# A comparative analysis of panchromatic and Bayer pattern sensors for aerial survey applications

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*Abstract: This paper aims at a quantitative comparison of the sensors resolving capabilities as well as detailed description of their advantages and disadvantages for aerial survey applications. The sensor technology employed in contemporary aerial camera systems can be primarily classified into two categories: Panchromatic and Bayer pattern sensors. This categorization is applicable to sensors based on Charge-Coupled Device (CCD) and Complementary Metal Oxide Semiconductor (CMOS) based sensor technologies. While the practical work presented in this paper was carried out with CCD sensors, the received results are valid for CMOS based sensors as well. The resolution potential of the Bayer pattern and the panchromatic sensor was verified with the help of siemens stars projected on a high-resolution color calibrated monitor. This set up enables an effective solution to display siemens stars in multiple colors. The received images delivered results, which were suitable for visual inspection. Past theoretical studies indicate varying resolution losses compared to panchromatic sensors when the colors blue or red are used on the resolution targets. The rather sparse distribution of 25 percent of the blue and red pixels is the underlying technical reason for this degradation. These claims were investigated using the identical lens for both the panchromatic and Bayer pattern sensor. The quantization of the sensor's resolution was based on a visual interpretation and delineation of the minimum acceptable resolution.*

## 1 Introduction

The sensor technology employed in contemporary aerial camera systems can be primarily classified into two categories: Panchromatic and Bayer pattern sensors. This categorization is applicable to sensors based on Charge-Coupled Device (CCD) and Complementary Metal Oxide Semiconductor (CMOS) based sensor technologies. A significant constraint in the design of aerial camera systems is the limited size of the camera opening in the aircraft's fuselage. Standard sizes for these holes have been established, and gyroscopic mount manufacturers have adapted their products accordingly, resulting in a maximum useable diameter of approximately 40 cm. Therefore, optimizing the utilization of available space is imperative to maximize the productivity and quality of aerial camera systems. Recent years have shown a general trend in the camera industry to primarily utilize Bayer pattern sensors. For applications in an aerial environment, both panchromatic and Bayer pattern sensors have their respective advantages and disadvantages, which are impacting the quality of the derived data products such as digital surface models (DSM) and true Orthophoto. Therefore, the quality of analysis conducted on those data sets are also affected by the underlying sensor technology.

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# 2 Sensor Technologies

## 2.1 Bayer pattern sensors

Named after their inventor Bryce Bayer these sensors feature a Red-Green-Blue color filter array (CFA) on top of an single solid state panchromatic image sensor (BAYER 1976). Mimicing the physiology of the human eye, twice the number of green filters are used compared to the red and blue ones. Even though different CFA layouts have been used in recent years the Bayer configuration is still the dominant layout. Used on both CCD's and CMOS sensors, the resulting image consists of a grey scale mosaic pattern formed by the individual filter pixel combination. A full color image is generated by a demosaicing process that interpolates the missing color information (LUKAC et al. 2006). The quality of the resulting image is highly depended on the quality of the demosaicing algorithm. The main quality factors to consider in this context are sharpness, noise, and aliasing artefacts. Due to the improvments in demosaicing algorithms, sharpness and noise are usually on a good quality level. It has to be considered though, that the inherent limitations of the used CFA can not be fully compensated when comparing results between bayer pattern and panchromatic sensors. It is imperative to consider the propensity of the Color Filter Array (CFA) to introduce color artifacts, such as moiré, maze artifacts (Fig. 1). and zipper patterns (Fig. 2), during the demosaicing process. Moiré artifacts manifest when two finely repetitive patterns overlay, generating a new third pattern (artifact) in the resulting image. This kind of artifact emerges when a signal with an energy level above the Nyquist frequency (KOREN 2020) is being captured. In an aerial context, the initial pattern is the sensor's pixel grid, and the secondary pattern originates from the patterns on the ground such as corrugated iron roofs, generating a parallel repeating structure. Moiré patterns often show as colorful, undulating, or grid-like patterns that were not originally present in the scene. Maze patterns, conversely, arise when the interpolation algorithm used during de-Bayering struggles to accurately estimate missing color information. Several factors contribute to this, including image noise, the employed interpolation method, or fine details on the ground that approach the limit of what the sensor-lens combination can resolve. Software-based approaches to correct these issues invariably compromise image radiometry when attempting to correct these problems. Given the objective to produce radiometrically accurate imagery, such solutions are not suitable for remote sensing applications. It should also be noted that artifacts pose challenges for classification algorithms and other applications, including dense image matching approaches for DSM generation.

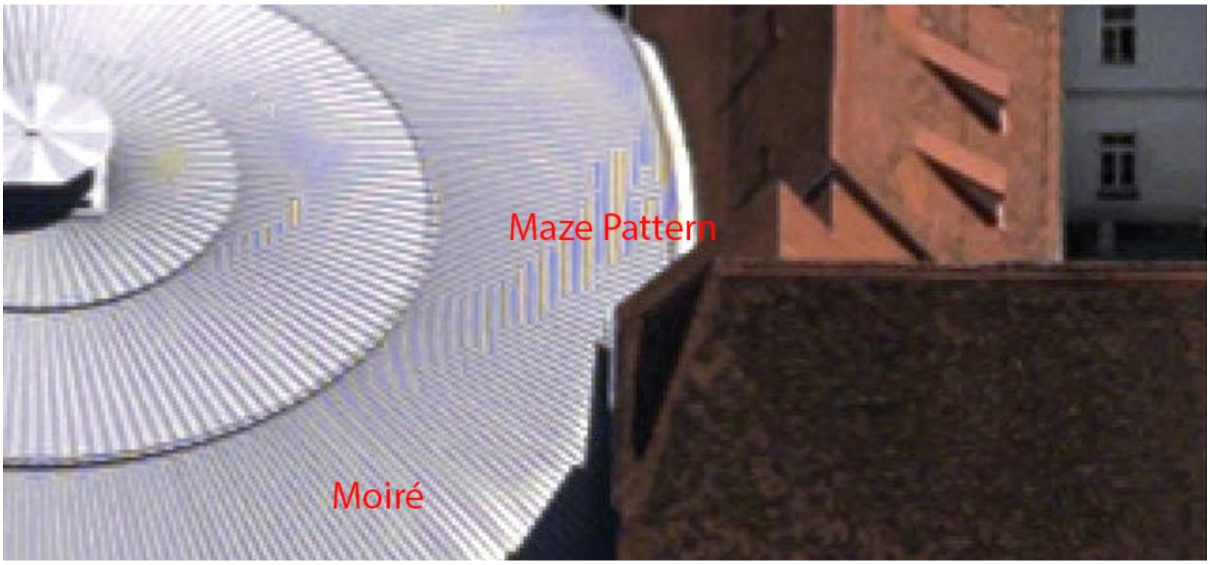



Fig. 1: Maze and Moirè artifacts on a single structure in an aerial oblique image

Fig. 2: Zipper artifacts on a vertical line (CHANG 2006)

### 2.2 Panchromatic sensors

For applications where highest resolving imagery was mandatory, the usage of panchromatic sensors have been the standard concept. The combination of high resolution panchromatic information with lower resolution multispectral information and combining them by means of pansharpening has been in use since decades. The lack of a CFA has two significant benefits. The first one is the higher amount of light in the magnitude of roughly one aperture step is available on pixel level. The second one is that no demosaicing hence no interpolation is necessary. Therefore, creating a higher resolving image compared to a Bayer pattern based image with the same pixel pitch, with a highly reduced magnitude of remaining artefacts.

## 3 Investigation and Methodology

Image analysis in the frequency domain using direct Fourier transformations to verify the impact of the CFA on image resolution was the starting point for this investigation (DUBOIS 2005), (ALLEYSSON et al. 2005). Literature indicates that the influence of a CFA on sharpness ranges from a loss of approximately 10 percent to as much as 50 percent, based on the resolution target's color.

We conducted an intensive examination of the sensor technology differences using a panchromatic CCD sensor and a Bayer pattern-based CCD sensor, both featuring a 5.2-micron pixel pitch and installed behind one and the same 40 mm lens.

The primary objective of the experiment was to employ a high-quality, color-calibrated 27-inch 4K monitor to display Siemens stars in the colors white (255/255/255), red (255/0/0), green (0/255/0), and blue (0/0/255). Given that the color of an object influences the resolution of a Bayer pattern-based image, this approach was chosen to generate accurately colored Siemens stars and quantify the image resolution loss. To verify the desired monitor output, we measured the emitted colors using a calibrated Avantes AVASPEC-ULS2048-USB2 spectrometer. The results of this control measurement are presented in figure 3. Despite the limited overlap between green and red, it still generates a sufficient response on the sensor.

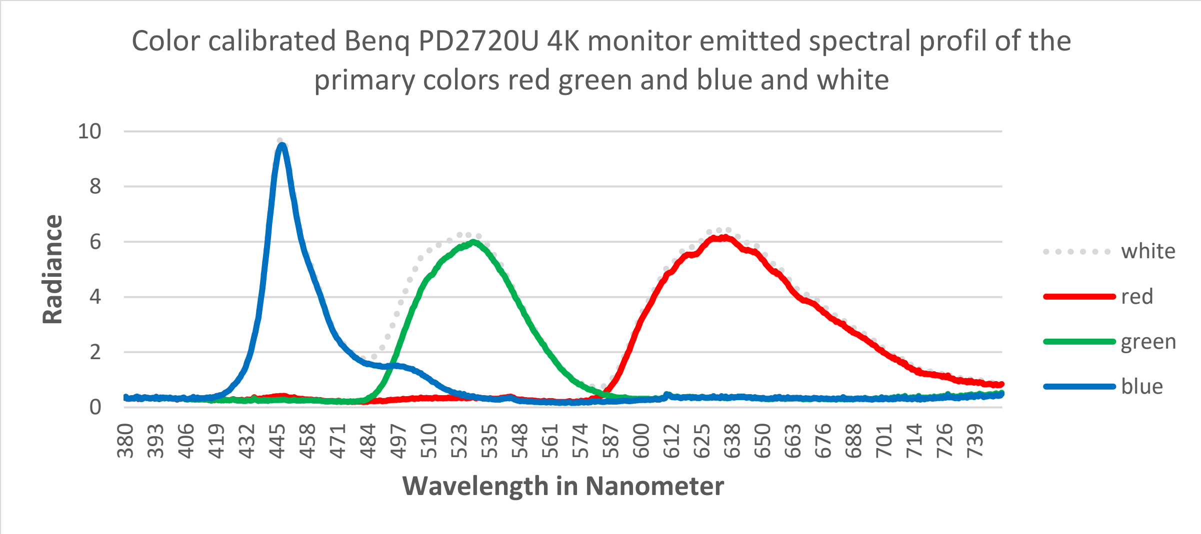



Fig. 3: Spectral profile of monitor emitted light

Based on the pixel size of 0.156 mm of the Benq PD2720U 4K monitor and the limitations of the office space, we selected a capture distance of 5310 mm, resulting in a Ground Sampling Distance (GSD) of 0.69 mm. This configuration yields a blur radius sufficiently large to facilitate clear interpretation. The blur radius denotes the area of the Siemens star that can no longer be resolved by the optical system, hence smaller radii are preferred. Careful alignment of the target and image plane was performed to ensure images of the resolution target free from angular distortions for both the Bayer pattern and panchromatic images. Furthermore, the monitor was positioned in the center of the image frame, to avoid any unwanted optical influences. Figure 4 displays the central portion of the image where the monitor was positioned, with the framed center part of the Siemens star serving as the crop for a more detailed visual inspection.

Fig. 4: Siemens star and selected center part

# 4 Results

## 4.1 Visual interpretation

To facilitate the attainment of quantitative outcomes during the comparative analysis, the determination of the blur radius will be conducted through thorough manual delineation.

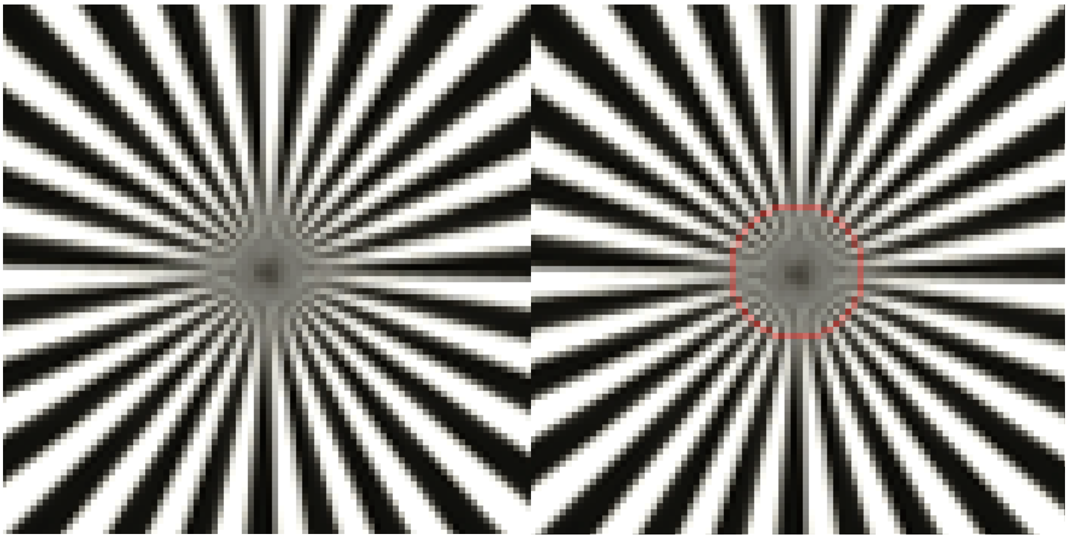
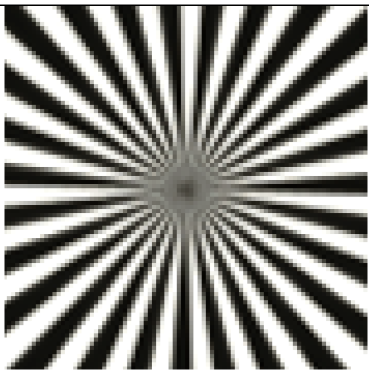
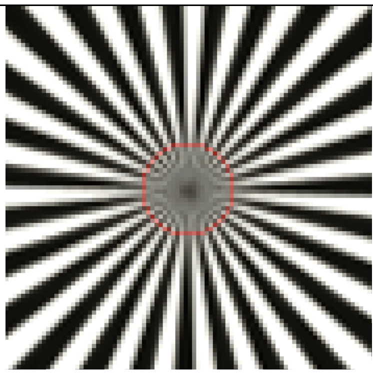
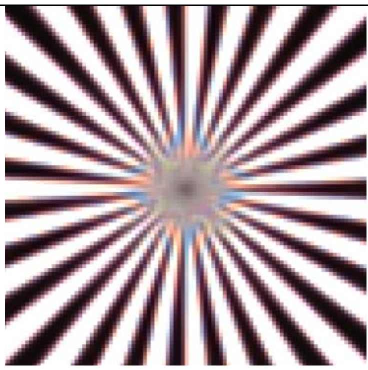
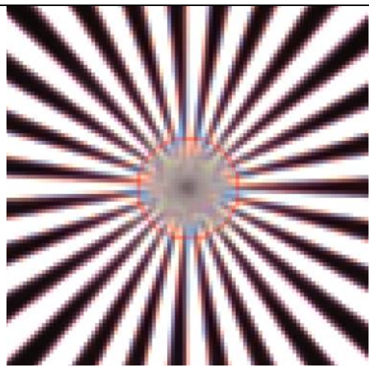
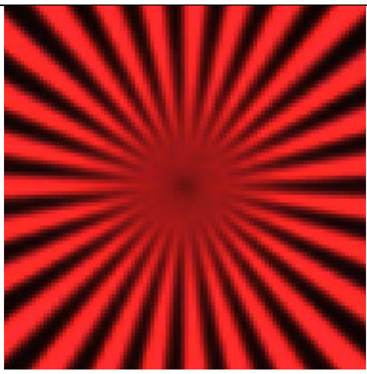
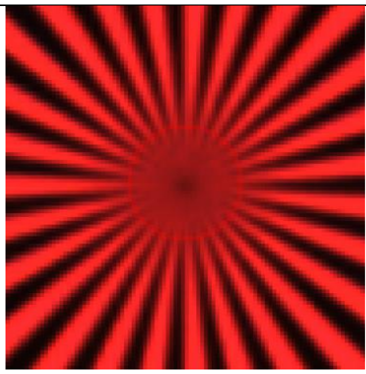
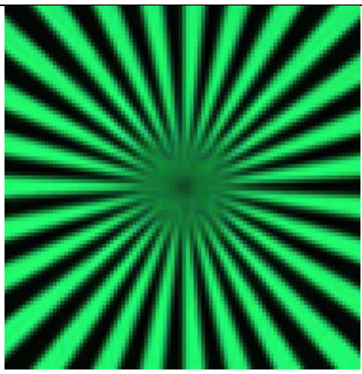
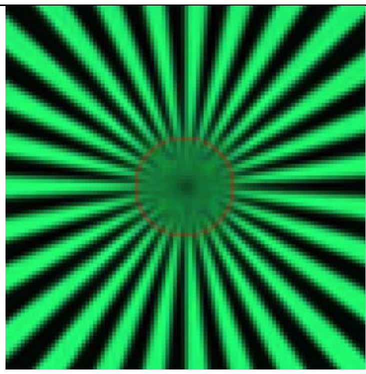
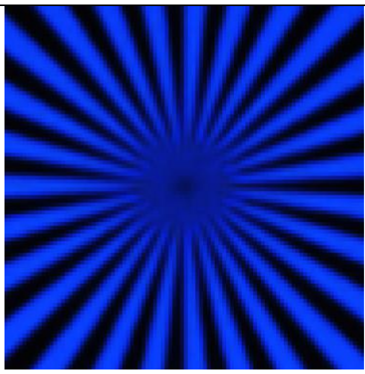
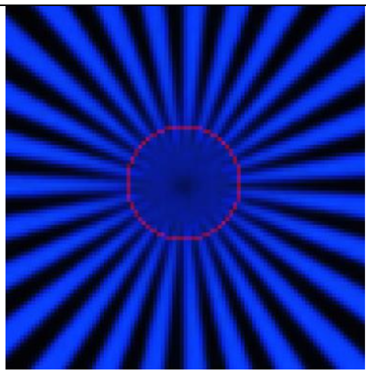


Fig. 5: Blur radius for the panchromatic sensor on a white siemens star, blur radius of 11 pixel

This procedure is repeated for all captured Siemens star patterns.

| | Stars | Stars with blur radius | Blur radius in pixel |
|---|---|---|---|
| Panchromatic Target White |  |  | 11 |
| Bayer Pattern Sensor Target White |  |  | 13 |

| | | | |
|---|---|---|---|
| Bayer Pattern Sensor<br>Target Red |  |  | 14 |
| Bayer Pattern Sensor<br>Target Green |  |  | 13 |
| Bayer Pattern Sensor<br>Target Blue |  |  | 14 |

Tab 1: 40 mm Resolution results

Using the derived blur radii, the differences in resolving power relative to the panchromatic sensor, which, unsurprisingly, exhibits superior performance, can be expressed. Furthermore, it is clearly visible that the different number of green pixels versus blue and red ones of the CFA leads to serious aliasing on the white Siemens star pattern, which has to be expected based on the papers from DUBOIS 2005, and ALLEYSSON et al. 2005. Comparisons with different demosaicing algorithms showed that Vexcel Imaging's algorithm is comparable with other high-quality algorithms such as Aliasing Minimization and Zipper Elimination (AMaZE) or Minimized-Laplacian Residual Interpolation (MLRI) (KIKU 2014).

| | | blur radius in px | in percent | delta to 100% |
|---|---|---|---|---|
| pan | all | 11 | 100 | 0 |
| bayer | white | 13 | 84.6 | 15.4 |
| | red | 14 | 78.6 | 21.4 |
| | green | 13 | 84.6 | 15.4 |
| | blue | 14 | 78.6 | 21.4 |

Tab 2: Resolution results

# 5 Practical implications

In aerial survey applications, the ability to fully resolve all details is paramount. This capability is also crucial when considering photogrammetric workflows and derived products like orthophotos, digital surface models (DSM), and 3D modeling. Before delving into the practical implications, it makes sense to briefly discuss two terms which are sometimes used interchangeably:

• Ground Sampling Distance (GSD)

• Resolution

Ground Sampling Distance precisely delineates the distance between two successive pixel centers on the ground, constituting a purely geometric parameter.

Resolution on the other hand describes the ability of an imaging system to resolve detail from the object that is being imaged. Increased resolution translates to finer details being discernible in the imagery. For instance, while a lower-resolution imaging system might depict a parking area made of concrete as a uniform surface, capturing the same area at the same GSD with a high-resolution imaging system could reveal it to be composed of paving stones. Failure to resolve the fine structures between these stones results in a homogenous looking surface.

Hence, the minimum 15 percent difference in table 2 implies that if the tested Bayer pattern sensor were employed to create imagery at a 5 cm GSD, the panchromatic sensor at the same GSD would provide a level of resolution that the Bayer pattern sensor with the same lens could only attain at a GSD of 4.23 cm. Consequently, end-users of a panchromatic-based dataset gain access to superior resolution. For the practical application, it could be argued that these distinctions should be considered to establish equitable conditions. This would enable users of panchromatic-based sensors to operate the camera system at least 15% higher and subsequently up sample the results to match the Bayer pattern equivalent GSD. In terms of efficiency, this translates directly to a 15% advantage.

# 6 Conclusion

In contexts where optimal image and data quality remain critical considerations, the panchromatic-based sensor design is still considered to be the premium standard. However, it is noteworthy that there are fundamental scenarios existing where the adoption of a more cost-effective and spatially efficient Bayer pattern sensor configuration possesses inherent merits. This is particularly evident in camera systems characterized by oblique cones, where spatial constraints necessitate the pragmatic adoption of Bayer pattern sensors as an acceptable and feasible solution.

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