

# RGBC-IR: A CFA for IR Assisted Color Imaging

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## Abstract

Modern RGB-IR cameras have evolved to capture accurate colors and infrared from a image single sensor. While these cameras can employ their RGB images to effectively denoise IR, they contain too few IR pixels to do the reverse: denoise RGB with IR.

Improving low light RGB with an IR illuminator is an important feature for upcoming automotive applications where cabins have to be kept dark at night so as not to distract the driver. Current solutions to this problem either discard the IR cut filter, take separate RGB and IR exposures and suffer from poor colors in the process. Or employ a bulky beam splitter architecture with separate RGB and IR sensors.

We propose a camera with a novel RGBC-IR color filter array containing clear pixels that are sensitive to both visible light and IR. Its RGB pixels feature an IR attenuating coating while its IR pixels contain a black filter that blocks visible light.

Multispectral demosaicking techniques are used to reconstruct RGB and IR images, as well as a high SNR luminance image containing the Clear, RGB and IR signals. Fusion techniques developed for RGBC image sensors and beam splitter RGB-IR cameras are used to denoise RGB and IR using the luminance.

## Introduction

RGB-IR cameras that capture IR in addition to color images have many applications such as driver and occupant monitoring systems, and video conferencing. Some early designs featured a beam splitter feeding separate IR and color sensors. For low light color imaging applications, assisted with IR illumination, this was followed by a fusion step to denoise the RGB with the IR [1, 2, 3, 4]. Other early designs for low light IR assisted color imaging dispensed with the IR cut filter and used multiple exposures on a single sensor synchronized with an IR illuminator [5]. In addition to motion artifacts, this design also suffered from poor colors if the visible illuminant also contained IR.

Newer designs based on single sensor RGB-IR have made rapid progress [6, 7] and can now capture usable image quality for most applications with the notable exception of low light imaging. RGB-IR image sensors typically feature a dual bandpass IR filter that passes a narrow band around 940 nm in addition to the visible spectrum. IR pixels are covered with a black filter that blocks the visible spectrum. Black, red, green and blue filters are transparent to IR as is the norm for organic dyes and pigments. This results in the contamination of R, G, B signals with IR, which is subtracted out in the color correction step of the pipeline following demosaicking.

While subtraction fixes the color, it adds the noise of the IR channel to R, G, B. Since photon shot noise increases with intensity, IR illumination of low light scenes adds too much noise to R,

G, B to be useful. IR block coating and interference filters have been developed [8], but using them on R, G, B pixels blocks too much IR for the IR illuminator to provide sufficient noise benefit. What is needed is a CFA that is sufficiently transparent to IR for IR illumination to be useful, but also prevents IR contamination by blocking IR on R, G, B pixels.

In the subsequent sections we describe a single sensor imager that can capture both RGB and IR with good color accuracy. The imager performs well even if the visible and the IR illuminants are of very different intensities. Furthermore, the imager is able to leverage the brighter illuminant to denoise the image with the dimmer illuminant.

## The RGBC-IR CFA

We devise a CFA with 5 types of pixels:

1. Clear pixels, without color filter, that admit all visible and IR light
2. IR pixels with black filter that blocks visible light but admits IR [8]
3. R, G, B pixels with red, green and blue color filters respectively and also an IR block coating [8]. This coating blocks 95% of the IR while the remaining 5% is removed in the color correction step.

The CFA pattern is designed in conjunction with the demosaicking algorithm. We assign half the pixels, in a quincunx pattern, to the clear channel with the understanding that a high SNR guide image will be reconstructed from it. The remaining colors, IR, R, G, B, are assigned to uniform sub-lattices of the CFA, either individually or in pairs to enable binning. The two resulting CFA patterns are shown in figure 1.

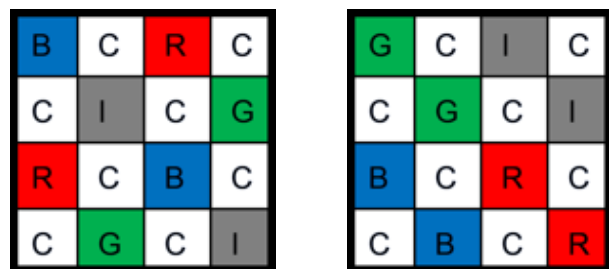


Figure 1: Proposed non-binnable RGBC-IR CFA (left), and 2:1 binnable RGBC-IR CFA (right).

## Processing Pipeline

The RGBC-IR pipeline is outlined in figure 2. Demosaicking consists of first reconstructing the clear color plane and then

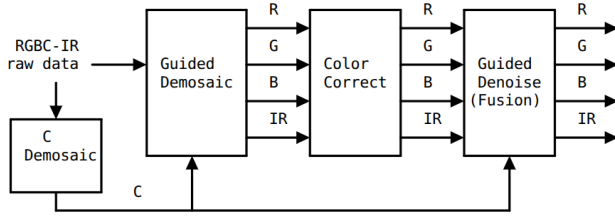


Figure 2: RGBC-IR Processing pipeline

using it as a guide image to reconstruct the R, G, B and IR color planes. High PSNR is achieved by public domain multispectral demosaicking algorithms such as [9], while good visual quality is achieved by commercial algorithms originally developed for RGBC [10].

The color correction step includes the removal of IR that leaks into RGB past the IR blocking filter and also the correction of crosstalk between RGB and IR. Next RGB is white balanced and a standard 3x3 color correction matrix is applied to it.

The SNR of R, G, B, IR, which are lower than that of C, is further lowered by the color correction step. R, G, B, IR color planes are then cleaned by a guided denoising/fusion step. High PSNR is achieved by adapting public domain algorithms developed for beam splitter cameras such as [3], while good visual quality is achieved by commercial algorithms originally developed for RGBC [10].

## Experiments

We conduct simulation studies of the non-binnable RGBC-IR pattern shown in figure 1. Starting with a raw image captured by a RGBC image sensor, we demosaic it, simulate the IR channel as a nonlinear function of the R, G, B color planes followed by remosaicking with the RGBC-IR CFA.

We add 5% of IR to the R, G and B channels to simulate IR leakage through the IR block coating and another 5% to simulate the crosstalk between the IR and R, G, B pixels.

Finally we add simulated read noise and shot noise of the popular ST Micro Sibuya RGB-IR sensor. We simulate the read noise as a Gaussian random variable with a mean of 4.9 electrons and photon shot noise as a Poissonian with conversion gain 0.16 quantization steps of a 10 bit value range per electron.

We simulate two levels of IR, one with IR strength at 1 typical of LED illumination, and the other with added IR illumination that creates a IR response in the sensor that is 6.6 times as strong as its G response, on average. The results are shown in figure 3.

## Conclusion

The IR illumination improves the luminance SNR by 20 db. Chrominance quality is largely unchanged on balance. On the one hand removal of IR from R, G, B increases chroma noise, but on the other hand the improved SNR of luminance makes chroma denoising more effective by clearly delineating edges and thus preventing the averaging of pixels across edges.

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## Author Biography

Tripurari Singh received his his PhD in Computer Science from the Johns Hopkins University (1999) and his Bachelors in Computer Science from the Indian Institute of Technology, Delhi, (1993). Thereafter he worked in the Operations Research industry, developing stochastic optimization algorithms, before switching to image processing. His work has focused on CFA design and the processing of raw sensor data in the presence of white/clear pixels, infrared pixels, chromatic aberration, multiple rounds of pixel binning and high chrominance resolution.

Mritunjay Singh has a background in Physics from Caltech and the Indian Institute of Technology, Mumbai. Thereafter he worked in the Operations Research industry, developing stochastic optimization algorithms, before switching to image processing. His work has focused on CFA design and the processing of raw sensor data in the presence of white/clear pixels, infrared pixels, chromatic aberration, multiple rounds of pixel binning and high chrominance resolution.



Figure 3: A crop of the “TE42” chart in low D65 light captured by the proposed RGBC-IR image sensor demonstrates the benefit of IR illumination. IR illuminator off (left) and IR illuminator on (right).