

PSYCHO-VISUALLY TUNED AREA-MORPHOLOGY TOOLS FOR IMPROVED IMAGE COMPRESSION

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Abstract In video compression, image pre-processing is used to improve the overall compression performance. A key requirement of any such system is the ability to remove noise and other higher frequency details while preserving the visual quality of the images. This paper presents a new approach to pre-filtering, based on area morphology. Both the standard area and a new constraint, based on the power within the granule, are investigated and psycho-visual experiments used to determine the highest value of each constraint for which the filtering is visually lossless. The compressibility of the pre-processed images, assessed by a number of compression methods, is significantly improved thus demonstrating the advantages of the area morphology methods, with the power constraint providing the greatest improvement over the original images.

Keywords: Morphology, Image Pre-processing, Psycho-visual Evaluation.

1. Introduction

Image pre-processing is used in video compression to remove noise from the video source, thus improving the overall compression performance. In addition to noise, other high frequency components can also be eliminated provided that the processed image is not degraded to such an extent that its visual quality is reduced. The resulting pre-processed sequence therefore has better frequency compaction properties and its transform coefficients can be accurately represented by fewer bits. To ensure that no noticeable distortion is introduced, pre-processing should preserve those significant edges and other image components that the Human Visual System (HVS) is sensitive to.

Most pre-processing systems are based on simple low-pass filters [1, 2]. Median filters are commonly used as they remove noise while preserving edge information to some degree. However, apart from the mask size, standard me-

dian filtering offers little control over the filtering action and therefore has to be implemented conditionally if significant changes to the image are to be avoided. Alternatively, the structure of Alternating Sequential Filters (ASF) have similar advantages and provide a finer control over the filtering action. Therefore ASF have the potential for more aggressive filtering without introducing any noticeable image distortions. This is advantageous for image pre-processing where it is desirable to simplify the image as much as possible while ensuring its output is visually lossless.

The above advantages provide the motivation for the use of Attribute based Mathematical Morphology (MM) [3]. This research investigates the use of the Area-Open-Close (AOC) ASF, or sieves, for use in image pre-processing. MM is the analysis of signals in terms of shape [4, 5] and has been used in a wide range of imaging applications such as enhancement and restoration [6], edge detection, and segmentation [7]. However, to date it has found only limited application in video sequence pre-processing [8]. Morphological sieves successively increase the size of local extrema regions until either the regions are no longer a local extrema or the region growth is stopped when a pre-determined constraint value is reached. For example, an AOC sieve will grow all regions until they reach a pre-determined area size. The result is an image with flat zones of constant intensity that has improved compressibility.

For morphological sieves to achieve visually lossless pre-processing, while at the same time removing as much high frequency information as possible, two key elements have to be determined: the constraint used to control region growth and the value at which to de-active regions. For the former, we propose the use of the power contained within the granules (see section 2), a measure motivated by the response of the HVS. To establish the power value at which to de-activate the regions a series of psychovisual tests were undertaken. For comparison the standard area constraint was also investigated.

The compressibility of the pre-processed images was assessed over a range of bit rates using both JPEG and JPEG2000. Results show that the power constraint consistently outperforms a standard area constraint.

2. Image pre-processing using area morphology

Area Morphology (AM) is an attribute based class of operators. Unlike basic morphological operators [9], an area operation does not require a fixed structuring element. Instead, it adapts to the contents of the image using some constraint (or attribute), such as area size or contrast, thus preserving more of the detail (edge information) within the image. A gray scale Area-Open (AO) is given by:

$$\gamma_{\lambda}^a(X) = \bigvee_{B \in A_{\lambda}} (X \circ B) \quad (1)$$

where A_{λ} is the set of subsets which are connected and whose area is greater or equal to λ . For this function to be an area opening, it must also satisfy the increasing criteria:

$$X \subseteq Y \Rightarrow \Psi(X) \subseteq \Psi(Y) \quad (2)$$

A practical algorithm for implementing AM was proposed in [10] and contains the following steps:

- 1 Extract the local and regional maxima,
- 2 For each region of size i (starting from 1) do the following,
 - (a) Find the highest gray-scale valued neighbor and then:
 - i If the neighbor is higher in value than the region, deactivate the region and move to the next region,
 - ii Otherwise add it to the region,
 - iii If some limit (e.g. area-size, contrast, volume, power) is exceeded by adding the neighbor, then deactivate it
 - iv Give all pixels of the region the gray-scale value of the neighbor last visited,
- 3 Increase i by 1,
- 4 Repeat steps 2, 3 and 4 until there are no active regions.

The dual of this, Area-Close (AC), is implemented in an identical manner using minima instead of maxima. Together they form an ASF [11] called an AOC given by:

$$AOC_i(X) = \varphi_i^a \gamma_i^a (\dots (\varphi_j^a \gamma_j^a (\dots (\varphi_1^a \gamma_1^a)))) \quad (3)$$

where $i \geq j \geq 1$, φ_i^a is an AC with a limit of i and γ_i^a is an AO with a limit of i .

An AOC ASF can also be thought of as a “sieve” where successively larger granules fall through the sieve as the attribute is increased. Traditionally, the area size is used as the attribute that constrains region growth. Other constraints have been proposed, such as volume, contrast and complexity [12] although none of these have been applied to video pre-processing.

The response of the HVS to changes in image intensity depends on both the intensity change and the area over which the change occurs. Simply put, the HVS is insensitive to large changes in intensity provided they only occur over a small area, or to small changes in intensity over a large area. Area alone is not sufficient, as it does not take into account the intensity change within the region. This provides the motivation for a constraint that depends on the power that is removed or added by each granule, given by $(\text{change in intensity})^2 \times \text{area}$, a measure that corresponds to the response of the HVS to incident radiation. The power removed is the sum of the squares of the new value of the region subtracted from the original intensity, given as:

$$P = \sum_{x \in X} (Y(x) - \alpha)^2 \quad (4)$$

where X is a set that contains the position of the members of a region, Y is the original image and α is the new intensity value of the region. A simple

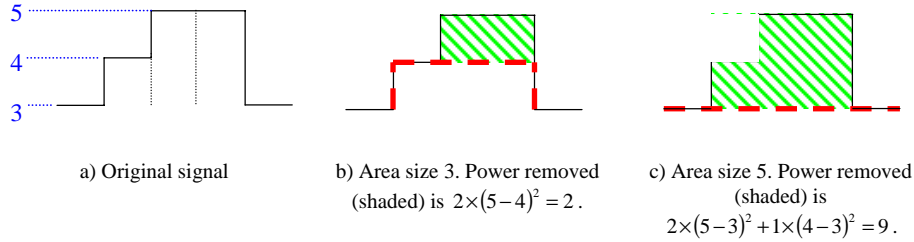


Figure 1. Area-Opening using the power constraint.

one-dimensional example a maximum region is shown in figure 1. By using power as the constraint, regions can continuously be grown, regardless of size, until the power that is removed (resp. added) to each maximal (resp. minimal) region in the image reaches a pre-determined threshold. Thus in some cases, for example a large, relatively flat background, the region can grow to be much larger than would be possible with the standard area constraint resulting in images that have a higher compressibility. The use of power to control the area size ensures that the attribute operator is an opening. However, the exact value of the power constraint that produces visually lossless images is still unknown and can only be found by psychovisual evaluation; this is discussed in the next section.

2.1 PSYCHO-VISUAL EVALUATION

Knowledge of the HVS can be exploited by image processing algorithms to improve the compression performance of images whilst retaining the original image quality by virtue of being visually lossless. There are many variations of how psychovisual evaluation should be undertaken [13, 14]. In this research a combination of the standards laid out by the International Telecommunications Union (ITU) [14] have been used.

The base method for this psychovisual evaluation is the Double Stimulus, Impairment Scale (DSIS) method. Essentially two images, the original and the impaired (processed), are individually displayed twice and the observer asked to vote on the quality of one compared to the other. However, in some cases, the observer may think that the impaired image is better than the original. The impairment scale does not accommodate this and hence the comparison scale (see Table 1) was used in its place, creating a method called Double Stimulus, Comparison Scale (DSCS).

For both the power constraint and the standard area constraint, psychovisual tests were used to establish the highest limit value that produced visually lossless images. In pre-filtering terms this corresponds to the most image simplification (removal of high frequency components) without introducing any noticeable image distortion.

Four images from the ITU test set were filtered with the AOC filter using area size and power as the constraint, see Table 2. Two sets of psychovisual

Scale	Description
-3	Much worse
-2	Worse
-1	Slightly worse
0	The same
1	Slightly better
2	Better
3	Much better

Table 1. The comparison scale.

tests using the filtered and original images were then undertaken, one set for the area constraint and one for the power. A total of 12 observers completed the tests and a complete set of results for the Mean Opinion Score (MOS) [13, 14] against constraint values is shown in figure 2.

Images	Barbara, Barbara2, Boats, Goldhill, Blackboard
Area Constraint	5, 8, 12, 15, 18, 22, 25, 28, 32, 35, 38, 42, 45, 48, 52
Power Constraint	500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500, 6000, 6500, 7000

Table 2. Images and constraints used in the visual tests .

In figure 2, a MOS of -1 indicates that the filtered image is worse than the unfiltered. Therefore the highest constraint value at which the MOS is less than -1 offers the most pre-filtering without introducing any visual distortion. For example, for the Barbara image, an area size of 8 must be used while for the Boats image an area size of 12 is acceptable. Similarly for the power constraint a value of 4500 can be used for Barbara and 4000 for Boats. It should be noted that the power constraint results in images with larger flat zones than the standard area constraint while still retaining the visually lossless property. For example, the Barbara image with the visually lossless power constraint of 2000 produced an image with flat zones up to an area of 720 pixels while the visually lossless area constraint was only 8.

From figure 2 it can be seen that there is little inter-image correlation between the minimum acceptable constraint value, for both the area and power constraints. To overcome this problem the visually lossless limits for each image were ranked and the minimum area and power values chosen. By taking this conservative approach it can be guaranteed that no visual distortion will be introduced across the image set, although as a consequence some images will not be filtered to their optimum.

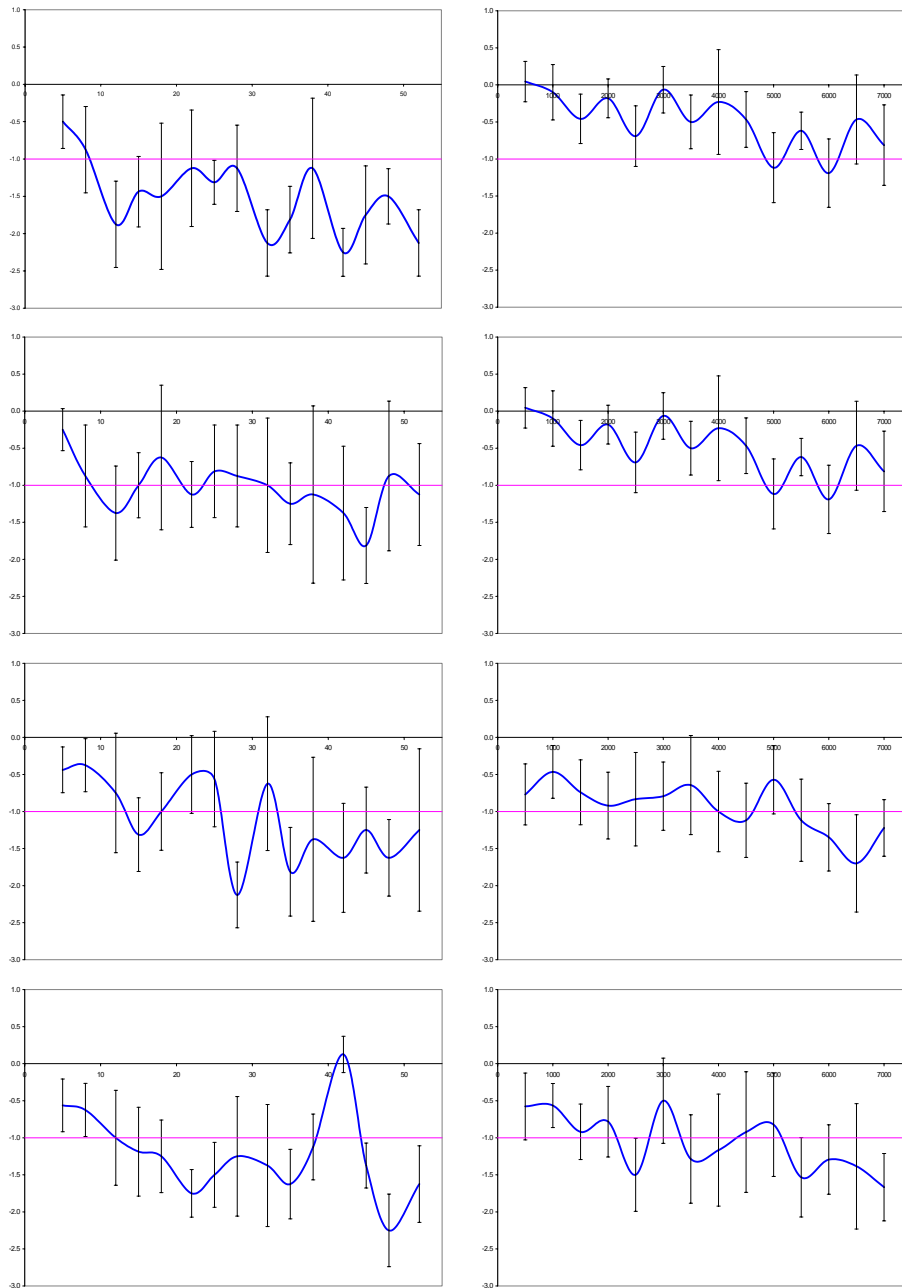


Figure 2. Psychovisual test results. Mean Observer Score against area (left) and power (right) for, in descending order, Barbara, Barbara2, Blackboard, Boats and Goldhill images.

3. Compression results

To determine the performance of the pre-processing methods the compressibility of the filtered images was assessed over a range of bit rates by a rate / distortion plot. Although the ultimate application area is video sequences in this initial assessment still image compression techniques were used as these are essentially very similar in nature to intra-frame compression techniques and produce results that are not perturbed by the relative proportions of intra-, inter- and bi-directional frames.

Two image compression / decompression (CODEC) methods were used: JPEG and JPEG2000. The first of these is a Discrete Cosine Transform based technique and is very similar to the intra-coding algorithm of MPEG-II. In contrast JPEG2000 is a wavelet based image CODEC. As the values used for the constraints (derived in the previous section) ensure the pre-processing is visually lossless, when quantifying the compression performance, the output of the CODEC is compared to its processed input, not the original image.

Figure 3 shows the rate-distortion graphs of the original and pre-processed images for JPEG and JPEG2000, using 8 and 2000 as the area and power limits respectively. As would be expected, the compressibility of all the images is improved by the pre-processing stage. In addition, for the majority of the images, the compression performance achieved by the images pre-filtered by the area sieve with the power constraint is better than that achieved using the area constraint.

The general trend for the filtered images is an increasing gain in compression ratio for the same Root Mean Square Error (RMSE) compared with the unprocessed image. The gain in compression ratio achieved by using the area and power constraints at a constant RMSE of 5 is shown in Table 3.

To provide a visual comparison the results for the Boats image using JPEG and JPEG2000 are shown in figure 4 for a RMSE of 7.

Image	Compression Ratio					
	JPEG			JPEG 2000		
	Un-processed	Area	Power	Un-processed	Area	Power
Barbara	8.08	9.27	9.45	11.60	13.84	14.11
Barbara2	6.73	8.55	8.73	10.10	12.61	13.05
Boats	15.89	19.22	20.85	23.18	30.44	33.13
Goldhill	10.81	17.35	20.27	14.72	24.22	29.65
Average		3.22	4.45		5.38	7.59
Improvement						

Table 3. Compression ratio performance of pre-processed images at an RMSE of 5.

4. Conclusions

This paper has presented a new pre-processing system for improving the compressibility of images based on AM. To restrict region growth both the standard

area constraint and a new constraint based on the power in the granule have been used. For both these constraints a series of psychovisual tests were used to determine the values at which the pre-processing was visually lossless, across a range of test images.

Both AM methods resulted in improved compression performance when the images were using JPEG and JPEG2000 with appreciably higher compression ratios being achieved, compared to the original images. The power constraint produced filtered images that had significantly larger flat zones than the area constraint and this was reflected in its improved compression performance.

Although the techniques described here are suitable for video pre - processing, we intend to extend this system to three-dimensions to produce a volumetric AM pre - processing system for video sequences. This will be based on this 2D version and will also be psycho-visually tuned for both area and power constraints.

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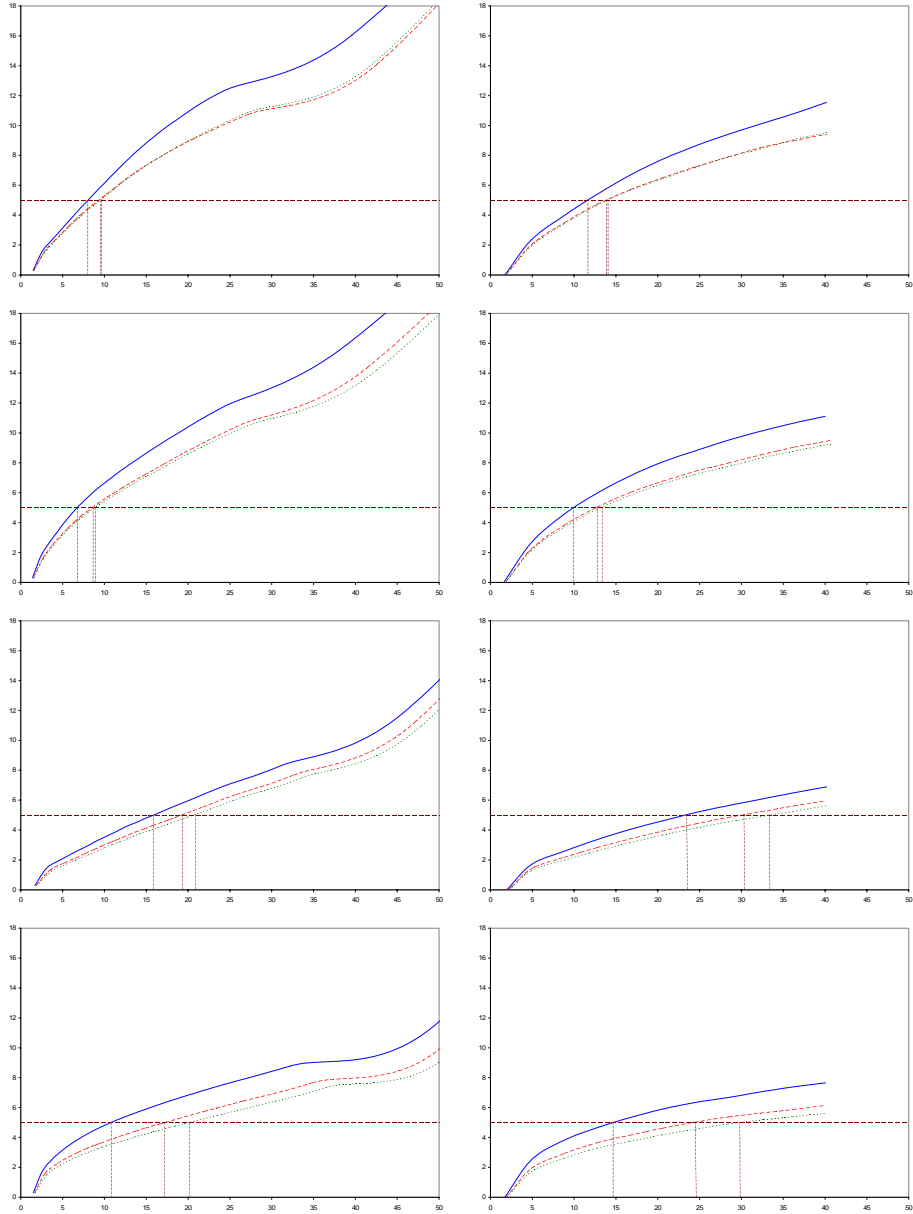


Figure 3. Rate distortion graphs (RMSE against Compression Ratio) produced by JPEG (left) and JPEG2000 (right) for, in descending order, Barbara, Barbara2, Boats and Goldhill images. Original images (solid line), pre-processed with an area constraint of 8 (dashed) and pre-processed with a power constraint of 2000 (dotted).

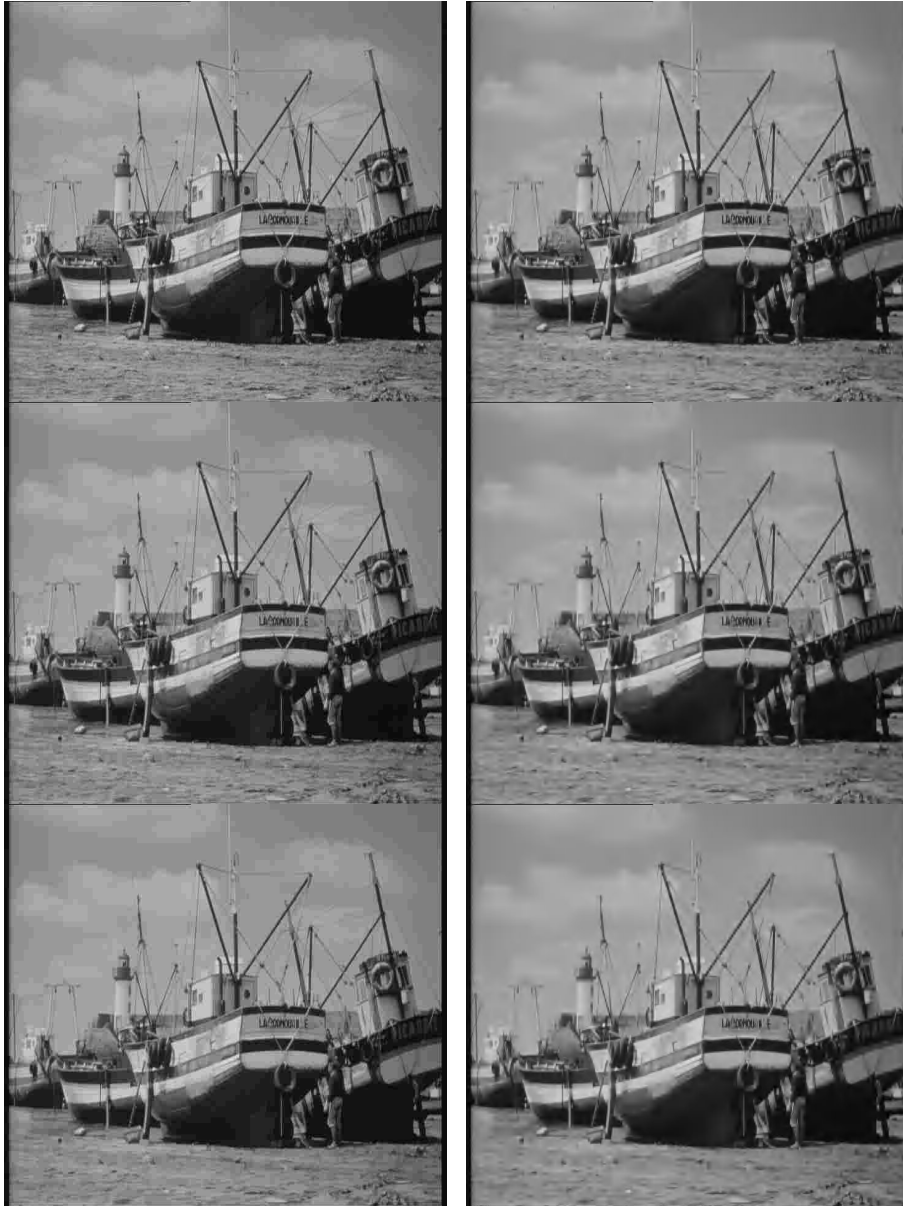


Figure 4. CODEC output of Boats image at a RMSE of 7 using JPEG (left) and JPEG 2000 (right) for, in descending order, original image, area constraint of 8 and power constraint of 2000. The compression ratios achieved for the JPEG images were 24.35, 29.54 and 30.50 respectively and 41.28, 52.82 and 58.43 for JPEG 2000.