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STANDARDS PROJECT: Analog Interface Performance Specifications for Digital Video Teleconferencing/Video Telephony Service

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TITLE: **LAPLACIAN EDGE MEASURE OF LIVE VIDEO QUALITY**

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ISSUE ADDRESSED: PARAMETER TO MEASURE RESOLUTION DEGRADATION IN LIVE VIDEO TELECONFERENCING/VIDEO TELEPHONY

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I. Introduction

In October, 1989, the Institute for Telecommunication Sciences (ITS) presented a contribution, T1Q1.5/89-118, [1] titled "**Objective Measures of Live Video Quality.**" It revisited a previously proposed Absolute Difference Measure and demonstrated initial results for a new Laplacian type Edge Measure applied to a single frame. A second contribution, T1Q1.5/89-119, [2] titled "A Measure of Edge Jerkiness" was also presented in October, 1989. This temporal resolution measure of jerkiness compliments other ITS measures of edge sharpness that reflect spatial resolution. Jerkiness was computed for codec distorted images of geometric objects in motion.

In this contribution the Laplacian type Edge Measure is revisited, a Median Filtering step is included, an optimum threshold is determined, and the measure averaged over a sequence of 8 frames. The sequence is from the same live desktop video teleconferencing (VTC) scenario as in [1] where significant motion distortion was produced by codec video compression. The sensitivity and reliability of the measure are enhanced by optimizing the Pel Intensity Threshold which determines the range of intensities integrated in determining the edge energy. The effect of the compression or transmission rate on image and edge degradation is shown.

II. Technical Background

One of the major effects of motion at reduced compression rates is image blurring and distortion of edges in the area of motion. The measure used here to determine edge distortion is based on a spatial filter or operator commonly used for point detection and more generally detection of gray level discontinuities [3] or edges. It will be referred to as a Laplacian type operator or filter.

A. Laplacian Operator

The 3x3 spatial filter mask for this particular Laplacian Operator consists of a weight of 8 in the center and -1 in all neighboring positions. The result of applying this mask in a constant gray level area is zero or black. If the mask is centered on an isolated point whose absolute intensity is greater than the background, then the result is greater than zero, corresponding to a brighter intensity than the black. One advantage of this mask is the non-directional symmetry about the center. It is different than the standard Laplacian mask defined by Gonzalez and Wintz [3] which exhibits a horizontal and vertical symmetry and is typically more sensitive to noise.

B. Laplacian Edge Measure

The parameter extracted from this Laplacian filter operation was the square of the total number of pixels (pels) greater than or equal to the optimized pel intensity (gray level) threshold T_0. We shall call this the Edge Measure for each frame or image. When this measure is applied to a sequence of frames and the results arithmetically averaged, it will be called Average Edge Measure. Squaring the total number of pixels increases the sensitivity of the measure. Consequently, if reduced sensitivity to compression rate or quality is desired, then this squaring step could be eliminated.

C. Median Filtering

The digitized images in this paper were first median filtered with a 3x3 mask to reduce noise while preserving edge sharpness. With this approach, the gray level of each pixel is replaced by the median value of the 3x3 array centered on the pixel. This procedure sorts the nine gray level values into 4 less than the median and 4 greater than the median and then makes the replacement with the median value.

D. Processing Steps

The following processing steps were used to produce the final graphs demonstrating compression rate effect on average edge degradation:

(1) Extract digitized images from codec input and output frames

(2) Median filter digitized images using 3x3 mask

(3) Edge detect images using 3x3 (8,-1) Laplacian Operator

(4) Compute magnitude of pixel values

(5) Compute Edge Measure for each image by squaring the sum of pixels having gray levels greater than or equal to the optimum threshold T_0

(6) Compute arithmetic Average Edge Measure over a windowed sequence of N frames to produce final metric value.

In (1), each frame corresponds to what would be viewed on a monitor in sequences of live video. In (5), after computing the magnitude of edge detected images, pixel or pel gray level intensities range from 0 to 2040. For display purposes these must be mapped onto the 0 to 255 range for an 8 bit system. This is done by mapping 255 through 2040 pel values into 255 and leaving

0 through 254 unchanged. Consequently, more resolution in the higher pel values is available for analysis if needed. The number of pixels with gray levels greater than 255 decreases very rapidly, as can be noted in Table I, and has corresponding reduced effect on the metric value. In this example, averaging over a sequence of 8 frames in (6) corresponded to 0.133 seconds of viewing time since each frame represented only one field update at 60 fields/s.

III. Sample Video Quality Objective Assessment Results

Representative live video teleconferencing data recorded in NTSC format was supplied by Delta Information Systems. This recorded data was played through a hybrid transform/DPCM codec at three rates (T1-1.544 Mbps, 1/2 T1-768 Kbps, 1/4 T1-384 Kbps). A section of desktop VTC with complex scenes and significant motion was selected for investigation. A sequence of 8 consistent frames within this section was selected for objective assessment of video quality degradation due to motion and lowered compression rate. As an expanded example, the NTSC source image and the three codec output images are shown in Fig. 1. Both hands were in motion as the person was talking and demonstrate increased blurring as the compression rate or transmission rate is decreased. Three additional events are worth noting. Blocking doesn't become noticeable until the rate is reduced to 1/4 T1, the lower lip is very distorted at 1/4 T1, and the document position at 1/2 T1 is significantly different than at the other rates due to the asynchronous codec output.

Fig. 2a shows the images of Fig. 1 after median filtering and edge detection. For an 8 bit display, gray levels above 255 (produced in Laplacian edge detection) were compressed into the 255 level. Since the average gray level is approximately 36 with a standard deviation of 65, these compressed levels are beyond the 3 standard deviation range and effect is minimal on the overall image. Edge detection using the Laplacian filter operation detects changes in gray levels or edges. Black represents regions of constant gray level and the brightest areas represent the transitions from constant gray level background to brighter areas. The NTSC image is significantly brightest indicating the sharpest transitions or edges and the brightness decreases consistently with compression rate reduction. For comparison purposes Fig. 2b was included showing the binary version of Fig. 2a. Binary images are shown since pel values below 50 (shown as black) are not used in calculating the Edge Measure and pel values from 50 to 2040 (shown as white) are weighted the same. The above expanded results were provided for clarity but represent only 1 of the 8 frames in the sequence. Results for the sequence of 8 frames are shown next.

In order to preserve more viewing detail, the 8 frames were split into Figs. 3a and 3b showing the first 4 frames at each rate in Fig. 3a and the second 4 in 3b before processing. Figs. 4a and 4b show the corresponding median filtered and edge detected binary versions of frames in Fig. 3.

The Average Edge Measure of the frames in Fig. 4 was computed for a range of pel intensity thresholds ranging from 1 to 400. The white edges at the top and bottom resulted from edge detection of the border and are not included in the energy calculations. The 255 level was also included since that is the highest level that is directly viewable and was used in our last contribution for a single frame result. Results are listed in Table I and used to obtain an optimum or best compromise threshold of T_0=50. One of the major goals in developing this measure has been determining a threshold that would show a consistent reduction in the measured value when the subjective video quality is reduced, such as going from the T1 rate to 1/2T1 and while going from 1/2T1 to 1/4T1. This would produce monotonically decreasing metric as quality or compression rate is lowered. These decreases in the Edge Measure were normalized to the T1 value and represented as percentage decreases in Fig. 5 to show the threshold effect on the Edge Measure for these two cases. At a threshold (T) of 50 the maximum decrease was attained of approximately 6% when going from T1 to 1/2T1. Simultaneously the decrease of about 7% was obtained when going from 1/2T1 to 1/4T1. Thresholds below 50 and above 200 produce an increasing Edge Measure for at least one case. Consequently, 50 was chosen as the optimum threshold (T_0). When subjectively classified training data becomes available, T_0 can be selected based directly on quality classes.

The effect of compression rate on average edge degradation or blurring is displayed in Fig. 6 using 4 different thresholds. The optimum threshold (T=50) result is plotted as a solid curve and shows that it is the only one of the 4 that maintains a strictly monotonic decrease in the metric as compression rate is decreased which correlates well with subjective intuition on quality. If pixels of all gray levels are used (T=1) in the computation of the metric, it becomes insensitive to compression rate. This insensitivity may be due to noise since pixel values near T=1 would indicate very little gray level change. Both the curves for T=255 and 400 increase instead of decrease when the compression rate drops from T1 to 1/2T1. However, both these curves demonstrate more sensitivity in the T1 and 1/4T1 regions. For the T=400 curve, the higher value of Average Edge Measure at 1/2T1 than at T1 is probably due to the small number of pixels above that threshold (32 compared to 1200 at T=50).

For comparison purposes the Sobel filter was revisited and calculated results shown in Table II. It was discussed in a previous contribution ([4] "A Measure of Edge Sharpness", T1Q1.5/89-110). Since the maximum pel value for the Sobel operation is approximately 1020 or half that for the Laplacian, threshold values do not take on the same meaning. The most significant result observed from Table II is that the maximum decrease in the normalized measure for a reduction in compression rate from T1 to 1/2T1 is 5.6% at a threshold (T) of 255. This is compared to the 5.9% at a T=50 for the Laplacian case. The maximum decrease in the Laplacian normalized measure when going from 1/2T1 to 1/4T1 is again about the same but at different threshold values. However, the Sobel maximums jointly occur at the threshold of 255.

Note the very stable monotonic performance of the Sobel filter at thresholds of 200 and above (which represents a measure of the sharpest edges). Note from the images in Fig. 1 that the quality degradation in changing from 1/2 T1 to 1/4 T1 is much greater than the quality degradation in changing from T1 to 1/2 T1. This unequal degradation in quality with compression rate reduction is successfully detected by both operators. For example, if this unequal change in the measure is the primary goal, then T=75 produces that result in the Laplacian measure. If a less sensitive measure of quality is desired, the measure can be computed based upon the number of pixels (as was done in [4]) rather than the square of the number of pixels performed here. For thresholds of 50 or below in Table II, the 1/4 T1 has more edge content than the 1/2 T1. This is probably due to increased quantization noise for the low bit rate. Threshold settings which are too low probably detect pixels due to noise and not edge content.

IV. Discussion

An Edge Measure based on Laplacian edge detection was proposed in the last contribution [1] which is sensitive to degradations in live video quality. It has been investigated in more detail demonstrating methods to improve its reliability and sensitivity. It was applied to a desktop VTC scenario with significant motion and complex detail. Improvements in the metric were made by determining an optimum threshold for the Edge Measure calculations and by averaging the Edge Measure over a sequence of 8 frames corresponding to 0.133 seconds viewing time. This measure should have wide applicability in measuring blurring or resolution degradation and correlates consistently with subjective opinion of the quality. The Laplacian Average Edge Measure results were compared to Sobel Average Edge Measure results for the same data corroborating both measures.

Future efforts will investigate other VTC scenarios such as graphics, podium-lecturing, and conference table settings, including thresholds and pixel value weightings for increased Average Edge Measure sensitivity. Other measures will also be investigated for added sensitivity at the 1/2T1 compression rate. Perhaps two or more measures can be combined to improve overall sensitivity and reliability even further.

References

[1] E. A. Quincy and K. E. Junker, "Objective measures of live video quality," ANSI Accredited Standards Working Group T1Q1.5, Contribution No. T1Q1.5/89-118, Oct. 1989.

[2] D. Parsavand and S. Wolf, "A measure of jerkiness," ANSI Accredited Standards Working Group T1Q1.5, Contribution No. T1Q1.5/89-119, Oct 89.

[3] R. C. Gonzalez and P. Wintz, Digital image processing, 2nd Edition, Addison-Wesley, Reading, MA, 1987.

[4] S. Wolf, D. Parsavand, and E. A. Quincy, "A measure of edge sharpness," ANSI Accredited Standards Working Group T1Q1.5, Contribution No. T1Q1.5/89-110, May 89.

TABLE I
Laplacian
Average Edge Measure Dependence on Threshold and Compression Rate

AVERAGE EDGE MEASURE ≥ THRESHOLD										
	Absolute (in thousands)				Normalized to T1				Differences	
Threshold	NTSC	T1	$\frac{1}{2}$T1	$\frac{1}{4}$T1	NTSC	T1	$\frac{1}{2}$T1	$\frac{1}{4}$T1	(T1−$\frac{1}{2}$T1)/T1	($\frac{1}{2}$T1−$\frac{1}{4}$T1)/T1
1	33900	36400	35600	36300	0.931	1.000	0.978	0.997	0.0220	-0.019
25	7230	5590	5310	5380	1.290	1.000	0.950	0.962	0.0501	-0.0125
50	2340	1530	1440	1330	1.530	1.000	0.941	0.869	0.0588	0.0719
75	981	601	568	483	1.630	1.000	0.945	0.804	0.0549	0.1410
100	476	279	266	215	1.710	1.000	0.953	0.771	0.0466	0.1830
150	143	81.5	79.8	58.6	1.750	1.000	0.979	0.719	0.0209	0.2660
200	51.7	29.5	28.7	20.8	1.750	1.000	0.973	0.705	0.0271	0.2750
255	19.4	11.1	11.2	8.17	1.750	1.000	1.010	0.736	-0.0090	0.2730
300	9.73	5.54	5.81	4.07	1.760	1.000	1.050	0.735	-0.0487	0.3141
400	2.01	1.05	1.19	0.737	1.910	1.000	1.130	0.702	-0.1333	0.4314

TABLE II
Sobel
Average Edge Measure Dependence on Threshold and Compression Rate

AVERAGE EDGE MEASURE ≥ THRESHOLD										
	Absolute (in millions)				Normalized to T1				Differences	
Threshold	NTSC	T1	$\frac{1}{2}$T1	$\frac{1}{4}$T1	NTSC	T1	$\frac{1}{2}$T1	$\frac{1}{4}$T1	(T1−$\frac{1}{2}$T1)/T1	($\frac{1}{2}$T1−$\frac{1}{4}$T1)/T1
1	34769	37489	36788	37418	0.927	1.000	0.981	0.998	0.019	-0.017
25	17122	16523	16217	17560	1.036	1.000	0.981	1.063	0.019	-0.082
50	8661.6	7276.3	7082.1	7463.1	1.1904	1.000	0.973	1.026	0.027	-0.053
75	4752	3593.5	3488	3422.6	1.323	1.000	0.971	0.952	0.029	0.019
100	2743.8	1946.2	1878.8	1723.3	1.410	1.000	0.965	0.885	0.035	0.080
150	1040.3	672.40	647.77	525.58	1.547	1.000	0.963	0.782	0.037	0.181
200	450.57	259.84	248.05	178.03	1.734	1.000	0.955	0.685	0.045	0.270
255	192.10	96.260	90.866	62.616	1.996	1.000	0.944	0.650	0.056	0.294
300	98.083	44.731	42.246	29.793	2.193	1.000	0.944	0.666	0.056	0.278
400	23.973	9.779	9.4741	6.7659	2.452	1.000	0.969	0.692	0.031	0.277

Fig. 1. Demonstration of motion distortion in compressed video images (From upper left clockwise: NTSC-none, T1, 1/2T1, 1/4T1).

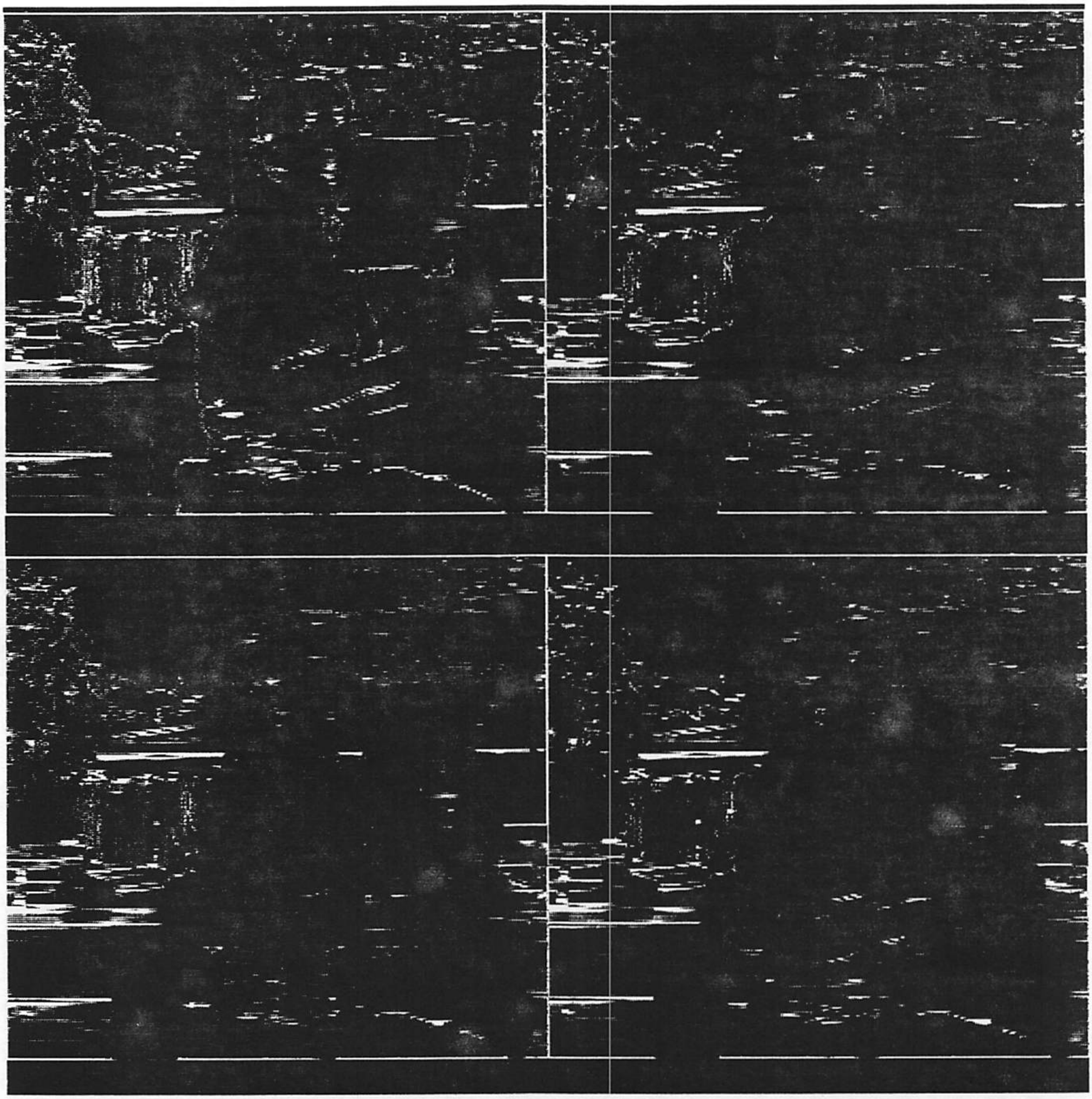

Fig. 2a. Median filtered (3x3) & Laplacian (3x3) edge detected gray level images of Fig. 1 (From upper left clockwise: NTSC, T1, 1/2T1, 1/4T1).

Fig. 2b. Median filtered (3x3) & Laplacian (3x3) edge detected binary images of Fig. 1 (From upper left clockwise: NTSC, T1, 1/2T1, 1/4T1).

Fig. 3a. Sequence (Left to right) of 1st 4 images used in average edge measure calculations (Top to bottom: NTSC, T1, 1/2T1, 1/4T1).

Fig. 3b. Sequence (Left to right) of 2nd 4 images used in average edge measure calculations (Top to bottom: NTSC, T1, 1/2T1, 1/4T1).

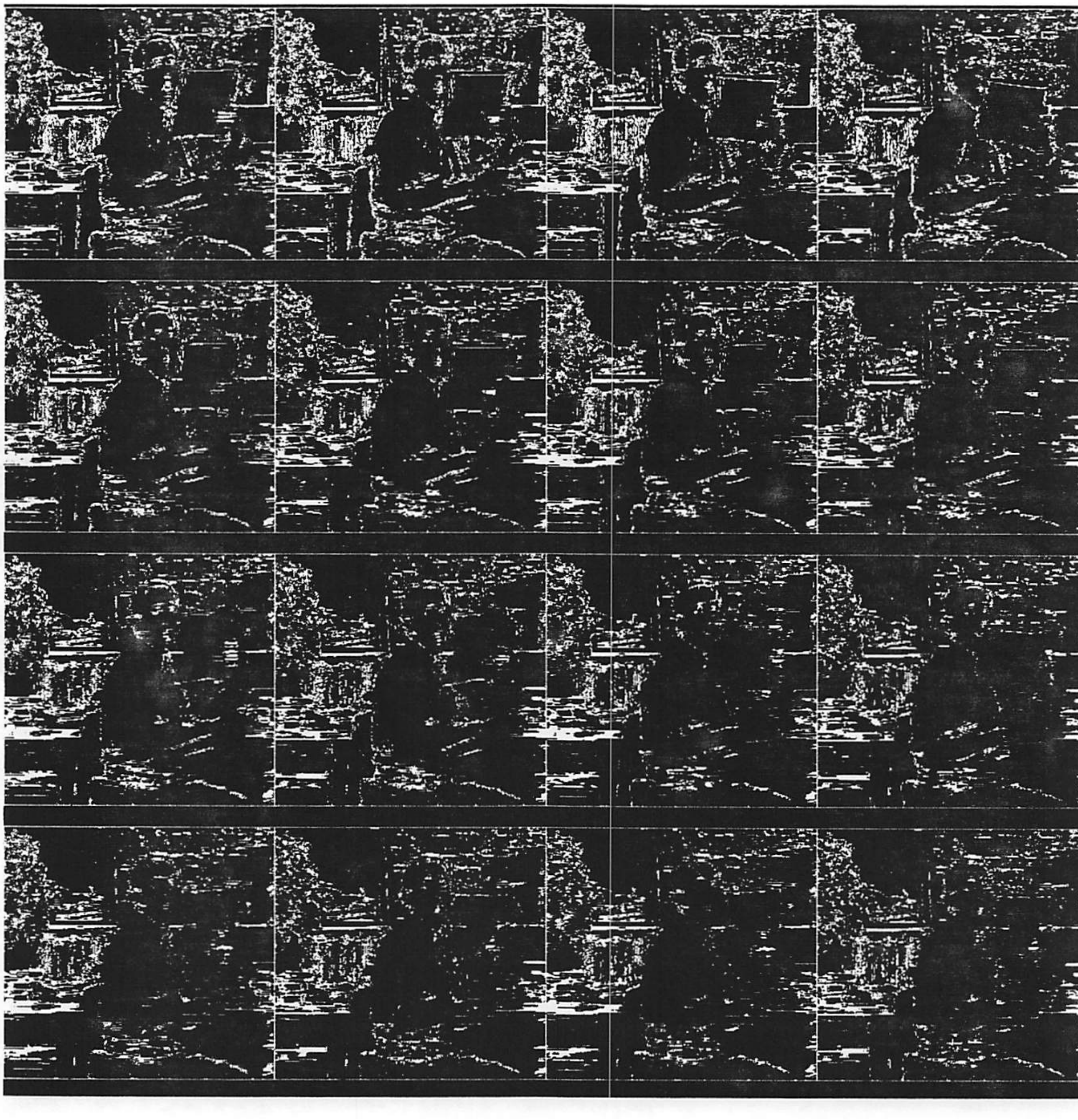

Fig. 4a. Median filtered (3x3) & Laplacian edge detected (3x3) binary images of Fig. 3a (Sequenced left to right; Top to bottom: NTSC, T1, 1/2T1, 1/4T1).

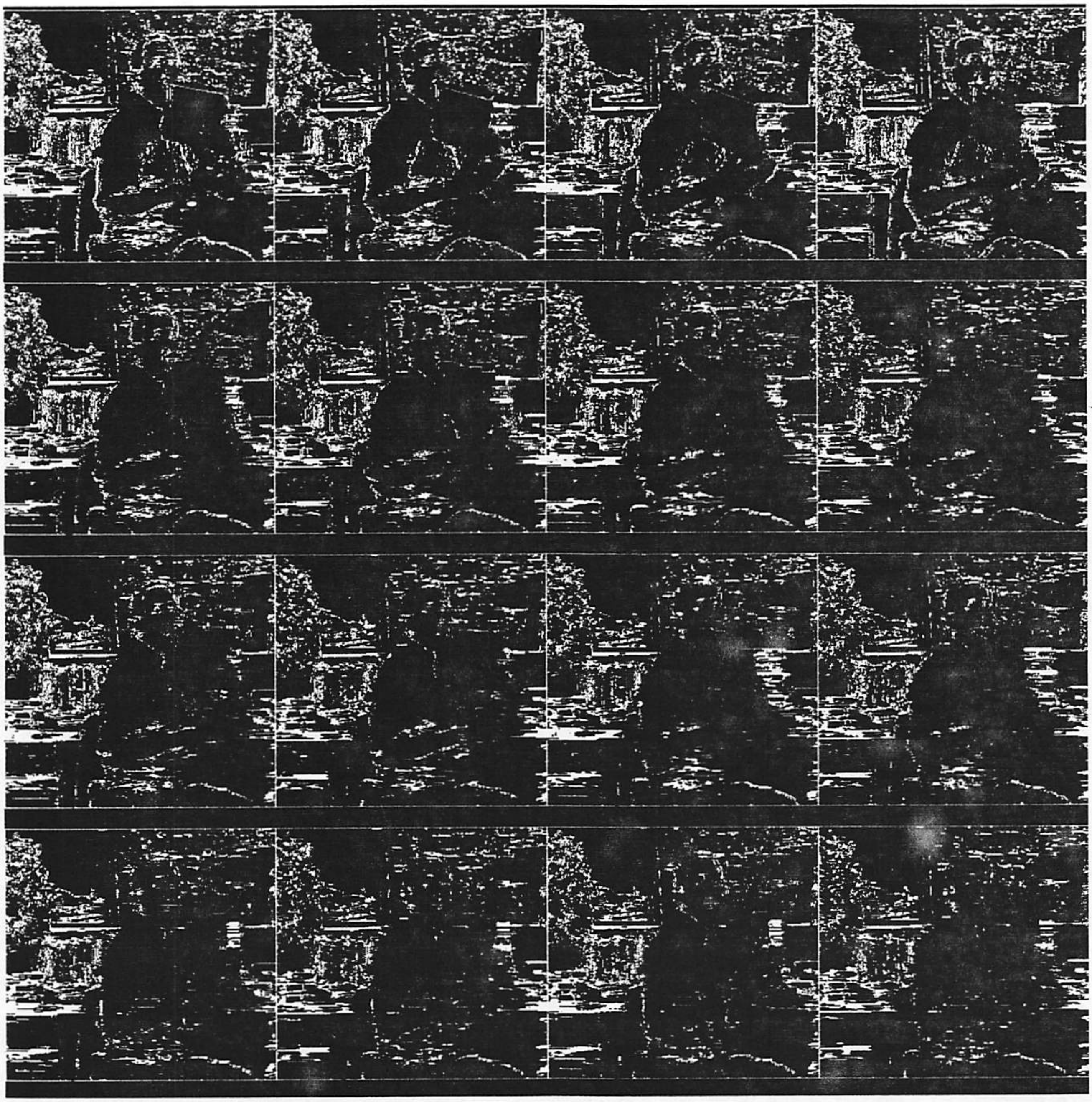

Fig. 4b. Median filtered (3x3) & Laplacian edge detected (3x3) binary images of Fig. 3b (Sequenced left to right; Top to bottom: NTSC, T1, 1/2T1, 1/4T1).

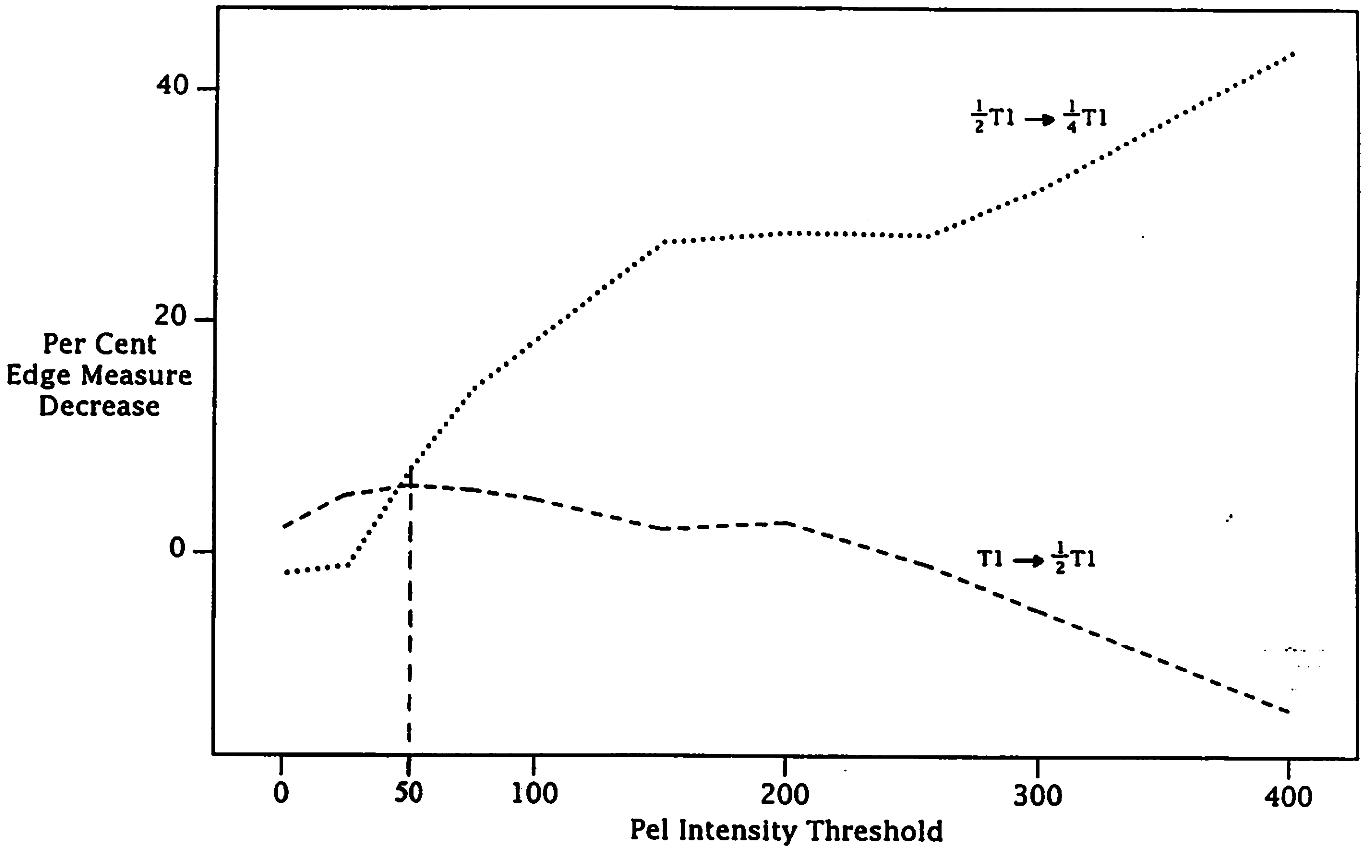

Fig. 5. Threshold effect on average edge measure decrease for reduced compression rates (T1 to 1/2T1 & 1/2T1 to 1/4T1).

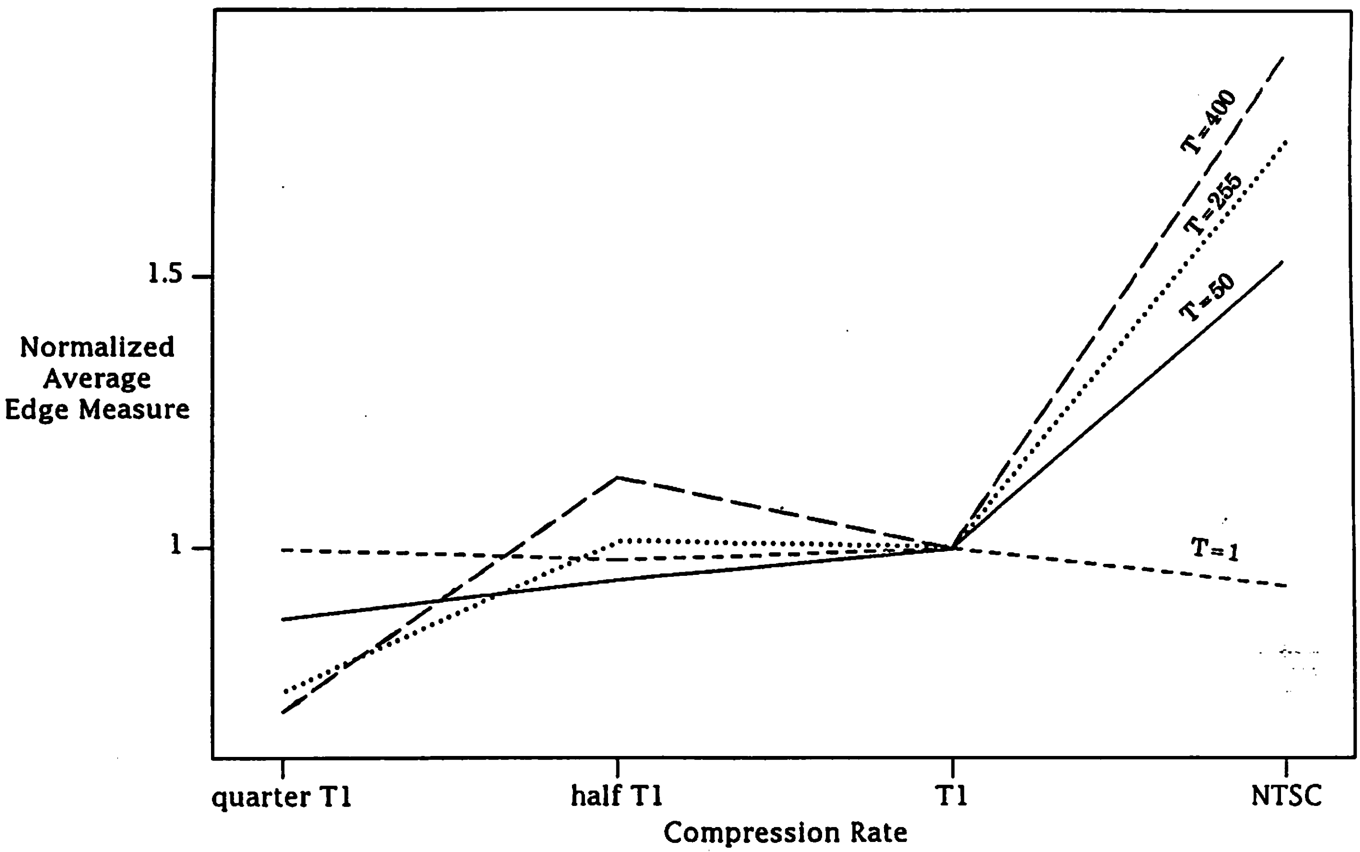

Fig. 6. Compression rate & threshold (T) effect on average edge measure.