# Subpixel-based Image Downsampling-some Analysis and Observation

Lu Fang, Oscar C. Au, Yi Yang, Weiran Tang, Xing Wen
Department of Electronic and Computer Engineering
Hong Kong University of Science and Technology
Email: {fanglu, eeau, yyang, tangweir, wxxab}@ust.hk

***Abstract*— Often we need to shrink a high resolution image (e.g. 10-mega pixel) in order to display it on a low resolution display (e.g mobile phone). Signal processing theory tells us that optimal decimation requires low-pass filtering with a suitable cut-off frequency followed by downsampling. In doing so, we need to remove lots of details in the original high resolution image. In this paper, we review some little known results on an interesting topic called subpixel rendering, which can provide apparent higher resolution at the expense of color fringing artifacts. We attempt to explain what happens and why this is even possible.**

## I. Background On Sub-pixel Rendering

Nowadays, there is a tremendous need to display high resolution images/video (e.g. 10 mega-pixel image or HDTV) on low resolution display terminals (e.g. digital camera, mobile phone, portable DVD). A simple way which we called Direct Pixel-based Downsampling (DPD) perform simple downsampling by selecting one out of every $N$ pixels. It can incur severe aliasing artifacts in regions with high spatial frequency. An improved scheme is called Pixel-based Downsampling with Anti-aliasing Filter (PDAF) in which an anti-aliasing filter is applied before DPD to suppress aliasing artifacts. However, it smooths the result at the expense of unpleasant blurring artifacts.

Subpixel rendering, taking advantage of the fact that each pixel on a color LCD is actually composed of individual addressable red, green, and blue subpixel stripes, can increase the apparent resolution of an LCD display while introducing some unpleasant color fringing artifacts. Fig.1 illustrates an example of whole pixel rendering and subpixel rendering by displaying the letter “m”. It is obvious that subpixel rendering can reduce staircase artifacts effectively and reconstruct the shape information more faithfully. Hence, subpixel rendering in downsampling schemes can potentially improve the apparent resolution, but research is needed to suppress the color artifacts.

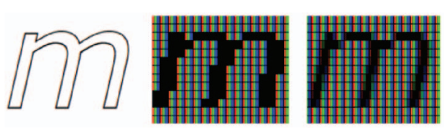


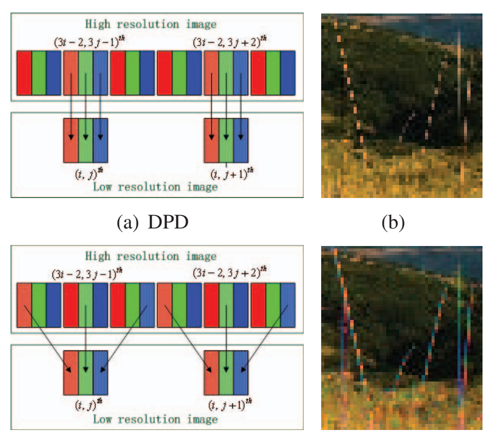
Fig. 1. (a) letter “m” in italic (left), (b) whole-pixel rendered “m” with jagged edges (middle), (c) subpixel rendered “m” with smooth edges (right)

In [1], a five-tap low-pass filter is added to subpixel-based downsampling to suppress color fringing somewhat at the expense of image blurring. It can only be adopted as an enhancement technique for achromatic image. Based on psychophysical experiments, [2] defines an error metric in frequency domain, and derives the filter coefficients by minimizing this metric. In [3], an algorithm based on human visual system is proposed to suppress visible chrominance aliasing.

The rest of the paper is organized as follows. In Section II, we introduce direct subpixel-based downsampling (DSD). Then in Section III, we analyze the performance as well as the problem of DSD based on experimental observations. Conclusions are given in Sections IV.

## II. Direct Subpixel-based Downsampling (DSD)

For simplicity, we assume that an input high resolution image of size $3M \times 3N$ is to be displayed on a $M \times N$ low resolution device. Daly et. al. proposed a simple subpixel-based downsampling scheme which we call Direct Subpixel-based Downsampling (DSD).




(a) DPD (b)

(c) DSD (d)

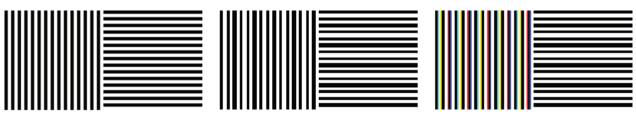
Fig. 2. (a) Direct Pixel-based Downsampling (DPD) (b) result of DPD where “grass” is broken (c) Direct Subpixel-based Downsampling (DSD) (d) result of DSD where “grass” is continuous but with color fringing artifacts

DSD decimates the red, green, and blue components alternately in the horizontal direction [4]. Let $(r_{i,j}, g_{i,j}, b_{i,j})$ be the $(i,j)^{th}$ pixel of the downsampled image. The method copies the red, green, blue components of the pixel from three different pixels in the high resolution image, such that $(r_{i,j}, g_{i,j}, b_{i,j}) = (R_{3i-2,3j-2}, G_{3i-2,3j-1}, B_{3i-2,3j})$ as shown in Fig.2(c), where $R_{3i-2,3j-2}$ is the red component of the $(3i-2, 3j-2)^{th}$ pixel of the high resolution image and so on. It is interesting to see that DSD may potentially present more high frequency details compared with DPD as illustrated in Fig.2(d), where "grass" is much more continuous than Fig.2(b).

## III. Potential Vs Problem

### A. Potential of DSD

From last section, we observe that DSD may give clearer and sharper downsampled images compared with DPD. To further understand the potential of DSD, we generate an original image with size of $210 \times 420$ containing two subimages with vertical and horizontal stripes. The width of each black line or white line is $7\ pixels (with 21\ subpixels)$. In other words, the number of black/white lines is 15 for each subimage, as shown in Fig.3(a).



(a) Original (b) DPD (c) DSD

Fig. 3. (a) original image (b) result of Direct Pixel-based Downsampling (DPD) (c) result of Direct Subpixel-based Downsampling (DSD)

In our experiment, the original $210 \times 420$ image is downsampled by a factor of 3 with DPD and DSD to produce two $70 \times 140$ images as shown in Fig.3(b) and Fig.3(c) respectively. We define a subpixel-based regularity measure for each subimage as follows:

$$Ave = \frac{\sum_{k=1}^{m} w_k}{m} - \frac{w_0}{3}; \quad Var = \frac{\sum_{k=1}^{m} (w_k - w_0/3)^2}{m} \qquad (1)$$

where $m$ is the number of black lines, $w_0$ is width of black lines in original image and $w_k$ $(k = 1, \cdots, m)$ is width of the $k^{th}$ black line in DPD/DSD image, with the unit of $subpixel$. In our experiment, $m = 15,\ w_0 = 21\ subpixels$. $(Ave, Var)$ for DPD and DSD are given by

| | Subimage-V | | Subimage-H | |
|---|---|---|---|---|
| | DPD | DSD | DPD | DSD |
| $Ave$ | 0 | 0 | 0 | 0 |
| $Var$ | 2 | 0 | 2 | 2 |

For the subimage with vertical lines, $Var$ of DPD is non-zero, indicating that the line spacing of DPD is irregular. On the contrary, DSD manages to keep the line spacing regular ($Var = 0$) at the expense of color fringing artifacts. For the subimage with horizontal lines, DSD gives exactly the same results as DPD.

### B. Shortcoming of DSD

*1) Sample Direction:* In our experiment, we observe that DSD can improve resolution at regions with vertical edges. But for horizontal lines and smooth regions, DSD is not better than DPD. These are due to the horizontal subsampling in DSD.

*2) Color Fringing Artifact:* Applying DSD to color images may cause very annoying perceptual color artifacts around edges. Fig.4 shows an example of a vertical edge in the original high resolution image, with a left pixel belonging to object 1 of white color, and the right two pixels belonging to object 2 of black color. After DSD takes the red component from the left pixel and green/blue components from the right two pixels to form one pixel, the pixel in the low resolution image is red, not black and not white. It is this artificial red color that causes the color fringing artifact.

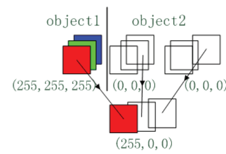



Fig. 4. example to show how color fringing occurs

In our experiment, as the line width of original image is $7\ pixels$, the subsampling may cross edges between black and white lines, with four conditions: (Black, White, White), (White, White, Black), (White, Black, Black), or (Black, Black, White). Thus, DSD may cause four different color fringing artifacts: Cyan, Yellow, Red and Blue, as illustrated in Fig.3(c).

In summary, exploiting subpixel in downsampling brings both opportunity as well as problem. We can potentially increase the apparent resolution of a patterned display by treating the subpixels separately. The potential luminance resolution is the subpixel resolution. The problem is that treating each subpixel purely as a luminance source, while ignoring color, can cause a large amount of color distortion. To balance the increased apparent resolution against the color fringing artifact is a research challenge.

## IV. Conclusion

In this paper, we review some little known results on subpixel rendering and its application to downsampling which can lead to higher apparent resolution compared with conventional downsampling approaches at the expense of some, often annoying, color artifacts. So, it is a critical research issue to develop theoretical results and analytical models to characterize subpixel-based downsampling of color images to be displayed on terminals of any pixel geometries, from both the multirate signal processing and human visual system perspectives.

## References

[1] S. Gibson, "Sub-Pixel Font Rendering Technology", from *http://www.grc.com/cleartype.htm*.

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[3] Dean S. Messing, Scott Daly, "Improved display resolution of subsampled color images using subpixel addressing," *IEEE International Conference on Image Processing*, Vol. 1, 22-25 Sept. 2002.

[4] Scott J. Daly et al, "Methods and Systems for Improving Display Resolution in Images Using Sub-pixel Sampling and Visual Error Filtering," *United States Patent*, US 6,608,632 B2, Aug.19, 2003.