# 行政院國家科學委員會補助專題研究計畫成果報告

## 可適性階層多解析彩色影像處理與分析

計畫類別：☑個別型計畫　　□整合型計畫
計畫編號：NSC 91ー2219ーEー002ー041
執行期間：91 年 8 月 1 日至 92 年 7 月 31 日

計畫主持人：林宗男
計畫參與人員：王欣平、詹凱傑

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- □出席國際學術會議心得報告及發表之論文各一份
- □國際合作研究計畫國外研究報告書一份

執行單位：國立台灣大學 電機工程系

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### 一、中英文摘要

本計劃是研究一個可適應性的多階層的影像濾波方法，處理由於在不同設備上的影像複製上所會出現的的人工圖樣及 moiré pattern。我們將分析 moiré pattern 在頻域及時域上的形式，並發展一套階層式濾波的方法，可有效的抑制 moiré 的人工圖樣且能增強影像輪廓。最後再將影像的邊緣分類，使的濾波器能達到在影像輪廓明顯的區域及平滑區域可以達到平穩轉換的效果，使的我們能得到較高的影像品質。

**ABSTRACT**

This paper describes a novel adaptive-hierarchical-filtering technique to achieve high-quality image enhancement when the image possesses the artifact of moiré pattern during the reproduction of the image by different computer peripherals such as color copier, or scanners plus printers.

Commercial magazine images are halftoned images. Unacceptable noises and moiré distortion may result when halftone images are copied (i.e., scanned and printed). In this paper, we analyze the formation of moiré patterns in the frequency and spatial domain. Based on the analysis, a set of hierarchical filter is developed to suppress the moiré artifacts and enhance the image adaptively. The hierarchical filter consists of a set of variable-length low-pass filters and high-pass filters. The low-pass filters have a nice inheritance of canceling aliased low frequency components (moiré distortion). High-pass filtering is also applied to sharpen image edges. An image classifier is developed to determine that an edge is either a global true edge (for sharpening enhancement) or a local halftone's micro-structural edge (for LPF for moiré reduction), so that adaptive filter technique can be applied to achieve the smooth transition between sharp edges and smooth halftone regions. Thus, we achieves overall high-quality output images.

Experimental results have been shown the effectiveness of the presented technique that works well on wide combinations of above-mentioned 6 factors, which will be explained during the following sections, for high-quality magazine image reproduction.

### 二、計畫緣由與目的

In printing industry, halftoning technology has been almost exclusively used for low-cost massive production of pictures, e.g., magazines, and newspapers. A halftone image is essentially a binary image (i.e., a printable form by a typesetter or a printer) whose picture element (i.e., pixel) is either "0" or "1" corresponding to white and black. A number of black/white pixels form a halftone dot. The perception of gray tone is achieved by varying the halftone dot size. Today, there are increasing needs to scan halftoned images for reproduction for display and/or printing applications such as desktop publishing, newspaper, and Yellow Pages production. However, when a halftoned image is scanned, unacceptable moiré distortion may result.

Much research has been done on the analysis and reduction of moiré patterns by various approaches as follows: (1) high frequency scanning (2) low pass filtering, (3) manipulation of the factors producing moiré patterns, and (4) post-scan image processing algorithms [1-4]. A. Rosenfeld and A. Kak showed that moiré patterns are caused by aliased frequencies produced when sampling images containing periodic structure [2]. T. S. Huang analyzed moiré patterns resulting from ideally sampling an image with uniform halftone dot patterns in the Fourier domain [3]. A. Steinbach and K. Y. Wong extended Huang's model to include the effects of scan aperture size and shape, and the reproduction printing process in the frequency domain [4]. J. Shu, R. Springer, and C. Yeh analyzed moiré formation factors and derived a formula to manipulate these factors to minimize moiré visibility [1]. J. Shu achieved moiré elimination and tone correction using a local tonal compensation technique [5].

However, there is no satisfactory result exist for the problem of halftone image reproduction. In this paper, we make efforts in tackling the problem of moiré suppression. A novel technique has been developed that applies adaptive hierarchical filters to remove moiré patterns adaptively.

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## 2. MOIRE ANALYSIS

The formation of moiré patterns depends on the following factors: (1) the halftone screen frequency (i.e., number of halftone dots per inch), (2) the scan frequency (i.e., number of scan spots per inch), (3) the angle between the scan direction and the halftone screen orientation, (4) the scanner aperture size and shape, (5) halftoning and printing mechanisms, (for example, error diffusion tends to randomize the moiré patterns, and cluster-dot or line screen show more moiré distortion.) (6) viewing conditions. Different magazine originals on different scanners, printers and copiers produce different moiré noises visually. This causes algorithm development difficult for moiré and noise removal. In addition image sharpening is usually required for enhancing reproduced image edges. However, the image sharpening also enhances moiré distortion and noises. Direct blurring methods can be used to reduce moiré distortion and noises but will greatly degrade the fidelity of image sharpness.

In the spatial domain, moiré patterns can be described as visible "beat" patterns resulting from the incorrect reproduction of halftone dots. As shown in Figure 1, the same size halftone dots before scanning become different size after scanning. The first halftone dot has 160% black pixel coverage and the 2nd halftone dot has 200% black pixel coverage. This error comes from the phase difference between halftone dots and scanned dots, and causes the cyclic change of lighter/darker zones, producing "beat" patterns.

From the uniform sampling theory and its application to halftoned images, we know the following facts: (1) any spatially bounded signal (e.g. size-limited imagery) has an infinite band in the spatial frequency domain; (2) if we digitally sample spatially bounded signals in the ideal sampling situation, aliasing is unavoidable; (3) if the sampled signal contains periodic structures, aliased frequencies may be seen in the output signal reconstructed from these samples; (4) if the sampled signal is from a halftone image, these visible aliased frequencies correspond to moiré patterns.

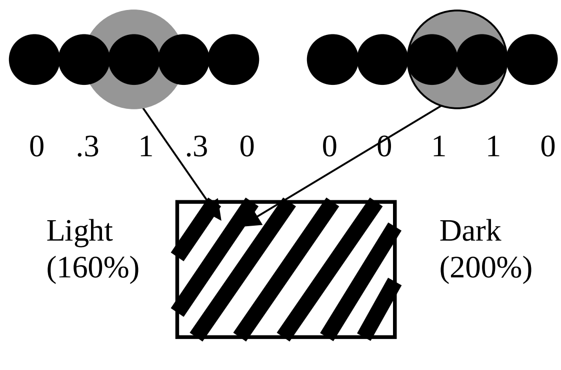
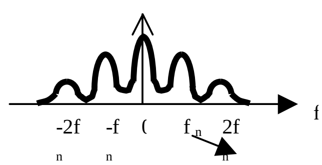



Figure 1. Spatial Analysis

As shown in Figure 2, in the frequency domain, moiré patterns are seen as aliased frequency components, which result from the scanning of screened art that possesses infinite bandwidth.



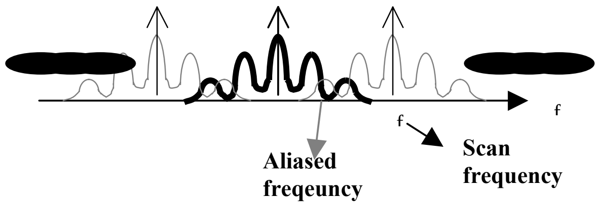



Figure 2. Frequency Analysis

## 3. ALIASED-FREQUENCY COMPONENT CANCELING FILTERING

The visibility of these aliased frequency components (i.e., moiré patterns) have a relation between scan frequency, screen frequency, and screen angle. We develop a set of low pass filters that have a nice inheritance of canceling aliased frequency components while the filtering processes. [6] [7] show the spectrum of the halftone image consists of the displaced spectra of nonlinearly transformed versions of the original continuous-tone image. The spectra repeat periodically with the halftone grid period. The zeroth-order spectrum is that of the quantized original image. The other spectra correspond to distortions of the original image. Figure 3 displays a schematic frequency relationship in frequency domain between a continuous-tone image and its corresponding halftoned iamge

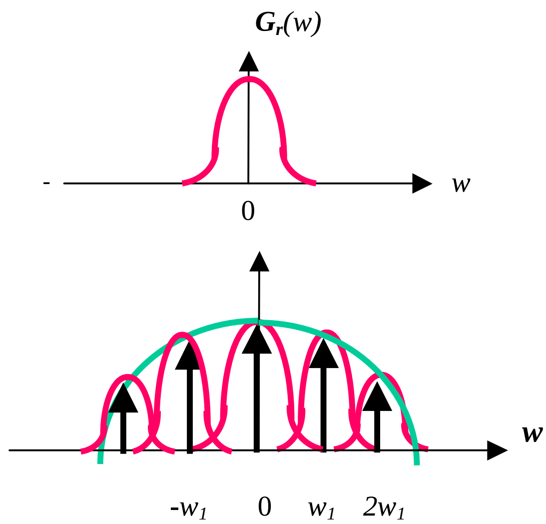



Figure 3. $G_r(w)$ is the frequency representation of the original continuous image and its transformed version of halftone image in frequency domain.

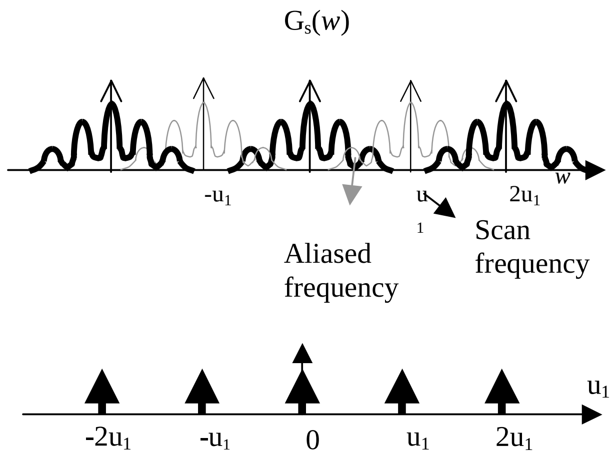



Figure 4. Frequency Analysis of Scanned Halftone.

$$g_s(r) = [h(r)\otimes a(r)] * \sum\sum \delta(\mathbf{r} - m\boldsymbol{\alpha}_1 - n\boldsymbol{\alpha}_2) \quad \textbf{(1)}$$

$$G_s(\mathbf{w}) = [H(\mathbf{w}) * A(\mathbf{w})] \otimes \sum\sum \delta(\mathbf{w} - k\mathbf{u}_1 - l\mathbf{u}_2) \quad \textbf{(2)}$$

The scanning process can be modeled by Equation(1) which shows the halftone image $h(r)$ convolves with the optical low-pass filter $a(r)$ then follows by a sampling process with the sampling grid defined by vectors of $\alpha_1$ and $\alpha_2$. The aliased frequency components which result from the scanning of screen image that possesses the infinite bandwidth cause the artifact of moiré patterns. Figure (4) illustrates the schematic explanation of how scanned halftone image results in moiré patterns. When we add a spatial phase delay $d$ to the scanning process, the sampling dynamics of scanning can be described by Equation (3). The frequency response of the delayed sampling grid is shown in Equation (4). The spatial delay effect becomes a phase shift $e^{-2\pi j\, d\cdot w}$ in the frequency domain. When the delay $d$ is half cycle of the scanning frequency (i.e., $d = \frac{1}{2}\alpha_i, \mathrm{i}=1,2$ ), the phase shift $e^{-2\pi j\, d\cdot w}$ in frequency components has an alternate sign changes as shown in Figure 5 in the one dimension case. If we add the original scanned image and the scanned image with half cycle phase delay $d = \frac{1}{2}\alpha$, the aliased frequency components

$$S_n(r) = \sum\sum \delta(\mathbf{r} - m\boldsymbol{\alpha}_1 - n\boldsymbol{\alpha}_2 - \mathbf{d}) \quad \textbf{(3)}$$

can be cancelled each other as illustrated in Figure. 6. The moiré patterns are therefore reduced.

$$F\{S_n(r)\} = C[\sum\sum \delta(\mathbf{w} - k\mathbf{u}_1 - \mathbf{l}\mathbf{u}_2)]\exp\{-2\pi j\mathbf{d}.\mathbf{w}\} \quad \textbf{(4)}$$

$$\exp\{-2\pi\, j\mathbf{d}\cdot\mathbf{w}\} = \begin{cases} 1, & \text{when k is even} \\ -1, & \text{when k is odd} \end{cases} \left( \text{if } \mathbf{d} = \frac{1}{2}\alpha_i, \right) \quad \textbf{(5)}$$

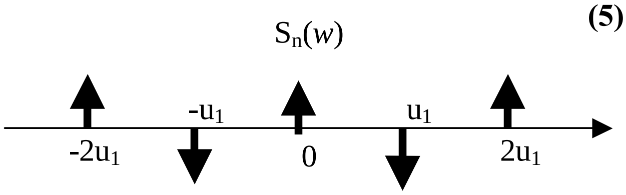



Figure 5. The phase shift in the frequency domain constitutes the alternate signs when d equals to half of the scan frequency.

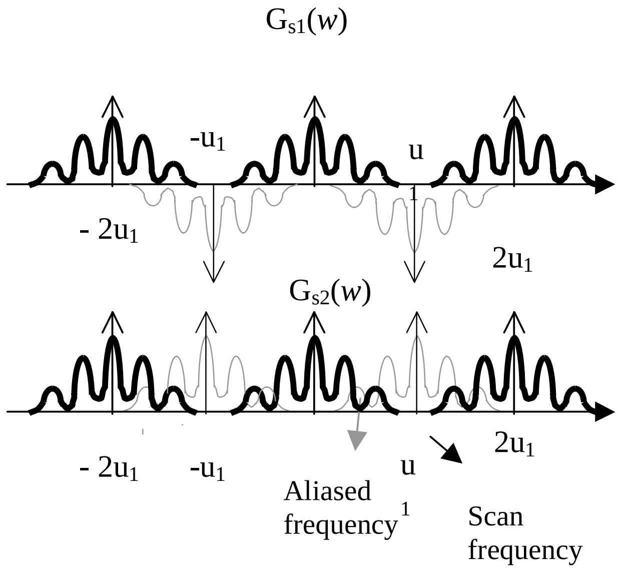



Figure 6. Halftone of Two Scans with ½ Phase Delay

The same phenomenon in 2-dimensional is illustrated in Figures 7 and 8. Figure 7 shows the screen angle is equal to zero degree. Figure 8 shows the screen angle is any degree. If we add four images (that include the original scan, and scanned with half cycle phase shifts horizontally ( $d = \frac{1}{2}\alpha_1$ ), vertically ( $d = \frac{1}{2}\alpha_2$ ), and diagonally( $d = \frac{1}{2}(\alpha_1 + \alpha_2)$ ), we can achieve the same effect of canceling aliased frequency components to achieve the moiré reduction.

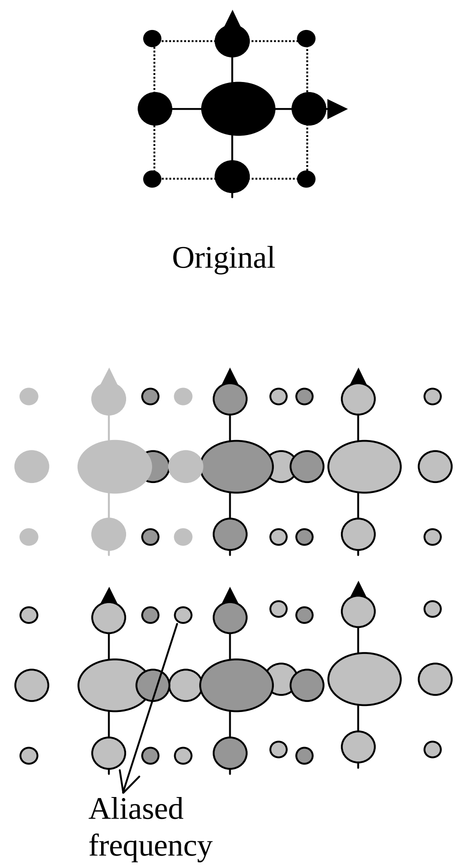



Figure 7. 2-Dimensional Frequency Analysis of Scanned 0 Degrees Halftones

## 4. ADAPTIVE HIERACHICAL FILTERING

From above frequency analysis, we know these anti-aliased filters can be constructed with 2x2 averaging filter, as illustrated in Figure. 9.

By the same reasons, 4x4 , 8x8, 16x16 averaging filters can be used which have the nice inheritance of canceling even more aliased low frequency components at the expense of larger size filters in the filtering process. Using the set of filters with size 2x2, 4x4, 8x8, …, etc., we can construct a set of pyramid of images, as shown in Figure 10.

The higher-level pyramid image has less moiré patterns. Detailed theoretical and analytical proof in Fourier frequency domain for the filtering process has been described as above.

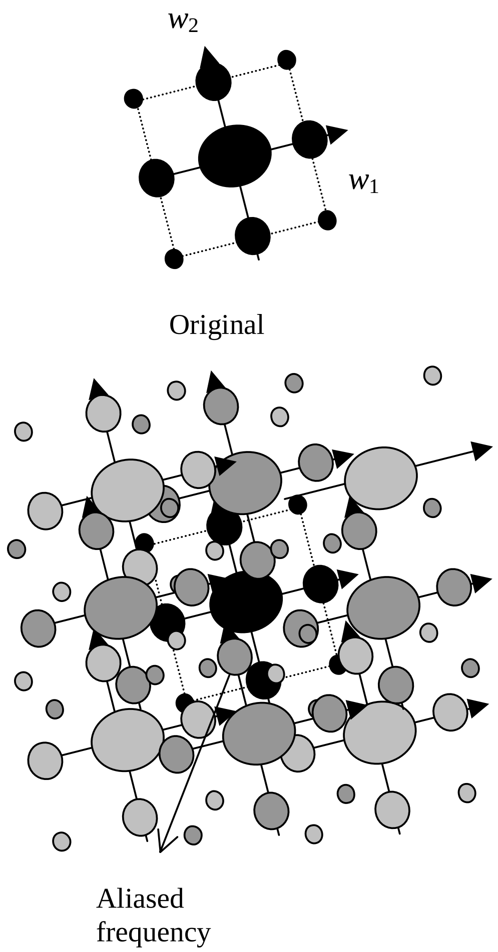



Figure 8. 2-Dimensional Frequency Analysis of Scanned Non-zero Degrees Halftones

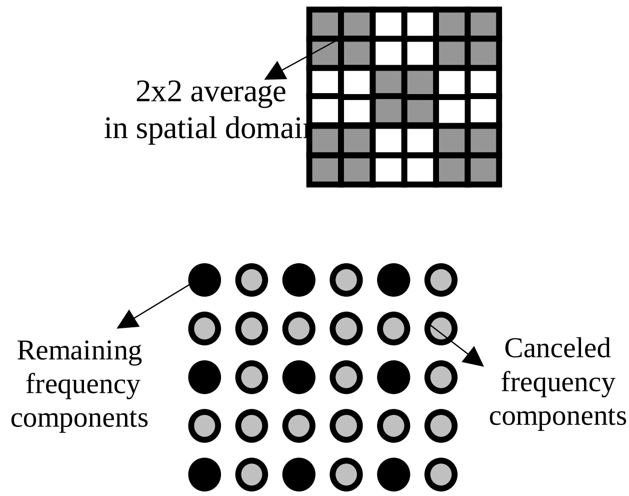
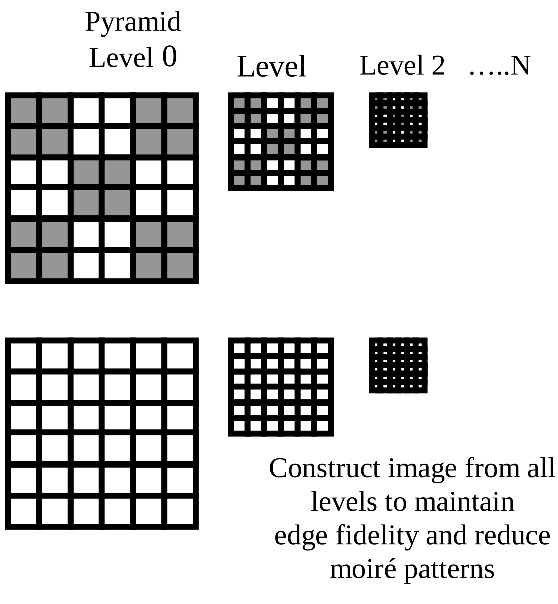



Figure 9. Anti-aliased 2x2 filtering

It illustrated why this set of filters can cancel the aliased low frequency noise components. Thus, the filtering process removes moiré distortion and noises. However, the LPF filtering process causes the penalty of that the image becomes more blurring. In order to maintain the sharpness of the image edges, a set of hierarchical high pass filters is also applied.



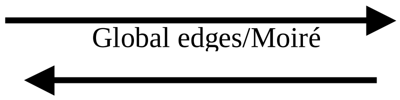



Figure 10. Anti-aliased pyramid image processing

An edge classification module is developed to determine that an edge is either a global true edge or a local halftone's micro-structural edge. From the original image, we construct a set of pyramid images. Image edges in higher layer pyramid are more global edges, while image edges in lower layer pyramid contains more halftone-dot microstructure edges (i.e., noises)

If the edge is a global edge, then the edge is maintained without LPF or is enhanced for sharpening purpose; non-edge and halftone's micro edge are filtered out by stronger LPF; the transition area between two situations above uses weak LPFs to avoid discontinuity between the transition. Thus, we achieves high-quality output images by removing moiré distortion and noises in smooth image regions, and also maintain (or enhance with unsharp masking technique) edge sharpness fidelity by applying the adaptive hierarchical filters according to regions which belong to either image edges or halftone areas.

## 三、結果與討論

Figure 11 are 4 halftone image with different LPIs of of 100, 133, 175 and 150 in the clockwise direction. The image is scanned at 100 dpi. We can see different moiré noises visually produced from different LPI images. Not all halftone images generate the same amount of moiré noise; noise becomes stronger when the halftone image is 133 LPI in this example. Figure 12 presents the result processed by the presented technique. In this experiment, the image classification module is constructed based on 2 layers of pyramid images. We can see that the moiré noise of the halftone images is reduced significantly. Another advantage of the proposed algorithm is the processing speed thanks to the design simplicity. Due to the efficiency and effectiveness, the proposed algorithm has been granted the US patent of 6,233,060 [8] and implemented in ASIC and several EPSON imaging products in the market.

## 四、計畫成果自評

In summary, this paper describes a novel technique that achieves high performance in terms of algorithm complexity and computational speed and high quality moiré suppression using an adaptive hierarchical filtering approach. The technique works very well for wide combinations of various screen frequencies, screen angles as well as scan frequencies on various scanners and printers for high-quality magazine image reproduction. Experimental results are shown in Figures 11 and 12. Figure 11 shows the original image scanned and printed at 600 dpi before applying the presented technique. Figure 12 shows the original in Figure 11 is processed by the presented technique. As shown, the presented technique has demonstrated the effectiveness of high-quality moiré suppression with shape edge fidelity results.

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Figure 11. 4 halftone images with 100, 133, 175, 150 LPIs starting from the left-upper corner in the clockwise direction scanned at 100 dpi.

Figure 12. Processed Image by the proposed Adaptive-Hierarchical-Filtering Technique