

# A Novel Hexagonal Photosite Grid

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## Abstract

Digital imaging has long been dominated by the use of square-grid photodiode arrays overlaid with a Bayer Color Filter Array (CFA). While this configuration has proven effective, it possesses inherent limitations in quantum efficiency, color fidelity, and effective spatial resolution due to light loss from trench/walls and the need for inefficient demosaicing algorithms. This paper introduces a novel sensor architecture featuring a hexagonal honeycomb grid of photodiodes with a corresponding red, green, and blue color filter pattern. We present a theoretical analysis demonstrating the advantages of this hexagonal geometry. Our findings indicate that the hexagonal array offers superior packing density, leading to a higher area to perimeter ratio and a theoretical increase in light sensitivity. Furthermore, the sampling lattice of a hexagonal grid provides a more isotropic response and improved angular resolution under demosaicing, which results in more accurate color interpolation and a significant reduction in aliasing artifacts such as color moiré. We project that this architecture can achieve a higher modulation transfer function (MTF) for a given photodiode count compared to traditional Bayer sensors, ultimately leading to images with superior detail and color rendition, particularly in photon-limited conditions, as well as a higher effective dynamic range due to an increased neighborhood availability of red and blue color inputs versus a bayer sensor.

## 1. Introduction

The modern digital camera sensor is a marvel of engineering, yet its fundamental design has remained largely unchanged for decades. The vast majority of sensors rely on a rectangular grid of photosites, each made sensitive to a single color (typically red, green, or blue) by a Color Filter Array (CFA). The most ubiquitous CFA is the Bayer pattern, which specifies a 2x2 mosaic of one red, one blue, and two green filters ([Bayer, 1976](#)). This design is effective but introduces a series of compromises.

Firstly, the square grid pattern often matches real world patterns of straight lines, creating a moire pattern at resolution matching the output image resolutions and necessitating either an anti-aliasing filter which blurs the input photons or a much higher input photosite count than resolution intended for output, which increases the data rate needed to be processed and stored.

Secondly as three color samples of red, green, and blue are needed for each output pixel interpolation must happen between photosites in a demosaicing process([Palum, 2001](#)).

However a “map coloring” of three colors onto a square grid creates an impossible ideal of

the three colors not touching while maintaining equal sampling, necessitating that one color be more represented than the others.

To overcome these limitations, we propose a departure from the traditional rectilinear grid. This paper investigates the theoretical benefits of a sensor architecture based on a hexagonal (honeycomb) photosite array.

## **2. Materials and Methods**

### **2.1. Hexagonal Array Geometry and Perimeter**

The proposed sensor model consists of a photodiode array where the centers of the photosites are arranged on a hexagonal lattice. The perimeter for a given hexagon of side length 1 is 6, while the equivalent perimeter of a given square of the same area is 6.444. Given interaction with walls designed to isolate pixel contributions from one another is non ideal ([Tournier et al.](#)) a smaller ratio of perimeter to area gives a more efficient (less perimeter per area) ratio. This means in a given hexagonal photosite grid photons will interact less with isolation walls/trenches than with a given square photosite grid of the exact same area/resolution, as given above.

### **2.2. Color Filter Array Configuration**

A corresponding RGB (or otherwise) color filter array is applied to the hexagonal grid. Various patterns are possible, the most notable (fig 1) is that a map coloring with three different colors, red, green, and blue filters, are possible to distribute equally and nontouching unlike with a square grid. However double green, one red, one blue colorings of hexagonal tilings are also possible such that a projected square pixel of equal hex to square area (black squares) may encompass all three colors in nigh any given position (fig 2). The key difference between a square and hex grid lies in the connectivity; each photosite in a hexagonal grid has six equidistant nearest neighbors, compared to the four in a square grid, providing a richer dataset for color interpolation.

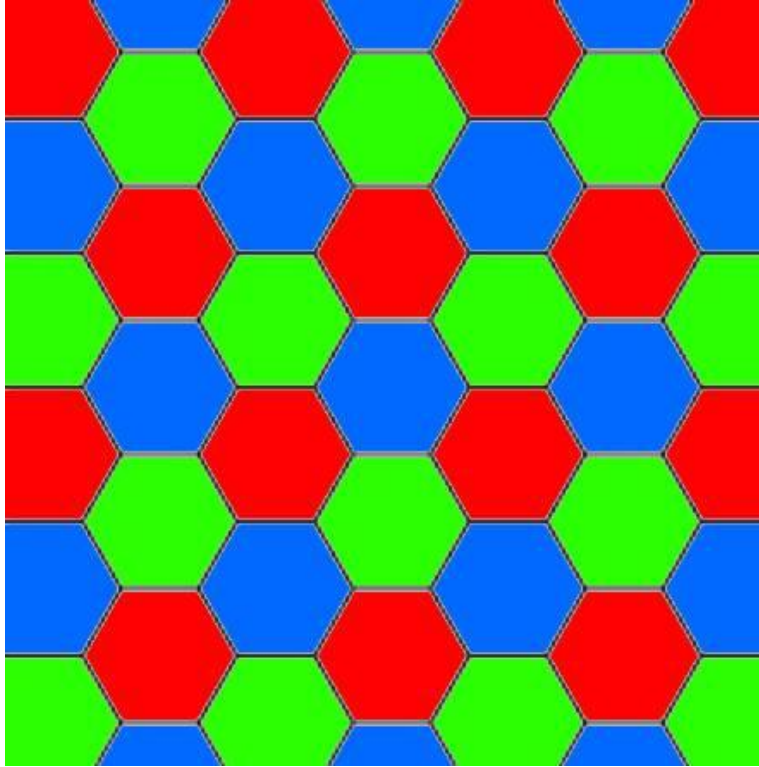


Fig 1

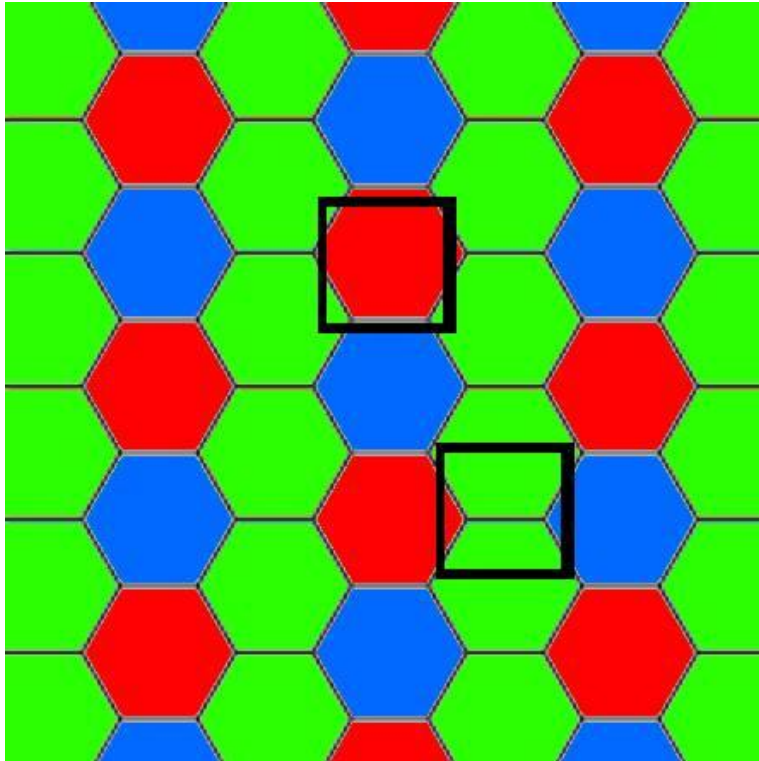


Fig 2

### 2.3. Demosaicing Estimation

Demosaicing is often carried out over a small areas for highly saturated photosites and larger areas for less saturated ones to compensate for signal to noise ratios. Over a small area a given demosaic, for a hex edge length of one, need only cover a length of 2 from barycenter in any given direction to cover all three colors (assuming no replacement). While a smallest possible bayer demosaic with all three colors must extend to an area of 2.2 (fig 3).

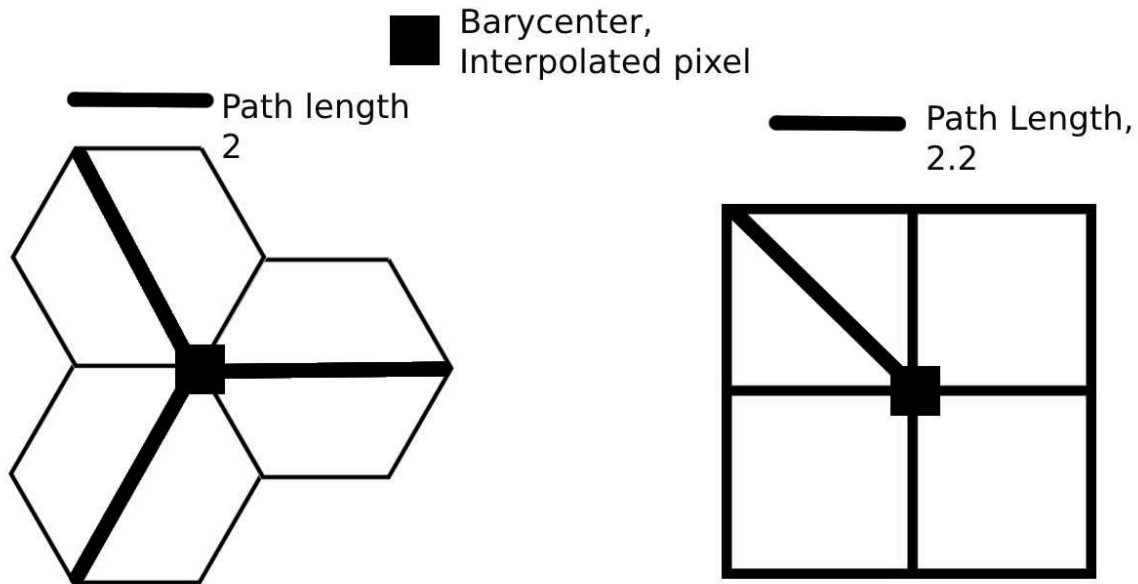


Fig 3

Over a larger given square area hexagonal grids tend to include more available interpolation photosites than a given square grid as well. EG given a hexagonal edge length of 1, then for a square bayer sensor, within a length of 3.22, barycenter to barycenter there will be 4 available blue photosites from a given blue photosite, 4 available red photosites from a red photosite, and 8 available green photosites from a given green photosite, totalling 16 possible same color interpolation candidates. However within a length of 3 an equal color distribution of a hex tiling there will be 6 of each color, totalling 18 possible interpolation candidates.

### 3. Projected Results

- **Dynamic Range:** Due to the higher replacement/interpolation candidate ratio compared to bayer filters it is expected signal to noise ratio areas may be better reconstructed with continued color accuracy compared to a bayer filter sensor

- **Color Fidelity:** With an equal tiling of red, green, and blue color filters possible it is expected that more equal color information will result in improved color fidelity, as compared in say a root mean square error comparison in a simulation, than a comparative bayer sensor.
- **Spatial Resolution:** With lower total length from interpolation barycenter to photosite edge possible with a hexagonal tiling higher spatial resolution is expected.

## 4. Discussion

The projected results strongly support the hypothesis that a hexagonal photosite array offers significant advantages over traditional square-grid sensors. The geometric efficiency of the honeycomb structure is the primary driver of these benefits. The improved packing of photosites directly addresses the critical issue of light loss in isolation trench equipped sensors.

Furthermore, the hexagonal grid's superior sampling properties lead to a more graceful and accurate demosaicing process. With six equidistant neighbors, the interpolation of color values is less prone to the errors that manifest as artifacts in Bayer sensors. This leads to an image that is not only cleaner but also retains more of the true spatial resolution captured by the photodiodes.

While the manufacturing of non-rectilinear semiconductor structures presents known challenges, advancements in photolithography make the production of hexagonal sensor arrays feasible. The computational overhead of a hexagonal-based processing pipeline is a consideration, but the potential for simplified and more accurate demosaicing algorithms using modern techniques such as machine learning make such things a non issue in the long run.

## 5. Conclusion

This paper has presented a theoretical framework for a novel digital image sensor based on a hexagonal photosite grid. Our analysis indicates that such a design can overcome many of the fundamental limitations of the long-standing Bayer filter paradigm. The projected improvements in light sensitivity, color accuracy, dynamic range, and effective spatial resolution represent a significant step forward in digital imaging technology. Future work will involve validating these results and exploration of further advancements

## 6. References

- [Color imaging array](#); Bayer; 1976
- [Image Sampling with the Bayer Color Filter Array](#); Palum, Russ; 2001;
- [Pixel-to-Pixel isolation by Deep Trench technology](#); Tournier, et al.;

