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AND9180/D

Sparse Color Filter Pattern Overview

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APPLICATION NOTE

Overview

The Sparse Color Filter Pattern (or Sparse CFA) is a four-channel alternative for obtaining full-color images from a single image sensor. By adding panchromatic (or "clear") pixels to the standard red, green, and blue pixels traditionally used for color capture, image sensors can realize a significant increase in light sensitivity – between two and four times compared to standard designs – while retaining overall image quality and color fidelity. Image sensors using this design allow end users to capture better pictures and video under low-light conditions, as well as utilize faster shutter speeds to reduce motion blur when imaging moving objects.

ON Semiconductor offers both the Sparse CFA and the traditional Bayer pattern on a broad range of interline image sensors. This paper discusses the performance of the Sparse CFA image compared with the Bayer CFA pattern.

COLOR FILTER PATTERNS

Color filter patterns work by placing a single color over a pixel of the imaging array. The missing color samples at each pixel location are then reconstructed using a CFA interpolation or demosaicking algorithm.

Bayer CFA

The Bayer CFA has been generally accepted as the industry standard for one-shot color image. The Bayer CFA (Figure 1) works by sensing only one color at each pixel location using red, green and blue filter material. Notice that the green channel comprises 50% of the scene information. This channel acts as the luminance channel and provides the spatial information for the scene. The final RGB space image requires three colors at each pixel location to generate a full-color image. The process of color filter array interpolation (known as demosaicking) is used to compute the missing color values. Techniques for Bayer interpolation are widely known and used.

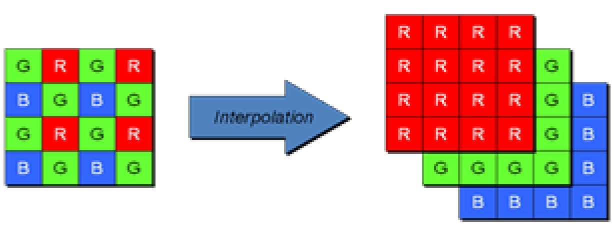

Figure 1. Bayer CFA

Sparse CFA

As compared to the Bayer CFA, the Sparse CFA uses four channels (red, green, blue, and panchromatic) to produce a final full-color (three-channel) image. Note that the arrangement of the panchromatic pixels (Figure 2) provides the same spatial information as that of the green channel in a Bayer CFA. This is one of the keys to the image reconstruction and improved sensitivity of the Sparse CFA. Since no wavelengths are blocked, the panchromatic pixel sensitivity is greater than the color pixels.

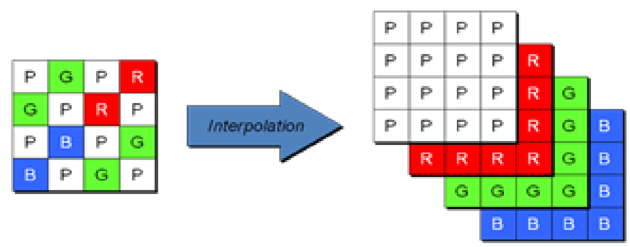

Figure 2. Sparse CFA Pattern

Image Processing

The image processing path described in this document for the Sparse CFA is similar to that for a standard Bayer CFA. In both image paths, luminance information in the final image is generated from half of the pixels on the image sensor (the panchromatic pixels for the Sparse CFA, and the green pixels for the Bayer CFA), while chrominance information is generated from the RGB pixels of the sensor (corresponding to half of the pixels for a Sparse CFA sensor, and all of the pixels for a Bayer CFA sensor). Because a dedicated panchromatic channel is available from the Sparse CFA, however, different image cleaning options are available in the image path for the Sparse CFA compared to the Bayer CFA.

Image processing of the Sparse CFA is performed at full resolution for panchromatic pixels and at half resolution for R, G, B pixels, in a manner analogous to a 4:1:1 YCC luma-chroma scheme. A simplified image processing block diagram is shown in Figure 3.

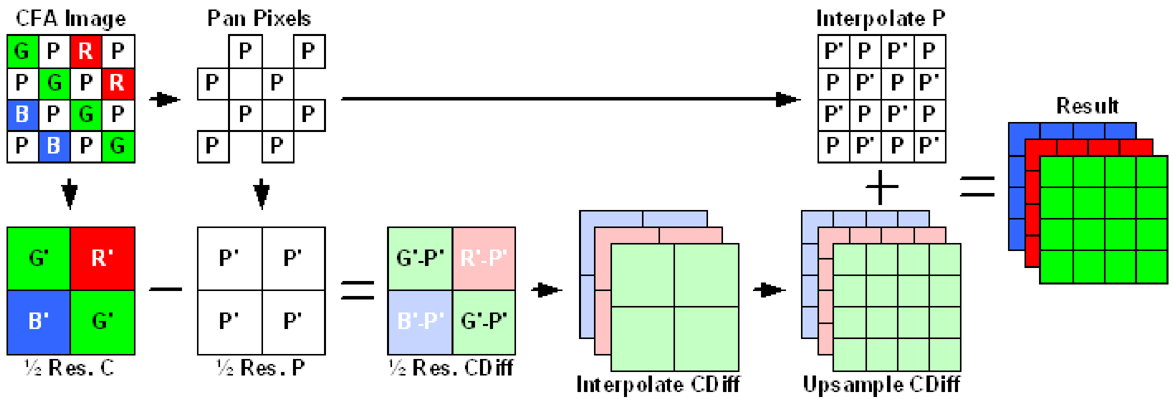

Figure 3. Sparse CFA Image Processing Path

The Sparse CFA image is composed of a luminance channel (panchromatic pixels) and a color channel (RGB pixels), providing the option to produce several outputs of a given image: a highly sensitive monochrome image (using pan pixels only), a low resolution color image for fast preview and a full-color image.

QE PERFORMANCE

Quantum Efficiency (QE) is a common measure of the spectral response of CCD imaging sensors. QE is a measure of the ratio of photo generated electrons captured by a pixel to the number of photons incident upon the pixel over a period of time. As can be seen in Figure 4, the integrated response of the panchromatic pixels is more than twice that of the individual color pixels.

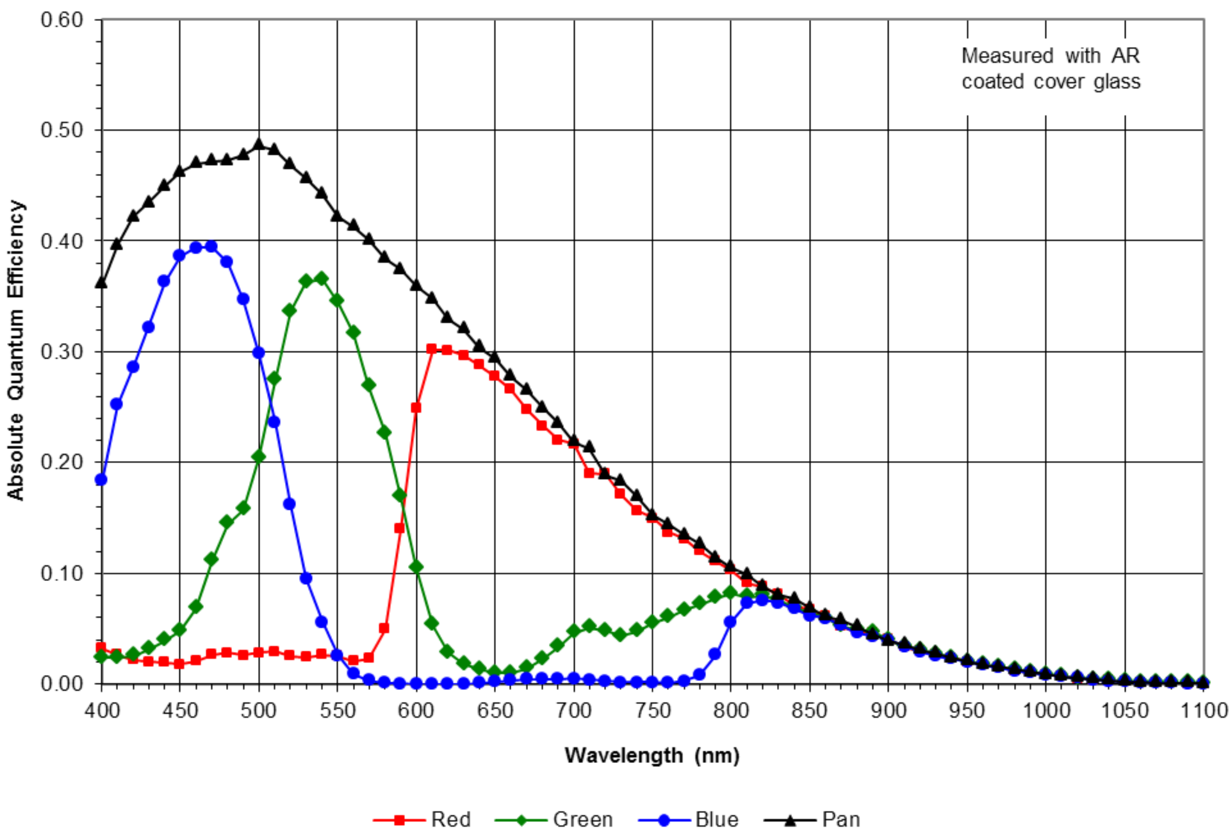

Figure 4. QE of Sparse CFA

RESULTS

The following image results show the performance of the Sparse CFA compared to a Bayer CFA using a typical 5.5-micron Interline Transfer CCD image sensor.

Typical Application

Figure 5 shows a traffic scene capture with the Bayer CFA and Sparse CFA. Imaging parameters such as lens aperture, exposure time, analog gain, etc. were the same for both captures. The Sparse CFA is over a stop brighter than the Bayer CFA. The Sparse CFA panchromatic channel (Figure 6) offers a fast, highly sensitive monochrome image that can be used for automatic number plate recognition (ANPR).

Figure 5. Bayer CFA (Left), Sparse CFA (Right)

Figure 6. Sparse CFA Panchromatic Only

Color Noise Performance

The following results demonstrate the color noise performance of the Sparse CFA compared to the Bayer CFA. For a scene with good illumination, there is no significant difference in the color or color noise between the Sparse CFA (bottom) and the Bayer CFA (top) as shown in Figure 7.

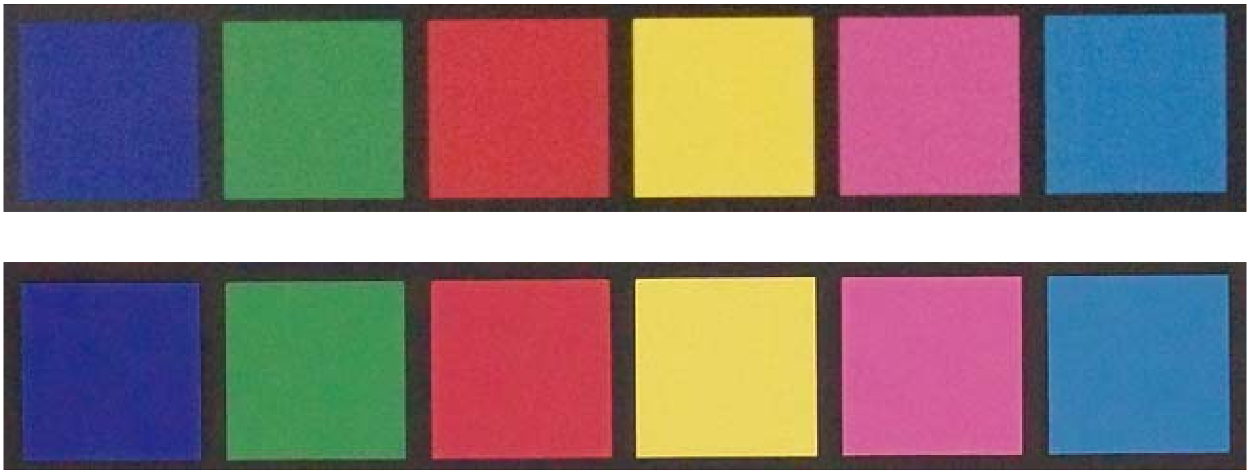

Figure 7. ISO 3200 Bayer CFA (Top), ISO 3200 Sparse CFA (Bottom)

For a scene that has very low light, the color noise is much less noticeable in the Sparse CFA (bottom) than the Bayer CFA (top) as shown in Figure 8. Because a dedicated panchromatic channel is available from the Sparse CFA, different image cleaning options are available in the image path for the Sparse CFA compared to the Bayer CFA. The actual color of the patches is the same between the Sparse CFA than the Bayer CFA.

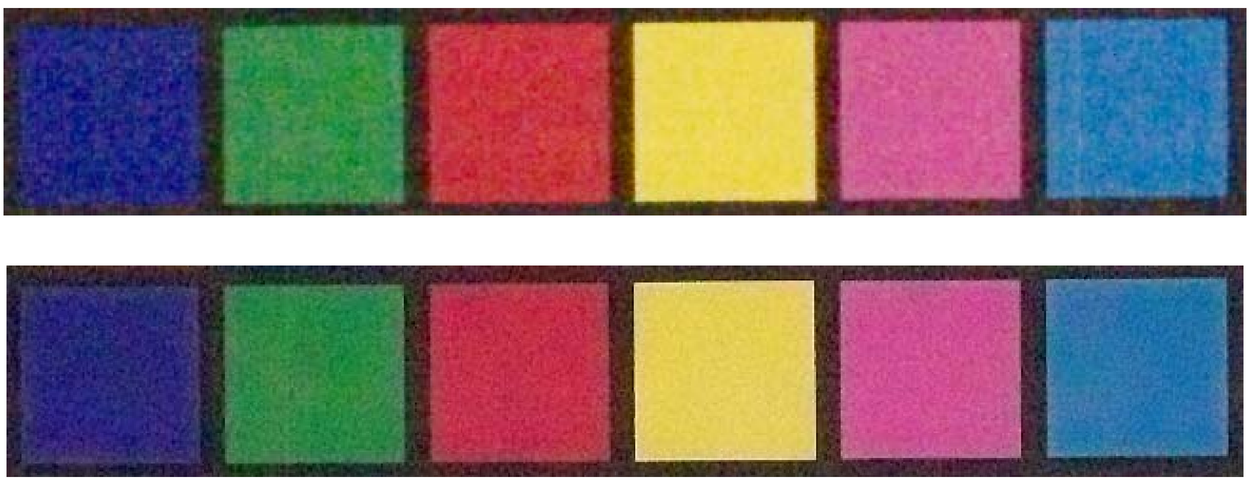

Figure 8. ISO 12800 Bayer CFA Digital Gain = 3.2 (Top), ISO 12800 Sparse CFA Digital Gain =1.4 (Bottom)

SNR10

SNR10 is a standardized metric used to compare capture systems under low light conditions. It is the scene lux value at which the ratio of signal-to-noise equals 10 for a fully-processed, 8-bit RGB image[1]. The conditions for capture are f#/2.8 and exposure time 66.66 ms. The illumination is measured with a light meter. The results are 6.4 lux for the Bayer CFA and 3.2 lux for the Sparse CFA. These results show a 2× increase in sensitivity for the Sparse CFA over the Bayer CFA (for a given sensor). This sensitivity increase is due to the CFA pattern.

[1] Refer to Application Note TND6115/D, Image Sensor ISO Measurement.

Low Light Performance

The Sparse CFA pattern was designed for improved low light performance while maintaining the raw resolution as compared to the Bayer CFA pattern. It is, therefore, instructive to analyze the noise cleaning for the resolution target for low light level captures. The captures in Figure 9 were made at approximately 13 lux. The Bayer CFA data required more digital gain to get the images to match in brightness. Applying more noise cleaning on the Bayer CFA image would make the detail more blurry.

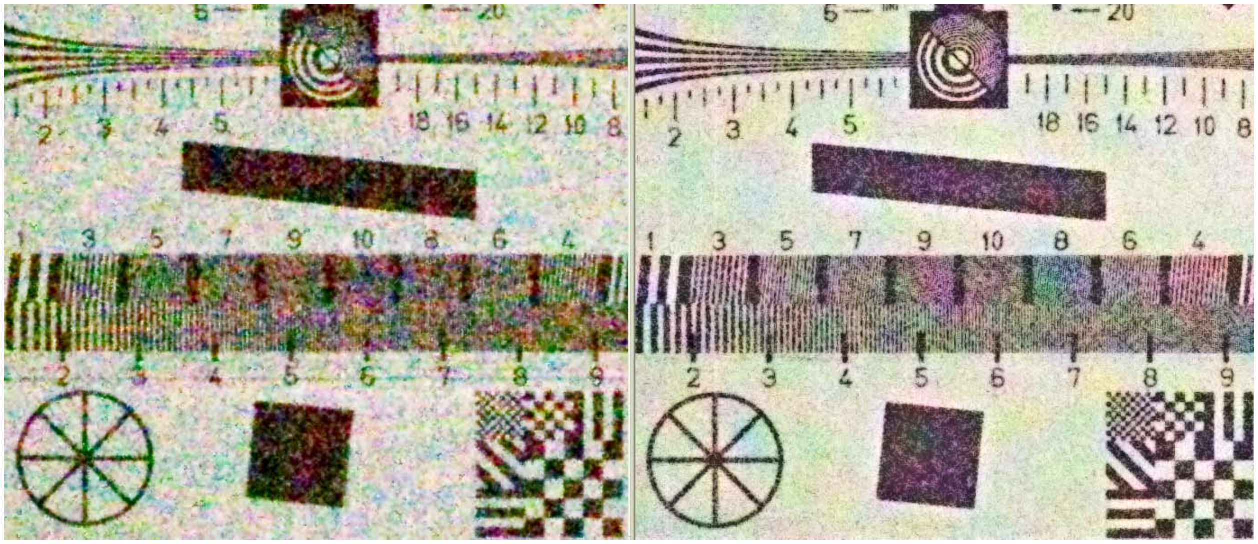

Figure 9. Bayer CFA with Strong Noise Cleaning (Left), Sparse CFA with Strong Noise Cleaning (Right)

The images in Figure 10 are a comparison of the Bayer green data and the Sparse CFA panchromatic data for a capture at approximately 3 lux. The Bayer green data was processed with the same interpolation method as that of the Sparse CFA panchromatic data. The resulting monochrome images show the spatial information that is available in each. The improved sensitivity of the pan pixels retains much more detail at low light levels. The images in Figure 11 are the fully color-processed images of the capture taken at approximately 3 lux.

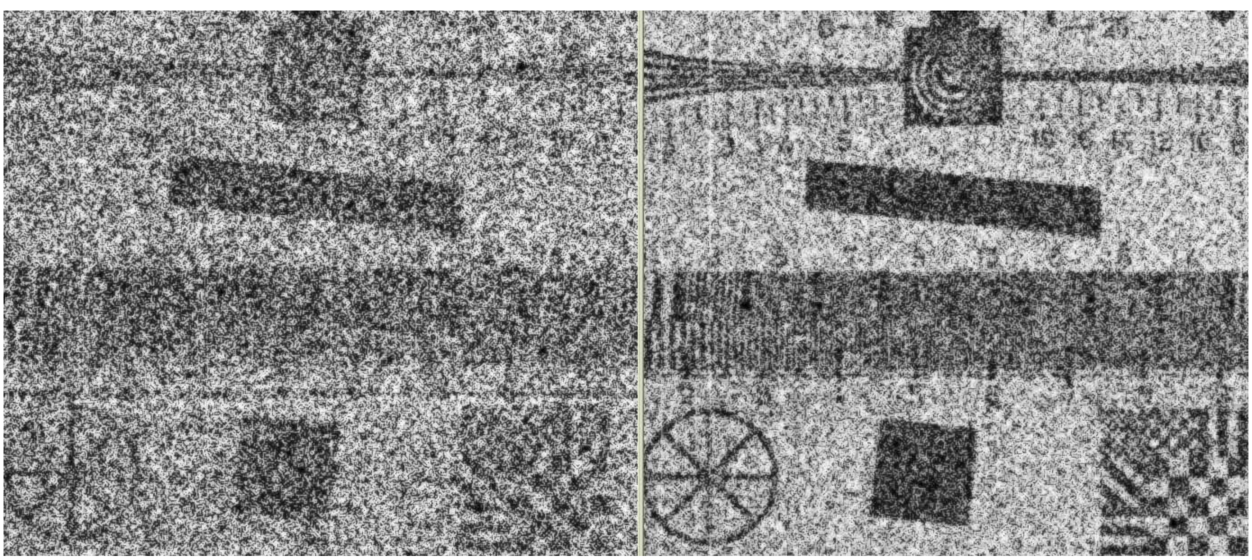

Figure 10. Interpolated Green of Bayer CFA (Left), Interpolated Green of Sparse CFA (Right)

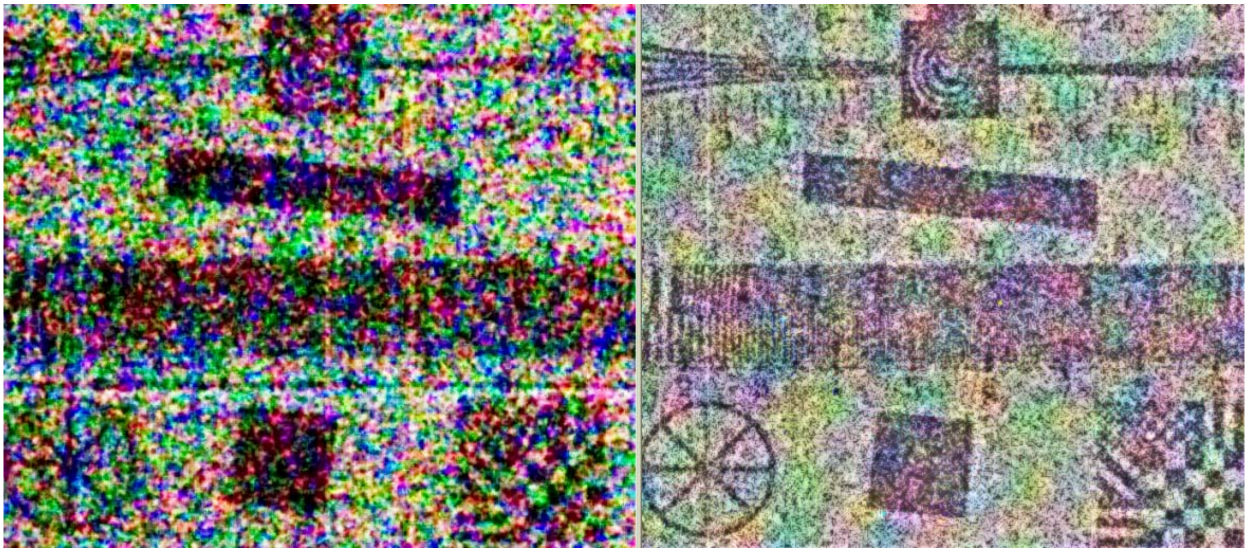

Figure 11. Bayer CFA 3 lux (Left), Sparse CFA 3 lux (Right)

Spatial Performance

A standard resolution chart (Figure 12) was captured and various sections were cropped to analyze image performance between the Sparse CFA and Bayer CFA with respect to spatial frequency. For the image height of 1080 pixels, the expected performance of the device is about 540 line pairs per image height.

There are two typical patterns of color aliasing seen in digital imaging: yellow-cyan and magenta-green. Yellow-cyan aliasing pattern occurs when the green channel is properly sampling the image, but the red and blue are not. Magenta-green aliasing pattern happens when all three channels alias. For the Bayer CFA image, the yellow-cyan pattern is typically more noticeable. For the Sparse CFA image, the magenta-green pattern is typically more noticeable. The color aliasing in the Sparse CFA image occurs at different frequencies than the color aliasing in the Bayer CFA image.

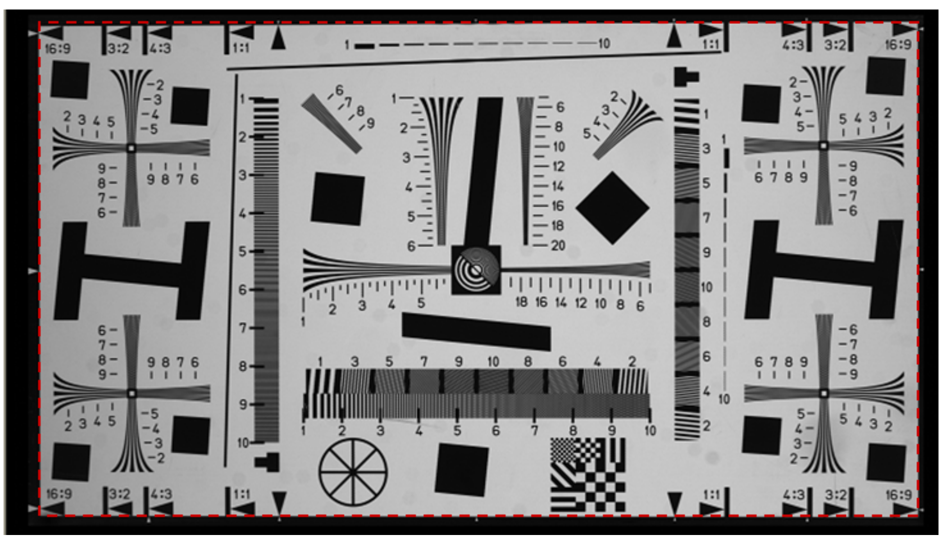

Figure 12. Resolution Target

Figure 13 shows the raw data for the KAI−02150 using a Bayer CFA and a Sparse CFA. The expected resolution is 540 lp/ph. The spatial performance of the raw data of both devices is similar, and both match the expected performance of the system. The Sparse CFA image appears darker because the red, green and blue pixels are less sensitive to light than the pan pixels.

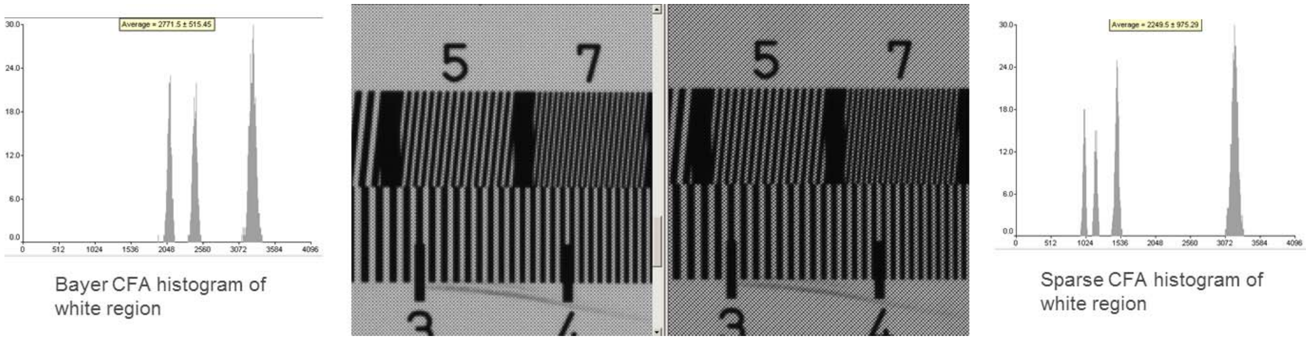

Figure 13. Raw Data Bayer CFA (Left), Sparse CFA (Right)

The images in Figure 14 were processed using standard interpolation methods for each CFA with no noise cleaning. The Processed Bayer CFA image does show a slight reversal (bending) of the lines in the 500 lp/ph target which is indicative of aliasing. The processed Sparse CFA image has different color aliasing at 500 lp/ph than the processed Bayer CFA image.

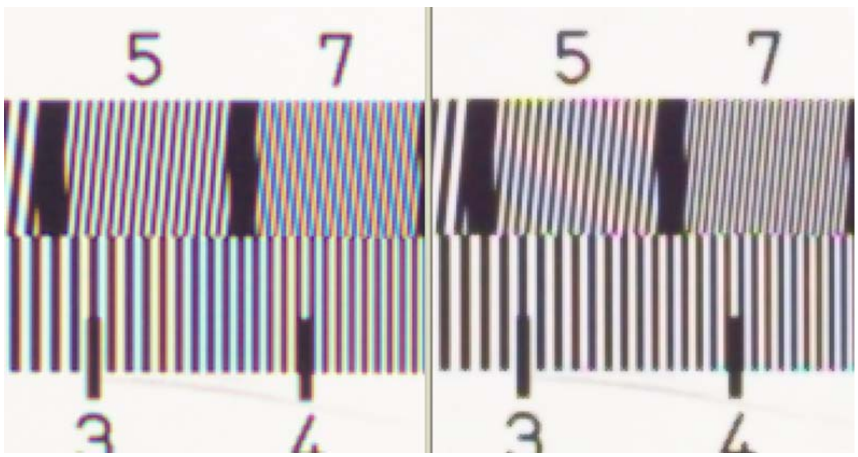

Figure 14. Color Processed Bayer CFA (Left), Sparse CFA (Right)

The color aliasing shows primarily as a magenta-green transition for the Sparse CFA. Simple nearest neighbor processing can be used to reduce the color aliasing (Figure 15).

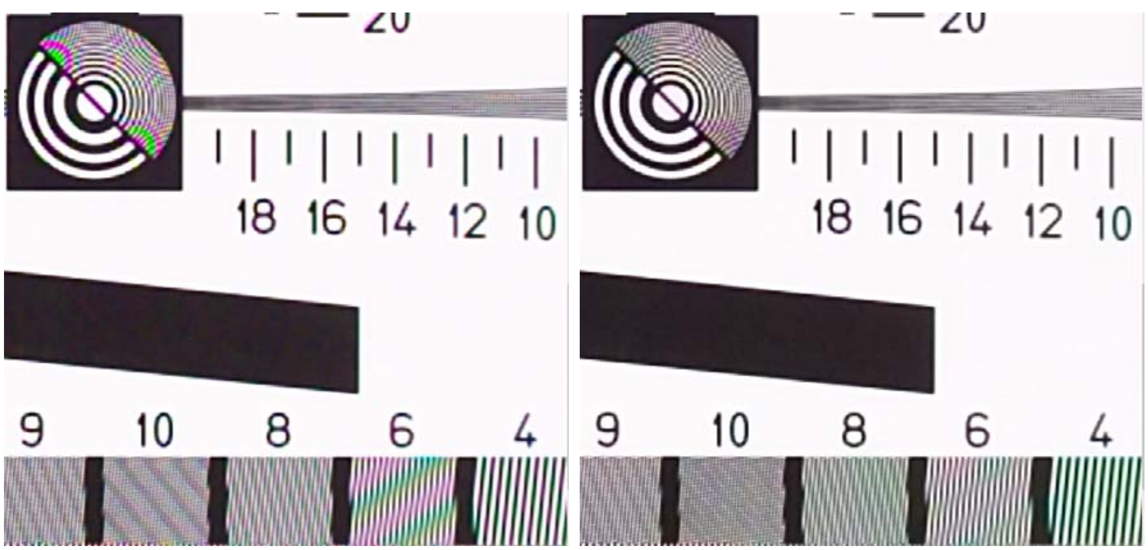

Figure 15. Color Processed Sparse CFA (Left), Sparse CFA (Right) with Reduced Color Aliasing

ADDITIONAL OPPORTUNITIES

The Sparse CFA pattern has 4 data channels. These channels can be leveraged beyond the typical RGB image output with an improvement in sensitivity.

Wider Dynamic Range

The panchromatic channel and the color channels have a 1-stop shift in sensitivity with each other. With careful attention to exposure, this shift in sensitivity can be exploited to produce an image with a wider dynamic range than either would have had on its own. Typically, exposure is set to the optimum performance for the panchromatic pixels. However, if the exposure is set to the color channels, and the panchromatic channel is allowed to clip in the highlights, the color channels (at a lower resolution) will still have useful data in the highlights to produce a full color image. The corresponding Bayer CFA at the same exposure for the green pixels, would result in clipped color pixels in the highlights (Figure 16).

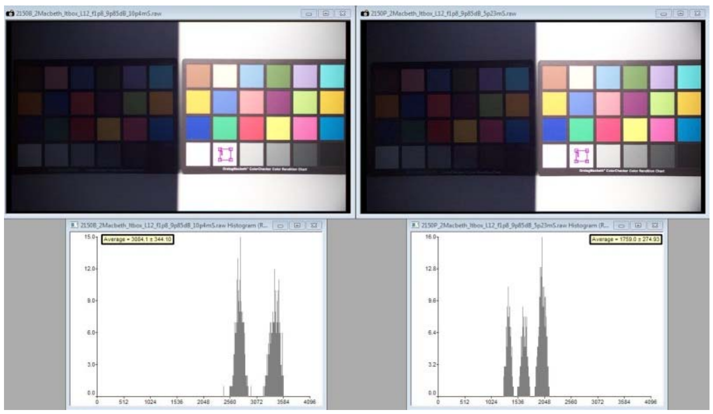

Figure 16. Bayer CFA with Green Pixels Clipped (Left), Sparse CFA with Panchromatic Pixels Clipped (Right)

Both captures can be digitally scaled to produce a more appropriate exposure. However, since the Bayer CFA green pixels are clipped in the highlights, the highlights do not have the correct color information and are pink in Figure 17 while the highlights are the correct color for the Sparse CFA image.

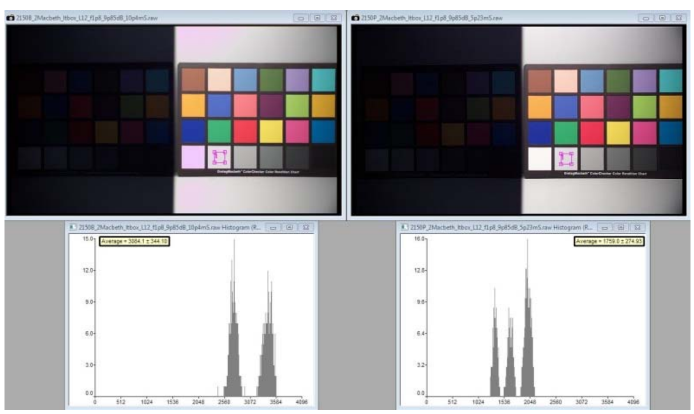

Figure 17. Bayer CFA (Left),Sparse CFA (Right) Both Digitally Scaled for Proper Exposure

Additional processing would be required to merge the data to an optimized wide dynamic range image. Figure 18 shows a simulation of tone mapping independently for the underexposed region and the overexposed region.

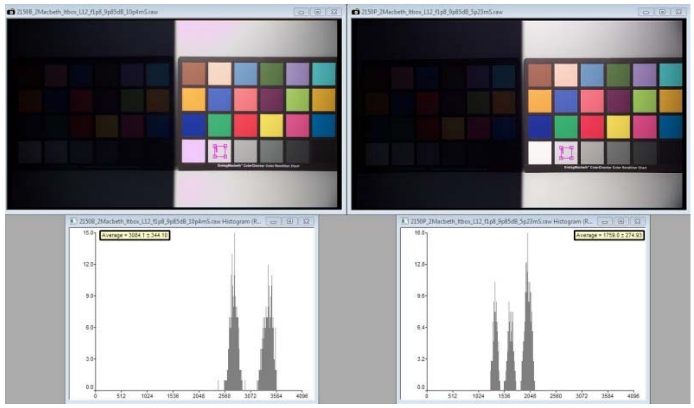

Figure 18. Bayer CFA (Left),Sparse CFA (right). Simulation of Independent Tone Mapping for Underexposed and Overexposed Regions

Near IR

The four data channels in the Sparse CFA pattern can also be exploited to use the near IR region (about 650−850 nm.) This is accomplished by exposing the panchromatic pixels to both visible and near IR illumination while restricting the color pixels to only visible illumination. The panchromatic pixels provide the luminance information while the color pixels provide the color information. The concept can be clearly demonstrated by capturing two images using the Sparse CFA with and without an IR-cut filter. The data can then be merged to produce a composite image with IR-sensitive panchromatic pixels and non-IR sensitive color pixels as shown in Figure 19 and Figure 20.

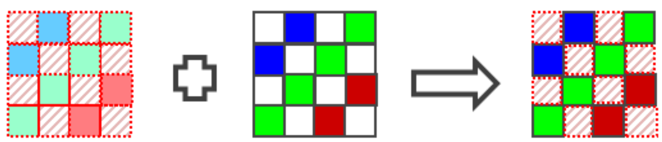

Figure 19. The diagram on the left represents a Sparse CFA Imager without an IR-cut filter while the diagram in the middle represents a Sparse CFA imager with an IR-cut filter. The panchromatic pixels with no IR cut are represented by the squares with the red diagonal lines. The resultant image is represented by the diagram on the right composed of panchromatic pixels from the capture with no IR cut and the color pixels from the capture with an IR cut.

The composite image can be processed through standard Sparse CFA image processing to produce a visible image of the scene with good color accuracy. Depending on the light source, there may also be as much as a 2× increase in sensitivity for the panchromatic pixels without the IR cut as compared to panchromatic pixels with the IR cut.

Figure 20. No IR-cut (Left), Normal Capture (Middle), Composite (Right)

The composite image above can be further processed to produce an IR-only image. Figure 21 shows the basic processing needed to compute the IR-only image. The Full IR only image and the RGB image are then used to create the NRG image. Techniques for computing the false color image (NRG – Near IR Red Green) or making an NDVI image (Normalized Difference Vegetation Index) are readily available[2].

[2] See http://publiclaboratory.org/tool/near−infrared−camera

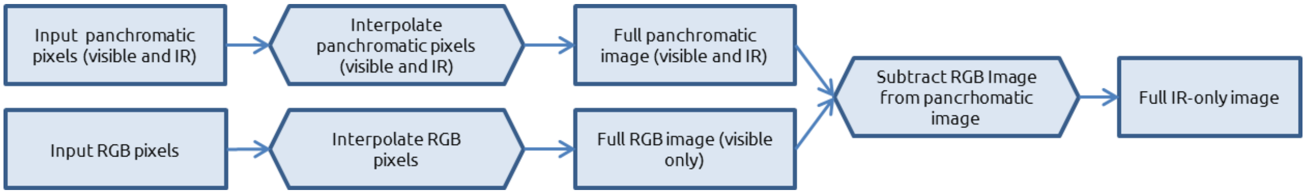

Figure 21. Steps for Creating a Full IR-only Image from a Sparse CFA

Infrared photography is used to monitor vegetation health and detect camouflage (camouflage does not reflect the near-IR like vegetation does and therefore becomes quite visible.) The right image in Figure 22 shows that the healthy vegetation is bright red in the false color image because plants reflect near IR light. Also, note the camouflage material hanging on the tree limb behind the post. It is not detectable in the normal capture (with IR cut) but very visible in the other images. The camouflage material does not reflect near IR light like the vegetation.

Figure 22. Normal Capture (Left), Visible+IR (Red Channel) Capture (Middle) and False Color Image to Show Vegetation Health (Right).

SPARSE CFA PROCESSING CODE SUPPORT

ON Semiconductor provides several avenues of support for the Sparse Color Filter Pattern. The first is Sensor Studio software, which is available from the ON Semiconductor web site and can process the Sparse CFA pattern and provide a RGB image. This allows users to process a raw Sparse CFA file with a known algorithm. The second form of support is C++ source code that can be compiled into an executable implementing the Sensor Studio Sparse CFA algorithm.

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