56 candidate measures for video quality assessment.

Parameter	Description	Reference
brightness metrics (global)	Metrics used for determining brightness separation between light sources when the sources are separated in luminance by large percentage differences. Developed from empirical models based on experimentation. The level of background illumination must be considered when developing the empirical models for global brightness metrics.	[2, 7.3.1]
brightness metrics (local)	Metrics used for determining incremental brightness between sources of light. The metrics are nonlinear and model brightness perception of the human eye. Local brightness metrics have been investigated for use in monochrome image fidelity measure.	[2, 7.3.1]
chrominance/ luminance intermodulation	Measured with a three level chrominance signal. Does not yield significant results.	[12]
chrominance nonlinear gain	Measured with a three level chrominance signal. Does not yield significant results.	[12]
chrominance nonlinear phase	Measured with a three level chrominance signal. Poor correlation with subjective tests.	[12]
chrominance to luminance inequality	Corresponds closely to that of the group delay of a band-limiting network which increases with the frequency. Measured with a modulated 12.5T sine square pulse. Poor correlation with subjective tests.	[12], [21]
chrominance to luminance gain inequality	The absence of this distortion is expressed as equality between the luminance and chrominance amplitudes. Measured with a modulated 12.5T sine square pulse. Poor correlation with subjective tests.	[12], [21]

Parameter	Description	Reference
color bar chart	Method of verifying adherence to the NTSC color signal specification. Spatial resolution response can be inferred by measuring the radiance response across a step transition.	[2, 7.2]
color image fidelity measures	Extension of mean square error to the color case. There has been very little testing to determine validity.	[2, 7.5]
color metrics (global)	Measure of the color difference between two colors when the colors are separated by distances greater than a few jncd.	[2, 7.3.2]
color metrics (local)	Measure of the incremental color difference between two colors separated by distances in the order of a few just noticeable color differences (jncd). Accurate color metrics exist in Riemannian space. Ad hoc color metrics exist in Euclidean space.	[2, 7.3.2], [1, 4.4.2], [1, 4.4.3], [18]
contrast, modulation, or modulation contrast	Defined as the maximum luminance minus the minimum luminance divided by the sum of the two.	[24], [26]
contrast ratio	The contrast ratio is given by (maximum screen brightness-minimum screen brightness)/(minimum screen brightness). Optimum ratio is dependent on ambient light, and particular application.	[3], [1, 4.0], [24]
contrast sensitivity function (CSF)	The contrast sensitivity function is defined as the ratio of the average background intensity to the peak amplitude of the spacial sinusoid at threshold that is used as the test stimulus. The contrast sensitivity function is the reciprocal of the contrast transfer function.	[3], [1, 4.3.1d], [14], [24], [25]

Parameter	Description	Reference
contrast transfer function (CTF)	The contrast transfer function or contrast threshold function has been used to describe visual capability. The contrast transfer function gives the minimum detectable contrast as a function of angular spacial frequency. The angular spacial frequency indicates the number of cycles of a periodic pattern that subtend an angle of one degree as measured from a particular viewing distance.	[3], [22, 3], [24]
cross-correlation function	Bivariate (numerical comparison between a pair of images) measure of image quality obtained by computing the two dimensional cross correlation between the reference image and the distorted image (computed for zero correlation shift). Usually normalized by the reference image energy. May be modified by performing an edge sharpening Laplacian operation on the spacial domain fields before correlation. Correlation may remain high even when the distorted image is of subjectively poor quality.	[2, 7.4]
detectable difference diagram	The detectable difference diagram is a means of determining how much the modulation transfer functions of two displays must differ before an observer can detect the difference.	[24]
difference error or normalized difference error	Bivariate measure of image quality obtained by computing the absolute error between the reference and the degraded image fields, normalized by the absolute magnitude of the reference image. Difficult to manipulate. Does not necessarily correlate well with subjective quality.	[2, 7.4]

Parameter	Description	Reference
differential gain	Corresponds to distortion measured in terms of the percent increase in the amplitude of the superimposed color sub-carrier as the luminance amplitude varies from the black level to the white level. Measured with a modulated step staircase. Poor correlation with subjective tests.	[12], [21]
differential phase	Corresponds to distortion measured in terms of a negative variation in the phase difference from the black level to the white level. Measured with a modulated step staircase. Poor correlation with subjective tests.	[12], [21]
equivalent rectangular passband measure	A monochrome univariate image fidelity measure computed by finding the equivalent rectangular passband of the image. Has not proved to be well correlated with subjective testing.	[2, 7.1], [24]
ghosting or echo	The power of the ghost is estimated and used as an indicator of ghosting. Impairment depends on the polarity of the echo, the time separation between the direct signal and the echo, and the distortion of the echo signal. Some estimate are based on linearity and pel independence assumptions.	[5], [21]
gray level histogram peaks	Useful for detecting white level burning and black level crushing.	[5]
gray scale	Useful for checking gray scale linearity. Spacial resolution response can be inferred by measuring the radiance response across a step transition. The least discernable level of gray is dependent on the contrast ratio.	[2, 7.2], [3]

Parameter	Description	Reference
gray-shade frequency product (GFP)	The gray-shade frequency product gives the area between the visual threshold curve (converted to gray shades) and the gray-shade response of the system.	[24]
GFP-log	Calculated by integrating the gray-shade response curve with respect to log spacial frequency.	[24]
integrated contrast sensitivity (ICS)	The integrated contrast sensitivity is defined as the integral of the ratio of the display modulation transfer function and the observer contrast transfer function.	[3], [24]
imps	Units of subjective impairment is given by the reciprocal of the normalized mean score minus 1. The subjective impairment rating when multiple impairments are present in an image has been empirically determined to be the summation of the subjective impairment ratings of the individual impairments taken separately (provided all impairments are unrelated).	[20]
just noticeable difference area (JNDA)	The just-noticeable difference area is defined as the area under the modulation transfer function after it has been transformed into just-noticeable difference levels using the detectable difference diagram.	[24]
JNDA-log	Same as the JNDA except the integration of the area is with respect to the log of the spatial frequency indicated by Weber's law. Correlates well with subjective quality.	[24]

Parameter	Description	Reference
K factor	A standard waveform is injected and the output waveform is compared with a template scaled by a factor of K. The smallest value of K which will accommodate the output response is the K rating. Test waveforms are chosen for there similarity to parts of actual picture signals. Some common test waveforms include (1) a sine squared pulse of half-amplitude duration 2T, where 2T equals the reciprocal of the system bandwidth (4 Mhz for NTSC) and (2) a shaped rectangular pulse approximately half the duration of a scan line.	[1, 4.1.3], [2, 7.2]
Kell factor	That number k such that an image rendered in n scan lines is equal in vertical resolution to the original unscanned image filtered to a bandwidth of nk/2 cycles per picture element. The Kell factor is an attempt to quantify practical vertical resolution as opposed to the ideal vertical resolution given by the sampling theorem. The Kell factor is not clearly defined, resulting in many different definitions.	[1, 4.1.4]
line time waveform distortion	Measured with a line bar. Does not yield significant results.	[12]
luminance difference threshold	Defined as just noticeable differences in the luminance of a perturbed edge over a non-perturbed edge. The luminance difference threshold is a function of the amplitude of the edge and is useful for designing differential pulse code modulation quantizers.	[1, 4.3.1b]
luminance nonlinearity	Measured with an unmodulated 5 step staircase. Unknown correlation with subjective tests.	[12]

Parameter	Description	Reference
mean square error or normalized mean square error	The mean square error between the reference and the distorted picture, possible normalized by the reference image energy. Usually applied after a nonlinear conversion of the intensity (such as a log or 1/3 power law) to offset the fact that the Weber fraction is constant over a wide range of intensities. The mean square error parameter is in wide use due to its simplicity and analytic tractability. There has been a great deal of effort to determine transformations of the image field that yield a mean square error that correlated well with subjective tests. However, correlation with subjective testing is not necessarily obtained.	[1, 4.5], [2, 7.4], [13]
modulation transfer factor	The ratio of the modulation at the output to the modulation at the input of a system for a particular spatial frequency sine-wave pattern.	[24]
modulation transfer function (MTF)	The modulation transfer function describes the spacial frequency response of the imaging system. The modulation transfer function is defined as the modulus of the normalized Fourier transform of the point-spread function of the system. Only applicable for linear, homogeneous systems.	[3], [22, 3], [24], [25], [26]
modulation transfer function area (MTFA)	The information bandpass of the display-observer system. Given by the area between the modulation transfer function and contrast transfer function curves. Combines characteristics of both human vision and display capability. Modified forms of the MTFA include band-limiting and taking the logarithm of the MTFA. By taking the logarithm of the MTFA, it may be possible to partially compensate for the effects of Weber's law. Appears to correlate well with subjective image quality.	[3], [22, 3], [24], [25]

Parameter	Description	Reference
noise visibility function f(x)	Defined as the ratio of the white noise power in the subjectively equivalent reference picture to the power of the noise that is added to the test picture only at pels where the spacial activity function lies in an incremental range around x. The spacial activity function consists of weighted sums of magnitudes of the horizontal and vertical gradients of luminance at several surrounding picture elements. Useful for evaluating the effect of masking (reduction in the visibility of the test stimuli by spacial or temporal nonuniformity of the background) when the magnitude of the coding distortion is large and considerably above the visibility threshold (suprathreshold condition).	[1, 4.3.1b], [1, 4.4.5]
patterns (grid and dot)	Useful for detecting geometric distortion and color primary misregistration in a color television display.	[2, 7.2]
patterns (intelligibility test)	With each pattern, the observer is asked to identify the proper symbols, and results are recorded in terms of the measured probability of detection as a function of symbol size.	[2, 7.8]
resolution (linear spacial frequency)	The maximum number of periodic elements that a viewer can observe before the periodic elements produce a continuum and cannot be resolved. Dependent on the imaging sensor and display device. Typically measured in TV lines per inch. A resolution chart may to used to determine resolution. There are indications that image quality (in regards to resolution) is determined by local, luminance-dependent human visual processing (local aspects such as edges and contours) rather than global frequency domain measures.	[3], [12], [17], [24], [26]

Parameter	Description	Reference
resolution (limiting)	Given by the intersection of the modulation transfer function and the contrast transfer function curves. Specifies the highest spacial frequency the display can produce which the observer can detect. Has not correlated well with subjective image quality.	[3], [24]
resolution (suprathreshold)	A single frequency figure of merit which provides information about the display/observer system in the middle range of spatial frequencies.	[24]
RAR or resolution addressability ratio	The RAR is defined as the 50% width of the scanning spot divided by the distance between the addressed pixels. Used to evaluate the visibility of raster structure and "jaggies".	[19]
short time waveform distortion	Expressed as the percent difference between the peak value of the pulse and the value of the luminance amplitude. Measured with a 2T sine square pulse. Poor correlation with subjective tests.	[12], [21]
signal-to-noise ratio (SNR)	The signal to noise ratio us defined as the ratio of the average number of photons in a test element to the rms deviation from the average. May be a function of many variables.	[3], [21]
signal-to-noise ratio at the display (SNRD)	The signal to noise ratio at the display has been used to characterize the sensor end of the display system (intended primarily to characterize effects due to noise). The display modulation transfer function has been assumed to be unity.	[22], [24]

Parameter	Description	Reference
square root integral formula (SQRI)	The square root integral formula is an empirically derived formula which is based on the analysis of measured data regarding the visible resolution of a display. Factors such as the modulation transfer function of the display and eye, the effect of added light on the perceived resolution of the display, and the display size can be accounted for. The SQRI appears to correlate well with subjective measures of image quality on CRT displays with different resolutions and addressabilities.	[19]
Strehl definition	A monochrome univariate image fidelity measure (a numerical rating assigned to a single image based upon measurements of the image field) of the reduction in contrast of an actual image in comparison to an ideal image. Does not always correlate with subjective image quality.	[2, 7.4]
subjective quality factor (SQF)	The subjective quality factor is a modified version of the modulation transfer function area and is a special case of the integrated contrast sensitivity. Excellent correlation has been obtained between the SQF and the rank order of subjectively ranked black and white photographs.	[24]
vector accuracy maximum amplitude error	Measured with a color bar chart. Poor correlation with subjective tests.	[12]
vector accuracy maximum phase error	Measured with a color bar chart. Poor correlation with subjective tests.	[12]

Parameter	Description	Reference
visibility threshold	Defined as the magnitude of the stimulus at which it becomes just visible or just invisible, i.e., the probability of detection by a human viewer is 50%. Easier to specify when the distortion is just barely visible than to specify the subjective magnitude of distortion that is clearly visible. Not useful when subjective magnitude of coding distortion is considerably above the visibility threshold. In addition, the visibility threshold depends on many global factors such as background luminance, which may be complex rather than uniform.	[1, 4.3]
Weber fraction	The ratio of the just noticeable difference in the intensity of illumination to the intensity of illumination. The Weber fraction is a function of the intensity of the background. Over the range of intensities where the Weber fraction is constant, equal changes in the logarithm of the intensity of the light can be related to equal just noticeable changes in intensity (referred to as Weber's law).	[2, 2.3], [1, 4.3.1a]
WPSNR	The ratio of the peak-to-peak luminance to the weighted rms noise, expressed in dB. The weighting function for the noise power is determined experimentally and incorporates visual effects of variations in the shape of the noise power spectrum. The subjective rating attached to the noise power depends upon many factors such as viewing distance, and display illumination.	[1, 4.3.2], [4]

Table III. Motion Sensitive Video Quality Measures

Table III contains 15 candidate measures for assessing quality of moving scene video.

Parameter	Description	Reference
cepstrum	A two dimensional Fourier transform is first performed, then a logarithm, and finally an inverse Fourier transform. Useful for detection of motion blur, focus blur, and ghosting. Linearity assumptions are made in that the image degradation process can be modeled as a convolution of the original undistorted image with the degrading point spread function. Not robust enough to detect impairments of images accurately in complex video environments when used as a univariate estimate. Motion blur and focus blur are difficult to separate. Different parts of the image may have different amounts of blurring.	[5], [6], [7]
critical flicker fusion frequency	The particular frequency of repetition at which the presentation cannot be differentiated from a steady nonflickering field. Dependent on parameters of the test stimulus and viewing conditions.	[1, 4.3.1c]
cross correlation with output error	The input image is cross correlated with the output error (the output error is obtained by subtracting the input image from the degraded output image). May be useful for estimating blur and displacement errors in image codec systems. Parameters or histograms of the parameters which can be obtained with the technique include: (1) the average displacement of error response (2) distance of ideal displacement error where the peak error response is maximum (3) variance of principal component error response (4) ratio of minor to major component's variance of peak error response (5) ratio of peak error response to the reciprocal of the density of the ideal blur	[11]

Parameter	Description	Reference
cross correlation with output error (continued)	(6) blur direction for non-ideal blur error response (7) skewness measure of peak error response along principal component (8) coefficient of excess (9) ratio of offset of peak error response from the average displacement of error response to the ideal blur half-width (10) approximate measure of proportion of peak error response due to displacement (11) normalized mean square error (12) normalized average error (13) normalized magnitude error. The technique may be extended to operate on sub-images.	
edge sharpness estimators	Derivative operators are applied to image and the magnitude of the derivative is used as an indicator of the sharpness of the edges. Histograms of the derivative magnitude may be used to make the process more robust. Useful as a measure of focal quality but sensitive to spurious noise.	[5]
frequency-domain models	Used for evaluation of picture quality. Takes into consideration the variation of the sensitivity of the human to different spacial and temporal frequencies. Cannot be uniquely derived based on experimental data. Models use threshold data and should only be used for evaluating whether the error is just visible.	[1, 4.5.2]

Parameter	Description	Reference
frequency response	A video sweep with markers is used to measure the amplitude versus frequency response. A figure of merit may be obtained by integrating (with respect to frequency, up to the frequency of zero response at the output) the sweep amplitude at the output and normalizing by the integral of the sweep amplitude of the input. Difficult to analyze because of aliasing and other distortions which may present. Correlates somewhat with subjective tests.	[12]
histogram of error image	First an error image is calculated as the difference between the distorted and an aligned reference image. Then, the histogram of the error image is formed. Parameters extracted from the histogram show promise as reliable indicators of motion distortion. Parameters which have been extracted from the error image histogram include histogram mean, standard deviation, and square root of (mean squared plus standard deviation squared).	[8]
image entropy or information density	The entropy in the image or the image error is used to obtain an estimate of the information or loss of information present in the image. Very expensive to compute. Good correlations have been obtained between the information density metric and performance variables for several target recognition studies.	[2, 7.6], [4], [24]
motion prediction errors	Pixel motion estimates (or errors in pixel motion estimates) of reference images and degraded images are compared to determine the amount of distortion which has been added. The technique may be extended to include multi-frame motion and weighting of the errors based on edginess and motion differential.	[10]

Parameter	Description	Reference
picture quality scale (PQS)	Picture quality scale given by a linear combination of the principal components of random error, autocorrelation of errors and blocking artifacts, and local errors along contours. Compensation can be made for Weber's law, nonlinear CRT characteristics, and the spacial frequency characteristics of human vision. Appears to correlate well with mean opinion scores of selected images.	[23]
rate distortion functions	The minimum channel rate required to transmit the source information over the channel while maintaining the average distortion to some maximum level. Very difficult numerical problem. Distortion measures may be modeled after properties of the human observer. How measure correlates with subjective testing is unclear.	[2, 7.7], [14], [15]
space-domain models	Used for evaluation of picture quality. Incorporates the operation of nonlinearity, filtering of the error, masking and averaging of the resultant error. In cases where an observer bases his estimate of picture quality on a few worst case local areas, space-domain models can model the error signal over small local areas and use the maximum for a prediction of picture quality. Cannot be uniquely derived based on experimental data. More experiments with coded pictures containing different types of distortions must be done in order to curve-fit the models to the experimental data.	[1, 4.5.1], [2, 7.4]

Parameter	Description	Reference
spacial gratings	The visual response to spacial and spatio-temporal sinusoidal gratings have been used to characterize the visual system as a linear system when small amplitude test stimuli are used. Results of these tests indicate that spatial and temporal properties of vision are not independent of each other.	[1, 4.3.1e]
temporal resolution estimate (temporal frequency response)	The root mean square (RMS) amplitude of the temporal intensity modulation at a fixed point in the image due to a rotating spoked wheel is used to form an estimate of the temporal resolution of teleconferencing video codecs.	[9]
Waf-SNR	The Waf-SNR is computed as the absolute difference error between the original and impaired images, where amplitude and frequency weighting are applied to the images before the difference is generated. Computation of the amplitude and frequency weighting takes into consideration Weber's law, nonlinear CRT characteristics, CRT luminance due to ambient light reflection, and human contrast sensitivity to sine-wave gratings. The Waf-SNR has been used for the following image impairments: additive granular noise, additive mosaic-like noise (typically seen with low-bit rate codecs when motion is present), degradation of amplitude resolution, and degradation of spacial resolution. The Waf-SNR appears to correlate well with mean opinion scores and can be used when multiple impairments are present.	[16]

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