Suppression of Noise in Historical Photographs Using a Fuzzy Truncated-Median Filter

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Abstract. To a large extent noise suppression algorithms have been designed to deal with the two most classically defined types of noise: impulsive and Gaussian noise. However digitized images such as those acquired from historical photographs such as albumen prints contain a form of quasi-noise we shall term *chaotic* noise. This paper describes the concept of chaotic noise and proposes two fuzzy filters to suppress various types of noise in historical photographs based on the truncated median, an approximation of the mode filter.

Keywords: noise suppression, chaotic noise, fuzzy filter, image quality.

1 Introduction

Photographs represent one of the oldest visual forms of media used to convey information. Historical images constitute an important part of our cultural and documentary heritage (see Figure 1). In many cases the views that these images represent have either changed significantly, or no longer exist, and as such they provide an invaluable insight into the state of structures and monuments of the past 150 years. The purpose of image enhancement is to improve the quality of an image. This usually means improving acuity, augmenting contrast, or suppressing noise. Noise can be described as any unwanted distortion in an image. The two most commonly portrayed types of noise in images are impulse noise and random noise. Impulse noise is characterized by spurious corrupted pixels, which may not effect the content of the image too greatly, and may be due to information loss. Random, or Gaussian noise can be triggered during the process of generating an image, and is analogous to film “grain”. In photography, the “grainy” effect of a photograph is caused by developed silver halide crystals that cluster together on the processed negative. When a photograph is printed these grain clusters are enlarged, becoming a perceptible pattern over the whole image. The presence of such film grain has a noticeable effect on the ability to discern small features in an image. Figure 1 shows an example of film grain noise. However there is also a form of quasi-noise we will categorize as *chaotic noise*. Chaotic noise may occur as the result of a deteriorative process, resulting in changes to the physical structure of a piece of art or photograph. When digitized, physical characteristics such as cracks in paintings and albumen prints manifest themselves as noise in the image, contributing to a decrease in image

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quality and aesthetic appeal. Consider the albumen print shown in Fig.2. Cracking of the albumen results in thousands of ultra fine fracture on the surface of the print. This is sometimes termed *crazing*. We term this sub-category of chaotic noise as *thread noise*[1], because the noise looks like threads in the image. It may also be the product of dirt which has accumulated on the emulsion. This dirt results in an overall grainy appearance of the photographs. It might also be that the noise was fashioned during photographic processing. Figure 3 shows an example of noise resulting from the presence of dirt on the emulation of a historical photograph.

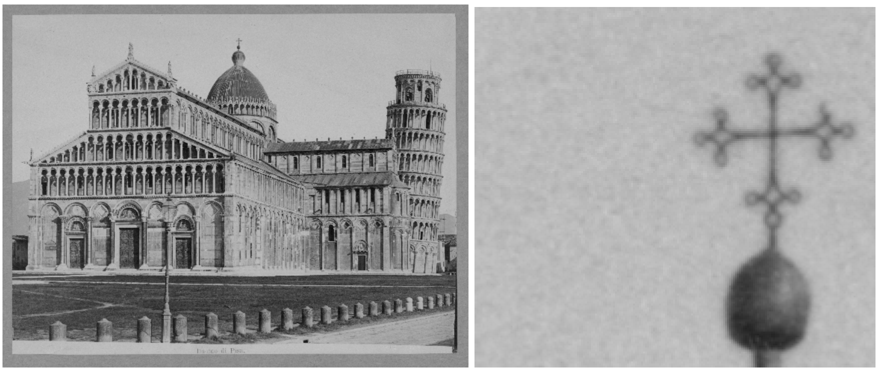


Fig. 1. An example of film grain noise

Fig. 2. The original (left) and enlarged region of interest showing an example of cracking manifesting itself as thread, or ribbon noise (right)

There are a multitude of nonlinear filters which have been developed to suppress noise in images. Noise suppression algorithms should possess two characteristics: the ability to suppress noise, and the ability to preserve edges within the image. Median filters provide a good balance of being able to reduce impulse noise, while preserving edges and only moderately attenuating noise in homogeneous or flat regions of an image. They operate by replacing a pixel by the median value obtained from a neighborhood surrounding the pixel. However the caveat with median filters is that their performance in suppressing random noise is somewhat mediocre. The moving average filter is a technique, adept at smoothing random noise, but suffers from an inability to preserve edges, or reduce impulse noise. There are few filters able to deal with noise such as thread noise. In this paper, we extend the fuzzy filters of Kwan and Cai [2]. They apply fuzzy membership weighted functions which incorporate aspects of both moving average and median filters. We take this a step further, advocating the use of truncated median (or quasi-mode) filters.

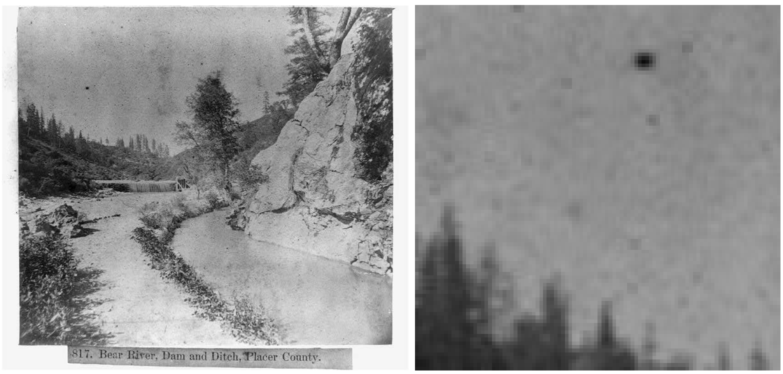


Fig. 3. The original (left) and enlarged region of interest showing an example of noise relating to the presence of dirt on the emulation (right)

2 Fuzzy Filtering

Fuzzy filters are based on the principle of a 2D filter [2] of the form:

$$I_e(i,j) = \frac{\sum_{(x,y)\in W} F\left[W(i+x,j+y)\right]\cdot W(i+x,j+y)}{\sum_{(x,y)\in W} F\left[W(i+x,j+y)\right]} \tag{1}$$

where $F\left[W\right]$ is the filtering function, and W is the sub-image being processed, centred on the pixel (i,j). The window is of size N, such that the range of x and y are: $-X \le x \le X$, and $-Y \le y \le Y$, where $N = 2X+1 = 2Y+1$. We use a value of $N = 5$ for both filters described in the next section.

Kwan [3] introduced a series of fuzzy filters based on symmetrical and asymmetrical triangular membership functions, used to filter impulse, random and mixed noise. Some of these include the *TMED* (symmetrical triangular fuzzy filter with median value), *GMED* (Gaussian fuzzy filter with median centre), *ATMED* (asymmetrical triangular fuzzy filter with median value), and three similar filters *GMAV*, *TMAV*, *ATMAV* where the median is replaced with a moving average. For example, the GMED incorporates a Gaussian which provides a "smoothing" affect on the image, and a median filter for filtering "impulse"-type noise and preserving edges.

3 Fuzzy Filters Using the Truncated Median

3.1 The TMOD and GMOD Filters

We introduce a *symmetrical triangular fuzzy filter with a truncated median* (TMOD) and the *Gaussian fuzzy filter with truncated median centre* (GMOD). This filter is used for filtering impulse, random and mixed noise of a sporadic nature. The TMOD filter is defined as:

$$F\left[W(i+x, j+y)\right]=\begin{cases}1-\left|W(i+x, j+y)-W_{tmed}\right|/W_{mm} & \text{if } \left|W(i+x, j+y)-W_{tmed}\right| \leq W_{mm} \\ 1 & \text{if } W_{mm}=0\end{cases} \tag{2}$$

$$W_{mm}=\max\left[W_{max}-W_{tmed}, W_{tmed}-W_{min}\right] \tag{3}$$

where W_{tmed} , W_{min} and W_{max} represent the truncated median, minimum and maximum values of the sub-image W respectively. The GMOD filter is defined as:

$$F\left[W(i+x, j+y)\right]=e^{-\frac{1}{2}\left[\frac{W(i+x, j+y)-W_{tmed}}{W_{\sigma}}\right]^{2}} \tag{4}$$

where W_{tmed} and W_{σ} represent the truncated median and variance of the sub-image W respectively.

3.2 The Truncated Median

The mode of an image neighborhood represents the most probable intensity value [4]. first Davies [4] points out that while the mode has redeemable characteristics as a noise suppression filter, it is difficult to implement in a small neighborhood with a sparse intensity distribution. A truncated median (sometimes called the trimmed median), offers an approximation of the mode. It is calculated by first extracting a neighborhood centred on pixel (i, j) (W) from the original image, and reshaping it into a vector, E. We then calculate the mean (E_{mean}), median (E_{med}), maximum (E_{max}), and minimum (E_{min}) values in the neighborhood. Now we can decide whether the neighborhood will be truncated on the upper or lower bound of the vector:

$$E_{trunc}=\begin{cases}E>=2E_{med}-E_{\min} & \text{if } E_{med}<E_{mean} \\ E<=2E_{med}-E_{\max} & \text{otherwise}\end{cases} \tag{5}$$

E_{trunc} now represents those values to be truncated from the vector *E*. After this we can calculate the median of the remaining elements, this will be the truncated median.

$$W_{tmed} = median\left(E_{trunc}\right) \tag{6}$$

Davies [4] introduced the truncated median as a filter which has a strong effect on edges, leading to a "crispening" of the image, and a contrast enhancement while suppressing noise in regions away from the edges.

4 Experiments

We will perform three experiments: (i) the first using an albumen print which contains thread noise, (ii) the second using an albumen print containing artificial Gaussian noise to simulate significant image grain, (iii) the third looks at suppression of the film-grain noise in the image shown in Fig 1. The first experiment tests the result of both filters against the standard median filter, whilst the second experiment uses the moving average filter as a simple comparative filter.

4.1 Metrics for Estimating Image Quality

The task in determining which of these algorithms does a better job at suppressing the cracking is by no means an easy one. There are various metrics which could be used for the task, but ultimately it is visual assessment that will have the greatest impact. Aesthetics play a more influential role when the object of enhancement scheme is a cultural artefact. To estimate the noise reduction characteristics associated with each algorithm, we use a an approximation of noise variance (NV) proposed by Rank et al. [5]. This metric is a no-reference metric. A higher value symbolizes the presence of more noise. In addition, for the experiment which adds artificial noise, we use a perceptual error measure in the form of the Watson metric [6]. This reference-based metric takes into account three factors: contrast sensitivity, luminance masking and contrast masking. The closer to zero the better the perceived image quality.

4.2 Experiment 1: Cracking in Albumen Prints

Albumen prints use the *albumen* found in egg-whites to bind the photographic chemicals to the paper. Albumen-coated paper prints were first used in 1850 by Louis Désiré Blanquart-Evrard [7], and were to become the predominant image format in the latter half of the nineteenth century, representing a substantial portion (approximately 80%) of the visual heritage of the period. Albumen is similar to gelatin in that it softens and swells in moist conditions and becomes brittle and contracts under dry conditions. Such mechanical or physical deformations result in the development of a network of *cracks* and *fissures*. Albumen cracking, or crazing as it is also termed is an attribute of albumen photographs which is important from both an aesthetic and conservation perspective. The images used in this experiment have been extracted from an albumen photograph of "The Crucifixion", in Santa Maria degli Angioli, (Lugano, Switzerland) a fresco by Bernardino Luini (1529). The print was taken in the latter portion of the 19th century. An example is shown in Fig.4.

Fig. 4. An Albumen print

Albumen prints offer a good example of thread noise. The images of Fig.5 demonstrate the nature of the cracking present in Fig.4.

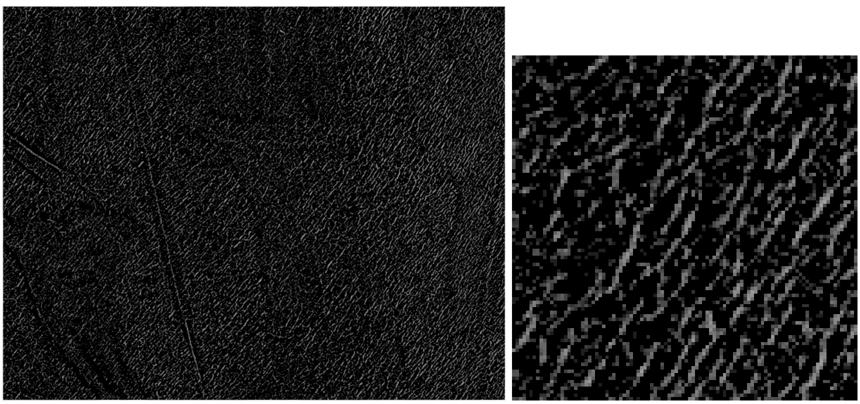


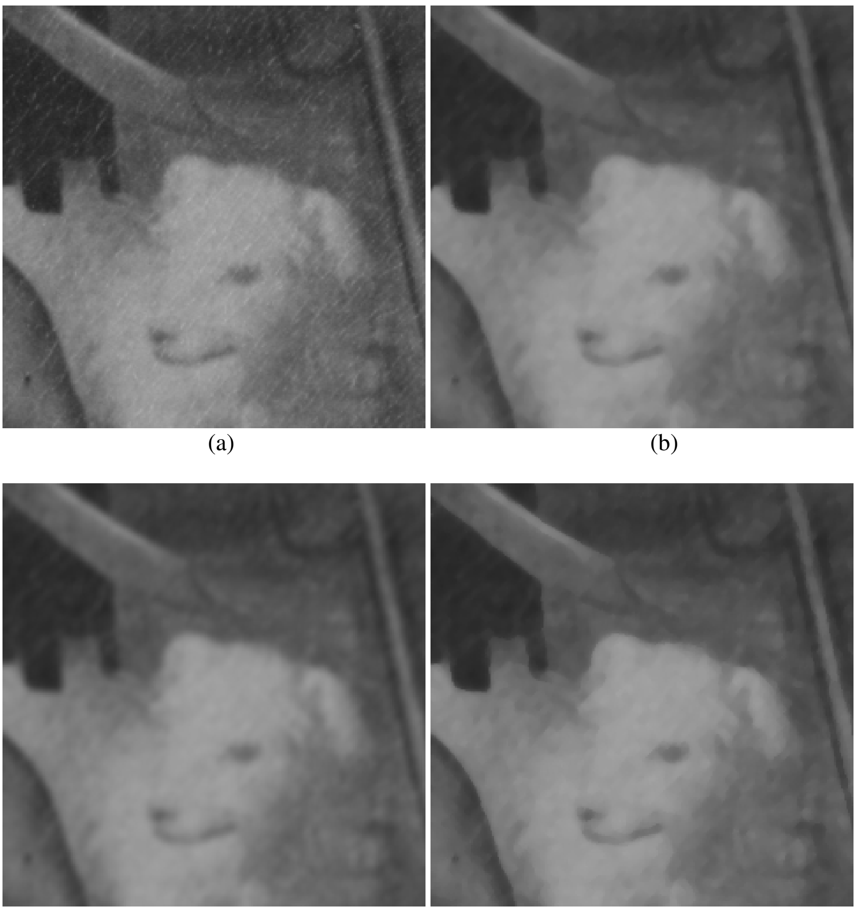
Fig. 5. The image of Fig.4 enhanced to delineate "chaotic" noise cracking (left) and an enlarged 100×100 region (right)

The calculated values for the noise variance are shown in Table 1. From the metrics we can discern that both the GMOD and TMOD fuzzy filters produced the lowest noise variance, better than the standard median filter (MED).

Table 1. NV Metric for Experiment 1

Algorithm	NV
Original image	5.8099
MED	1.5776
GMOD	1.0000
TMOD	1.0034

To investigate the effect of the fuzzy filtering algorithms it is appropriate to extract a sample region (240×240 pixels) from each of the images, which are shown collectively in Figure 6. The reference image extracted from Figure 4 is shown in the Figure 6(a). This image quite clearly shows cracks running approximately 45 degrees from the lower-left to the upper-right. Of the three processed images in Figure 6, the image processed by the GMOD filter has suppressed the cracking, but at the expense of smoothing some of the edges. FIRE filter still seems to contain a great deal of residual streaks from the cracking. The TMOD algorithm has suppressed the cracking but maintained most of the image details, with edges of some objects actually appearing as if they have been sharpened.



(a) (b)

(c) (d)

Fig. 6. Result of processing the enlarged ROI depicting: (a) Original image, (b) MED filter, GMOD filter, and (d) TMOD filter

To illustrate further, we extracted a 30×30 region from each of the processed images to illustrate the effect of each of the filters (Figure 7). The sub-images represent the region incorporating the dog's eye. While the metrics used to measure the ability of the algorithms to suppress cracks show a likeness, it is hard to judge the result from using quantitative measures alone. The GMOD filter has blurred the edge of the eye, whereas the TMOD filter has maintained a crisper edge, more so than even the median filter.

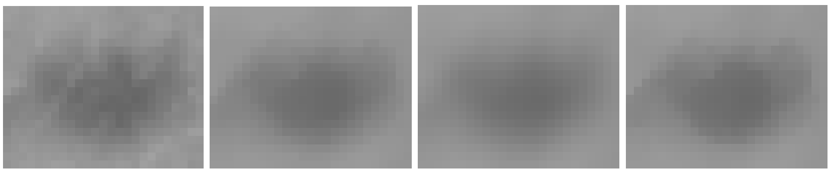
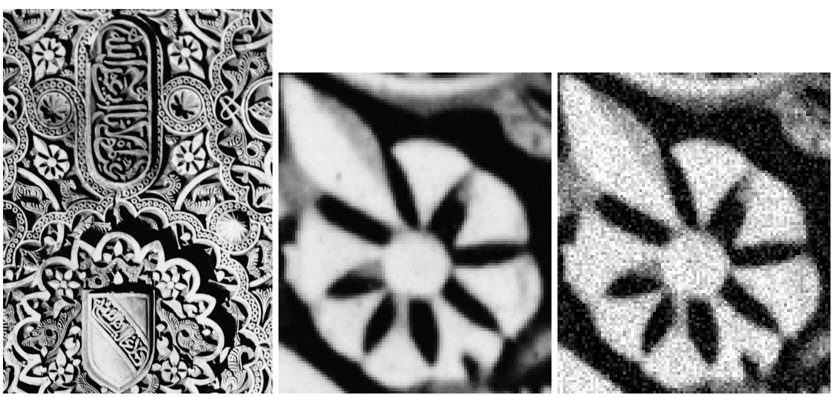


Fig. 7. Enlarged regions from the raw and processed images, showing the dog's eye (original, MED, GMOD, TMOD)

4.3 Experiment 2: Simulated Noise

The second experiment involves the use of simulated noise in a realistic image. The image is from the Library of Congress collection, an albumen photograph of architectural decorations from Granada, Spain taken between 1860 and 1880. An example of a portion of the image (700×1000 pixels) is shown in Fig. 8a. To this image we have added Gaussian white noise with zero mean and 0.01 variance. Fig. 8b shows an enlarged region and Fig. 8c the same region containing noise.



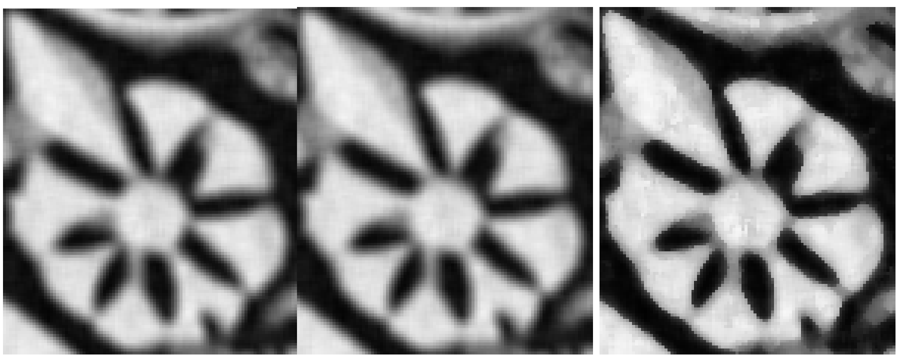
(a) (b) (c)

Fig. 8. Image containing synthetic noise (a) Original, and enlarged sections depicting: (b) Original, and (c) Gaussian noise

The results for the GMOD, TMOD and moving average (MAV) filters are shown in Fig. 9. From the quantitative metrics shown in Table 2, it can be discerned that all three algorithms resulted in a substantial reduction in the noise variance. The TMOD has a higher NV than either MAV or GMOD due to the smoothing nature of the latter two algorithms. The Watson metric, used as a measure of perceptual error, shows a similarity between the moving average and GMOD filter, and a slightly better result than the TMOD filter. In spite of this, when we visually assess the result of the algorithms we notice an intrinsic blur in both the GMOD and MAV filters, whilst the TMOD filter has preserved the edges.

Table 2. Metrics for Experiment 2

Algorithm	NV	Watson
Original image	509.5151	0.4556
MAV	3.5458	0.2702
GMOD	3.6086	0.2704
TMOD	9.6145	0.2615

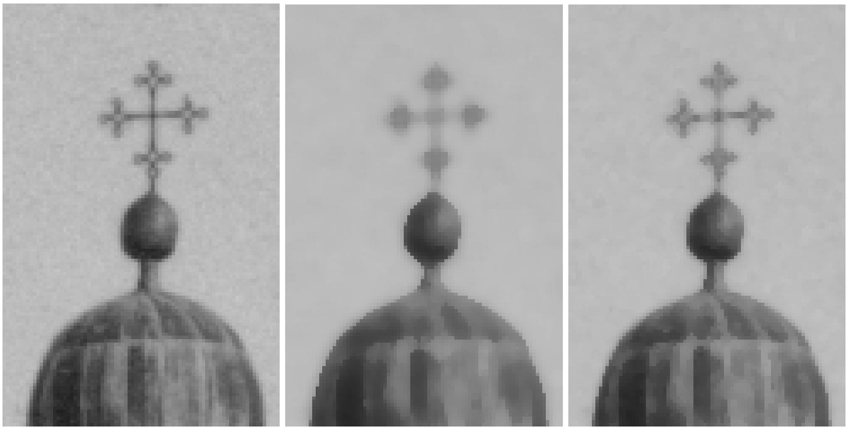


(a) (b) (c)

Fig. 9. Result of processing the enlarged ROI depicting: (a) Moving average, (b) GMOD filter, and (c) TMOD filter

4.4 Experiment 3: Film-Grain Noise

This experiment involved suppressing the film grain in the historical photograph of the cathedral and Leaning Tower of Pisa (2496×1944 pixels). To investigate the effect of the TMOD filtering algorithm we have extracted a sample region (82×126 pixels) from Fig.1. The results are shown in Fig.10 for both N=5 and N=3. For N=5, the background image "graininess" has been diminished, at the expense of an erosive effect on fine details. For N=3, more details have been preserved at the expense of some noise retention. Noise variance metrics are NV = 6.4867 for the original, and NV= 1.0115 (N=5), and NV = 3.0469 (N=3). However since this extracted region represents only 0.02% of the entire image, a reduction in very fine details may be the tradeoff to effective noise suppression.



(a) (b) (c)

Fig. 10. Suppression of grain noise from Fig.1 (a) Original, (b) TMOD filter (N=5), (c) TMOD filter (N=3)

5 Conclusion

The task of removing noise from images is unquestionably significant. It is important to recognize that chaotic noise, such as that found in historical photographs which have been digitized cannot be treated as normal noise, nor can it be treated as a series of concrete structures to be removed. Very few traditional methods of noise suppression focus on noise outside the domains of "impulse" or "Gaussian" noise. Suppressing artifacts such as thread noise which has a more chaotic behavior is complicated by the nature of the defects: the large population size, density and inhomogeneous characteristics. This paper has explored the use of two fuzzy filters based on the notion of truncated median: the GMOD and TMOD filters. In both experiments, involving thread noise and Gaussian noise, both filters worked well, with the TMOD filter having the advantage of suppressing noise while being able to preserve edges. As with all enhancement algorithms, many of the observations relating to the ability of these algorithms to remove cracking were based on visual assessment. Though not ideal, it is difficult to find quantitative metrics which can be used to evaluate the behaviour of such distinct algorithms. Future work will focus on comparing a multitude of differing noise suppression algorithms in the contact of historical images, and applying the TMOD filter to colour images.

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