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A New Descreening Technique in the Frequency Domain

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Abstract

In this paper a new algorithm to obtain a continuous tone image starting from a halftoned one is proposed. This descreening technique is based on Butterworth filtering in the frequency domain. It removes the pattern of the original screen leaving unchanged the colors in the image. The proposed algorithm ensures fast and effective results, and can be used also by non-qualified operators.

Categories and Subject Descriptors (according to ACM CCS): I.4.3 [Image processing and Computer Vision]: Restoration

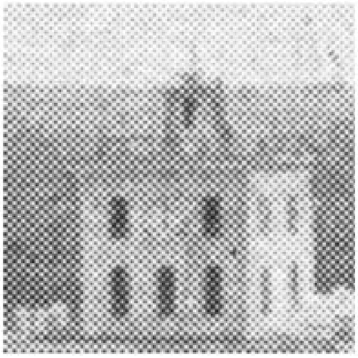
1. Introduction

A grayscale photograph has hundreds of shades of gray, while black-and-white display devices requires only binary images. Hence, when an image is reproduced, the continuous tone image is converted in a binary image. This converting process, called *screening* or *halftoning*, breaks an image into a series of dots with different sizes. Each size approximate a shade of color: a group of large dots placed closely together appears black; a group of smaller dots with larger spaces between them produces a weaker gray shade; while a group of even smaller dots spaced widely apart appears almost white (Fig. 1).

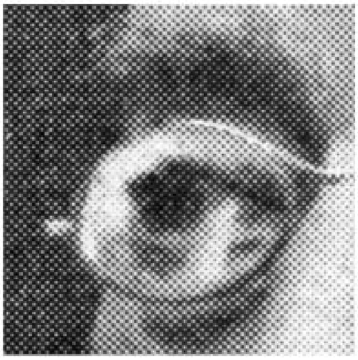
In traditional graphic arts, screening was generally done using a screen-like pattern etched into a glass plate. Each dot in the screen have size equal to the others. When the light cross the dots, the screen in the darker area produces less reflection and the dots appears bigger than the ones in the white area where the light reflected is higher. Usually, a camera operator had several of these plates, each with a different pattern. The image to be reproduced was projected through a chosen screen onto film, and the resulting image looked like the original except that it was broken into a lot of little dots. Today, there are several digital algorithm to obtain a screened image. The Section 2 reports a simple heuristic technique to derive a screened image starting from a raster image.

Usually, the image processing operators work better if they are applied over a continuous tone image. For example, scaling a screened image produces severe aliasing. To enable these operations, gray images need to be reconstructed from the halftones through *inverse halftoning* or *descreening*. However, the screening operators lost some information, and there is no way to reconstruct a perfect gray image from the given halftoned image. Many efficient inverse halftoning algorithms have been developed in the past several years to improve the quality of the reconstructed image (more details in Section 3). Often, the performance of these methods is related to the knowledge of the used halftoning algorithm. Some of these, improve the final quality using unsharp masking techniques. Anyway, when the halftoning algorithm is unknown or very difficult to understand, they could fail. More general methods are desired.

In this paper a novel descreening technique is proposed. It is based over the idea that the original screen pattern is easy to detect in Fourier domain. They are localized in the peaks out of the central region around the *DC* component. If they are removed the image appears like the original continuous tone and any regular pattern is detectable. To remove these peaks we use a particular filter derived by classical Butterworth filter. How build this filter is the aim of this paper. This approach can be applied over all the screened image, and do not depend by the halftoning algorithm used. Moreover, the method parameters are related to the image resolution and they not change for images with the same resolution. In



(a)



(b)

Figure 1: *In (a) and (b) some magnified details of two different halftoned images.*

these case, the algorithm works automatically, and no user intervention is required.

The rest of the paper is organized as follows. Section 2 shows how to generate a typical screened image, while Section 3 reports some descreening techniques. In Section 4 our algorithm is proposed, while an exhaustive set of experiments is reported in Section 5. Conclusions end the paper.

2. How create an halftoned image

Imagesetters create halftone screens using screen frequencies, measured in lines per inch (lpi). A screen frequency can be represented by a grid. Each square in this grid is a halftone cell, capable of holding one halftone dot. Higher screen frequencies produce finer halftone screens. Lower screen frequencies produce coarser halftone screens. Often, frequency is determined by the type of paper used to print the image: newspapers typically use an 85-to-100 lpi screen to print halftones, while magazines using glossy paper need a finer screen and may use 133-to-150 lpi or higher to print halftones. For very high quality promotional materials or fine art reproduction, frequencies of 180-to-200 or more should be used. To create halftone dots, the halftone grid is superimposed on an image. Each halftone cell is assigned a different sized dot to represent the image data for the cell. When looked at together, the dots resemble the original image. In the superimposed image, some cells would be white, some black, and the rest various shades of gray depending on the size of the halftone dot.

In a real-world application, there would be hundreds of imagesetter spots per halftone cell. Each of the imagesetter spots within a halftone cell can be turned on (producing a color in your final output) or left off (producing white). The combination of imagesetter spots produces a halftone dot of a specific size and shape. In reality, the imagesetter images at the intersection of the lines on the grid to make a spot. If the halftone dot needs to be bigger, the image recorder turns on more imagesetter spots. If the halftone dot needs to be smaller, the image recorder turns on fewer imagesetter spots. To create different shapes, the image recorder turns the imagesetter spots on in different sequences. Each sequence is determined by a mathematical equation called a spot function. A separate spot function exists for each dot shape. Common shapes include round, diamond, square, and elliptical. PostScript generally requires at least 256 levels of gray to properly reproduce an image. Because of this, imagesetter manufacturers have adopted 256 gray levels as a de facto standard. The more imagesetter spots the halftone cells contain, the more shades of gray (also called gray levels) they can reproduce, and the more accurately the output represents the colors in the original picture.

As with everything in the prepress industry, there is a trade-off when you deal with screen frequencies and gray levels. Higher screen frequencies, because they contain more halftone cells, produce finer screens that can capture more detail from the original photo. However, because resolution remains constant, the more halftone cells you have, the fewer imagesetter spots they contain. As the number of imagesetter spots decreases, so does the number of gray levels each halftone cell can reproduce.

Breaking the image into a series of dots solves the problem of how to reproduce tones, but creates a problem of its own. The eye detects patterns quickly. When you print your output, you do not want the dot pattern to detract from the image it creates. One way to prevent the pattern from becoming distracting is to rotate the grid. The degree of rotation the eye notices least is 45^o. The dot pattern still exists, but it is much less noticeable. When a simple black-and-white halftone is created, the halftone screen is rotated 45^o. The printed output is an image that your eyes perceive as a black - and- white photograph, not as a series of dots.

3. Related works

In literature there are many methods to invert the halftoning. There are algorithms based on the Gaussian lowpass filtering [DVKVE98], on spatial varying FIR filtering [KDVEB98], on nonlinear filtering technique [SK01], on maximum a posteriori estimation [Ste97], on projection onto convex sets [HZ95], on wavelet approach [XOR96], on vector quantization technique [LY98], and on the lookup table (LUT) [CW05]. The main problem of these approach is that they first create a smoothed image and then enhance the quality of the result. For example, in the most recent paper ([CW05]) an hybrid inverse halftoning algorithm that combines the LUT approach and the filtering technique is proposed. The LUT technique is used as a preprocessing step to transform the given halftone image to a base gray image. Then, the edges in the continuous tone image are remarked to better reconstruct the image. On the other hand is not simple to understand what is edge and not. So the accuracy of these results depends on this difficult task.

The regular pattern of the screen can be considered as a periodic noise (shot noise) of a digital images. These artifacts can be revealed in Fourier space as high amplitude at specific frequencies in the spectrum. There is a family of Fourier filters that removes the power frequency artifacts, they are called notch filters ([GW02]). These are special form of a bandreject filter, which "notches" out selected frequencies instead entire band. Usually, they are used for images that have been corrupted with a sinusoidal interference pattern (poor broadcast television images, vibrating mechanical system such as a ship or a satellite). In [HT05] a technique to remove horizontal and vertical sinusoidal waves added to the image is proposed. It removes the periodic noise using a median filter in the Fourier space. Despite this approach preserves the uncorrupted regions, it can not used in descreening problem, since the screening dot is not exactly added noise but it is the information itself. The screen pattern is more complex than the shot noise one, hence more sophisticated analysis is required to achieve satisfactory results.

Usually, commercial scanners have a Descreen filter that minimize the regular patterns when the image is acquired. They use average filters that slow the scan considerably but does not give appreciable results. For this reason, imagesetters use tricks to obtain more interesting results. They scan the image at 2X or more than the desired resolution, then apply a blur or despeckle filter, and resample to the desired final size before using a sharpening filter. Despite the number of operations is high, the accuracy of the results is low.

4. The proposed algorithm

The descreen algorithm proposed in this paper works in the frequency domain. The basic idea is that the screen pattern can be detected and properly removed because it is intrinsically regular and periodic. In some sense, the screen signal can be associated with some kinds of periodical noise. The main differences is that such "noisy" values cannot be completely removed because it carry out also the original signal. Preserving, of course, the right amount of low frequencies component it is possible to properly search the anomalous peaks and delete them in a suitable way (Fig. 2). These peaks are properly characterized by some peaks located at a given distance from the DC component. In such manner the main low pass component are preserved and the final recovered image is not too blurry. If the noise peak has distance r than DC, and the original image has size $M \times M$, the classical Butterworth filter is expressed by the following equation [GW02]:

$$H(i,j) = (1 + \frac{D(i,j) * W}{(D(i,j)^2 - r^2)^{2n}})^{-1} \quad (1)$$
$$with \quad i,j = -M/2, \ldots, M/2$$

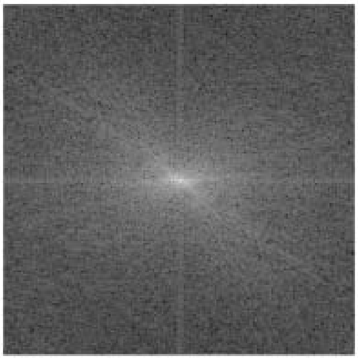
where n and W are the degree and the width of the filter, respectively; and $D(i,j)$ is the Euclidian distance between the value with the coordinate (i,j) and DC. Due to the Fourier symmetry there are four peaks at distance r from the center; the bandreject Butterworth filter remove all of them. In the descreen case, the regular peaks in the frequency domain are numerous (Fig. 2(b)). We have observed that the screen pattern is eliminated if all the points in K different rings are eliminated. We propose to eliminate this peaks using a particular filter derived from the Butterworth. If the peaks far from DC component are situated ad distance r_k, with $k = 1, \cdots, K$, the proposed filter is described by the following equation:

$$\begin{aligned} H(i,j) &= 1 - \sum_{k=1}^{K} (1 - H_k(i,j)) \quad (2) \\ &= 1 - \sum_{k=1}^{K} (1 - (1 + \frac{D(i,j) * W_k}{(D(i,j)^2 - r_k^2)^{2n}})^{-1}) \end{aligned}$$

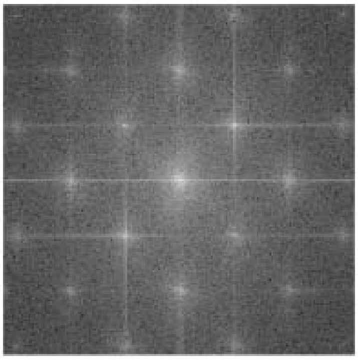
A typical plot of such filter for $K = 3$ and $W_k = 30$ for $k = 1, 2, 3$ is showed in Fig. 3.

5. Experimental results

The algorithm proposed in this paper needs the specification of parameters n and W_k. For old manual screened images, we have chosen to put the former equal to 1 and $W_k = 30$ for $k = 1, 2, 3$. The number of Butterworth K that is experimentally fixed to 3, and the radii r_k in Eq. 2 are automatically determined using a simple but effective heuristic. Since the DC component is in the center of the Fourier transform, we use as r_1 the position of the peak of maximum value far from DC. The r_2 is the position of the second maximum far from



(a)



(b)

Figure 2: *(a) Example of Fourier transform of a continuous tone image; (b) Fourier transform of the halftoned image in Fig. 1(b).*

DC and different from r_1. Finally, r_3 is the next higher value not in the center of the frequency domain and with $r_3 \neq r_1$ and $r_3 \neq r_2$. Using these parameters, the filtered frequency domain in Fig. 2(a) is reported in Fig. 5.

The set of 30 images processed in our experiments are real scans of screened images. They belong to the *Candiani* collection of the Pordenone Museum, Italy, hence an "original" version without defects does not exist. Consequently, the performances of the algorithm cannot be quantitatively compared using MSE or PSNR. We remark that the proposed method does not need any selection by the user and all the parameters are experimental determined as the best for this kind of screened images. Hence, they have not be adjusted

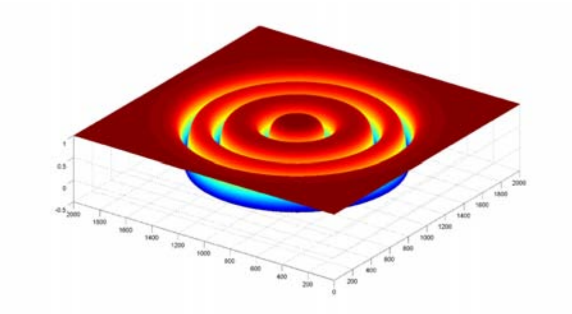


Figure 3: *Plot of the proposed filter.*

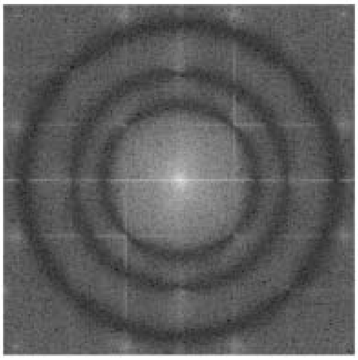
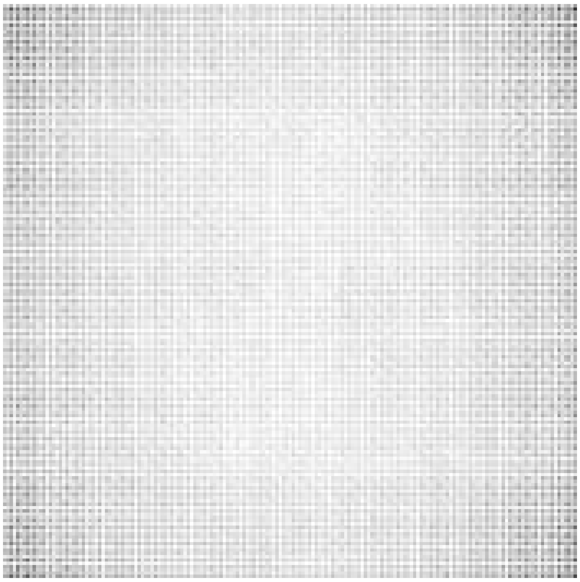


Figure 5: *Example of frequency domain in Fig. 2(b) after filtering.*

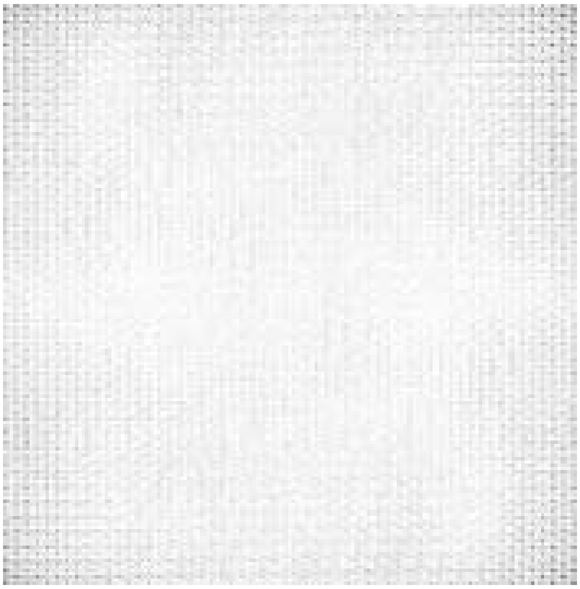
for each image and then the method appears automatic to the final user.

Fig. 4 reports some descreened images. The regular pattern is removed in all the images, even if the details are still present. In Fig. 4(d) the stains over the image are reconstructed and the clock between the windows is more visible in the restored image. Fig. 4(e) reports a particular pattern used in the image of Fifties. Also this pattern can be removed using our algorithm. The result in Fig. 4(f) shows a perfectly reconstructed images where the details are preserved (like the scratch over the woman's face).

As proof that our algorithm remove only the screen pattern, we have inverted the fourier domain and, hence, we have reconstructed only the removed frequency. Fig. 6 shows two examples of this reconstruction. It is possible to notice that the pattern is regular and there are not visible details of the original image (Fig. 4(c)). Moreover, if this pattern is subtracted to the input image, the continuous tone image is obtained. This confirm that the proposed algorithm works with the right frequency peaks.



(a)



(b)

Figure 6: *(a) and (b) are the negative of the pattern screen in Fig 4(c) and 4(e), respectively.*

6. Conclusions and future works

A new algorithm to reconstruct a continuous tone from an halftoned image has been proposed. This descreening technique automatically removes the higher peaks in the frequency domain out of the central area around the *DC*. In this way, all the frequency related to the screen pattern are reduced and the final image is perfectly reconstructed. The proposed algorithm ensures fast and effective results, and can be used also by non-qualified operators.

The next step of our research is to understand the relation between the resolution of the image and the radii r_k in Eq. 2. Moreover, we want to apply the proposed algorithm over a simulated halftoned images where the original is known, and computing several quality measures.

7. Aknowledgements

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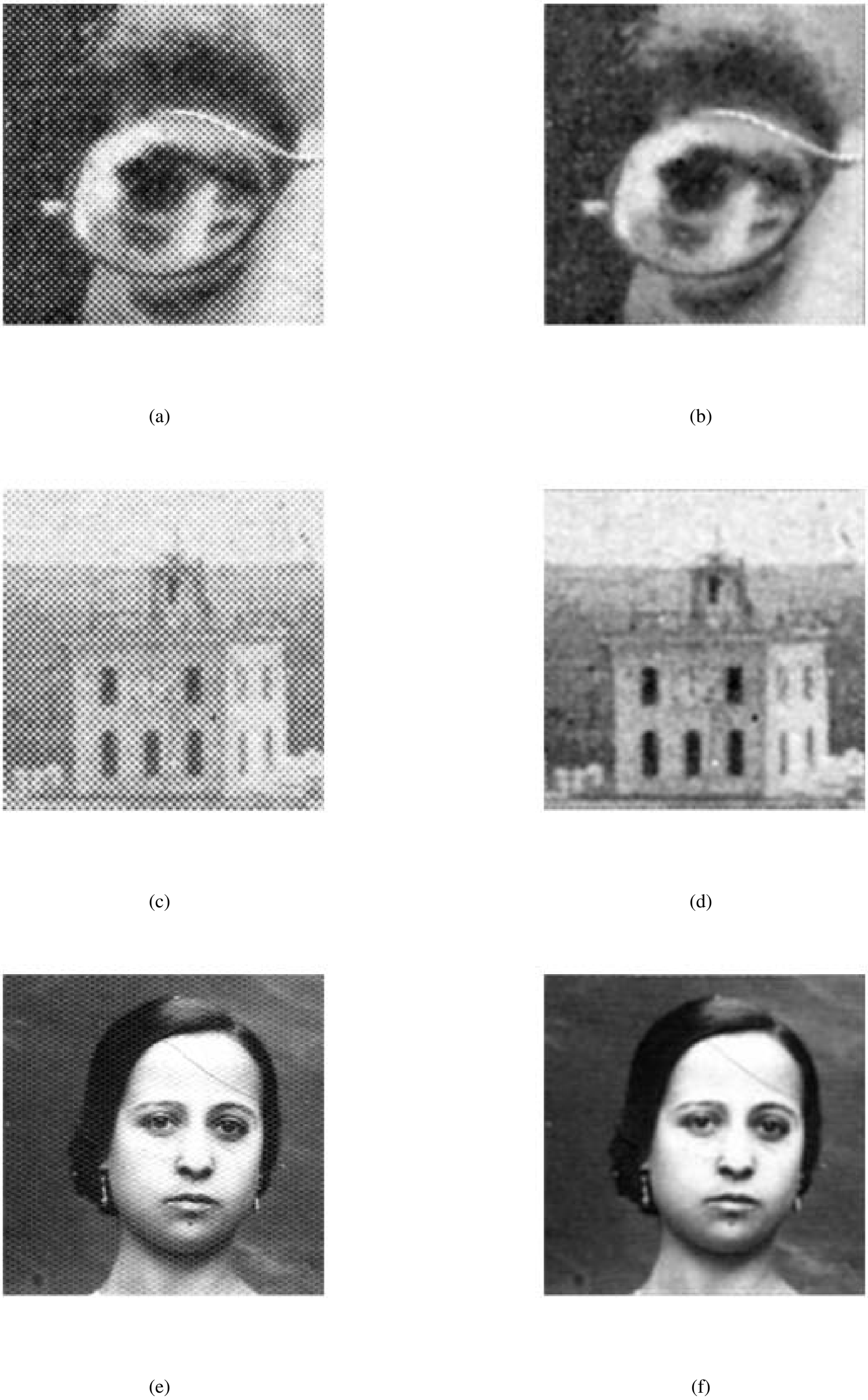

Figure 4: *(a), (c) and (e) Original halftoned images; (b), (d) and (f) restored images.*