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# Image Quality Improvement by Dynamically Correcting Maze Noise Pixels in CMOS mobile Image Sensor

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## Abstract

*In the past, high resolution was the trend in the mobile image sensor. Currently, smartphones equipped with 200 million pixel sensor. Recently, efforts have been made to increase profits through miniaturization of pixel size and reduction of chip size by increasing production. The smaller the pixel size, less light is received, with increases noise and deteriorates the image quality. Smartphone manufacturers request specialized features. Therefore, sensor development organization focuses on increasing profits and installing sensors with additional functions such as high sensitivity, high dynamic range, including autofocus pixel. Such efforts do not only bring good results in terms of image quality of the sensor. Inevitably, side effects occur. One of them is maze noise.*

*In this paper, we introduce the image quality performance improved through digital processing of maze noise in CMOS mobile image sensor.*

## Introduction

In general, CMOS mobile image sensors are basically equipped with a Bayer pattern. The Bayer pattern consists of one R, one B and two G pixels [1]. For distinction, the G pixel next to the R pixel is called Gr pixel, and the G pixel next to the B pixel is called the Gb pixel as shown Figure 1.

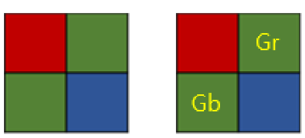


*Figure 1. Bayer Pattern for Sensor*

In flat image, the code values of the two G pixels must be the same. In reality, they are often not same [2]. If the difference in code values is large, maze noise appears in the final Application Processor's Image Signal Processor processed JPG image, as shown in Figure 2 and 3.

*Figure 2. (a) Normal Image (b) Maze Noise Image*

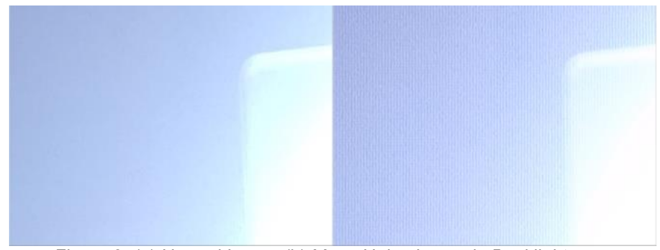

*Figure 3. (a) Normal Image (b) Maze Noise Image in Backlight*

There are various reasons for code difference to occur. Among them, the code difference caused by signal interference between adjacent pixels when light is incident obliquely due to the influence of micro lenses and color filters is called crosstalk [3]. This can be controlled to an appropriate level by improving design and manufacturing process technologies [4]. However as pixel sizes decrease, crosstalk becomes more sensitive to even small changes. Some Gr and Gb pixels have different shapes. These pixel designs are intentionally created to reflect customer requirements. Asymmetry in the pixel structure also causes code differences. Various micro lenses and color filters are utilized to increase sensitivity. These factors contribute to code differences. This sensor development environment provides conditions favorable for the occurrence of Maze Noise.

## Proposed approach

This study proposes a dynamic correction algorithm that distinguishes between areas where Maze Noise is noticeable and areas where it is not, and perform correction. In order to improve the image quality performance of the image sensor, as shown in figure 4, we considered a method to reduce the Maze Noise by digitally correcting Gr and Gb signals before processing the raw file obtained from the image sensor with the image signal processor of the application processor. Convention correction methods often lead to resolution degradation. It is important to correct Gr and Gb signals while maintaining the resolution.

To prevent resolution degradation, three cases were considered. The first method involves distinguishing scenes and performing correction accordingly. It is expected that significant maze noise will occur in scenes with clear skies or in backlight situations. To suppress side effects, it does not function properly under very low illumination. Only Gr and Gb pixels exceeding a threshold are corrected, similar to bad pixel correction. This approach improves resolution and texture degradation in high frequency regions, excluding flat areas. The second method fundamentally prevents resolution loss by skipping the correction block when maze noise is not noticeable. Third, if resolution loss occurs due to correction, the flat areas are left as they are, and weak sharpening correction is applied only to the high frequency areas to recover the resolution loss.

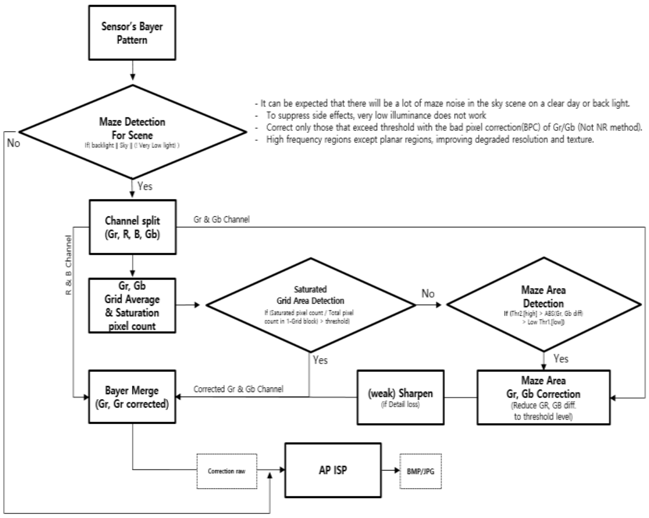


*Figure 4. Maze Noise Correction*

When correcting maze noise, in order to minimize resolution loss, it is important to distinguish between flat and high-frequency areas in the raw file where maze noise occurs and to limit the correction area to the flat area. Rather than extensive correction such as noise reduction, it is judged that a method of correcting only Gr and Gb signals that exceed the threshold such as Bad Pixel Correction is effective according to the following equation (1). To prevent resolution loss in high frequency ranges, details are restored by performing sharpening correction in parallel.

$$\Delta_G = |Gr_{in} - Gb_{in}|,\ \emptyset(\Delta_G) = \begin{cases} 0\ if\ \Delta_G < T & (Bypass) \\ 1\ if\ \Delta_G \geq T & (Correction) \end{cases} \tag{1}$$

$$Gr_{out} = (1 - \alpha) \cdot Gr_{in} + \alpha \cdot \left( \frac{\sum w_i \cdot p_j}{\sum w_i} \right)$$

$$Gb_{out} = (1 - \alpha) \cdot Gb_{in} + \alpha \cdot \left( \frac{\sum w_i \cdot p_j}{\sum w_i} \right)$$

$$P_{\text{final}} = P_{corrected} + \beta \cdot (P_{in} - LPF(P_{in}))$$

From the perspective of actual image, as shown in Figure 5, the image can be divided into three areas based on the Gr Gb difference (%). The first is the General Noise Area below the Threshold (Low). This area contains general temporal noise where no maze occurs, so there is no need for maze correction. The second is the Maze Noise Area between the Threshold (Low) and Threshold (High). This area is where Maze occurs most frequently and is a critical area from a digital correction perspective. The third is the Edge Area above the Threshold (High). It is normal for the Gr Gb Difference value to be very large at the edge areas of an image. Therefore, it is not important to correct this area.

The target is the Maze Noise Area, where digital correction is performed with a focus solely on this region, while the Image Signal Processor of the Application Processor, rather than the sensor, handles general image quality optimization for the remaining two areas. The reason for this division is ultimately to minimize the correction range and effectively select it, thereby minimizing the degradation of the original image resolution and texture.

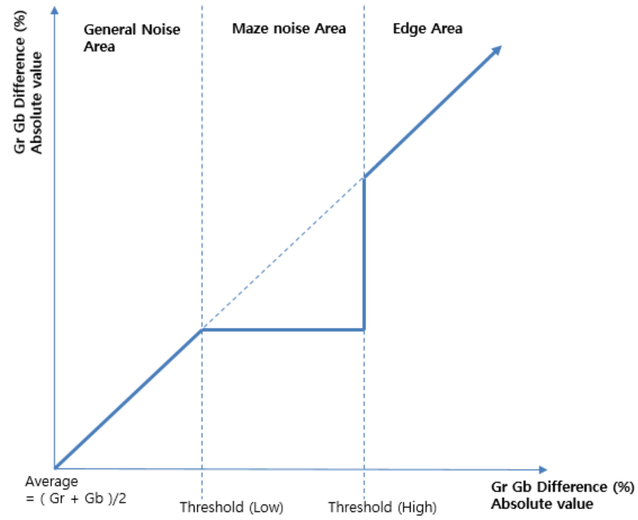


*Figure 5. Correction Threshold*

This shows the areas in the original image where maze noise was detected as shown in Figure 6 and 7. Importantly, excluding the General Noise Area and Edge Area, the remaining area is the Maze Noise Area, which refers to the black areas. Ultimately, by correcting only this maze noise area rather than the entire image, the degradation of resolution and texture can be minimized.

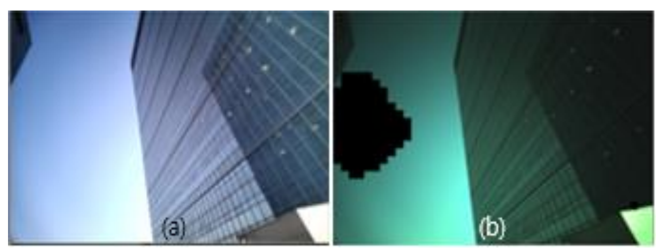


*Figure 6. (a) Original (b) Maze Noise Detection Area*

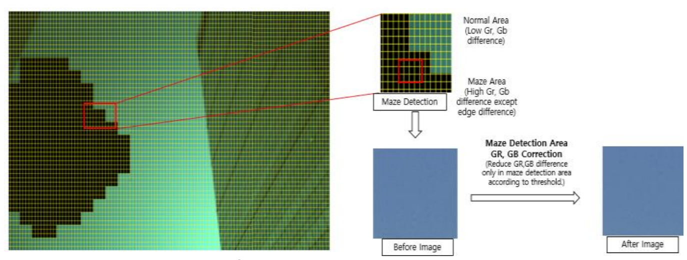


*Figure 7. Maze Noise Correction Process*

## How to Evaluation Method

To evaluate image quality, we prepared camera module of 50Mega Pixel CMOS image sensor with a size of 0.64um pixels. We obtained raw data using the acquired module, a development board for capture, and laptop based raw capture software. The raw data was captured in Bayer mode of sensor. We captured various raw images, including the sky, landscape on clear days, and backlight scenes. As shown in Figure 8, since there is no visibility of the Maze when the Gr Gb difference is small, we selected and obtained raw files showing a difference of at least 4% as targets for correction. To calculate a difference of 4% or more we utilized the following equation (2).

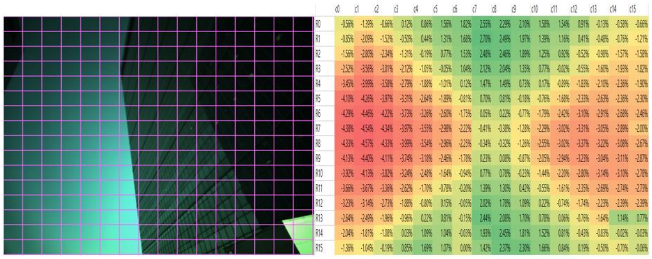

Figure 8. Gr, Gb Difference of Raw Before Correction

$$Gr\ Gb\ Difference\ (\%) = \frac{(Gr_{in} - Gb_{in})}{(Gr_{in} + Gb_{in})/2} \cdot 100 \qquad (2)$$

Maze Noise Correction is performed on the acquired raw data. Subsequently, the processed raw data is run through the Application Processor's Image Signal Processor Simulation to obtain the JPG images. The Image Signal Processor parameters are set identically and applied. The image quality is compared with the reference to verify the improvement in Maze Noise as shown in Figure 9.

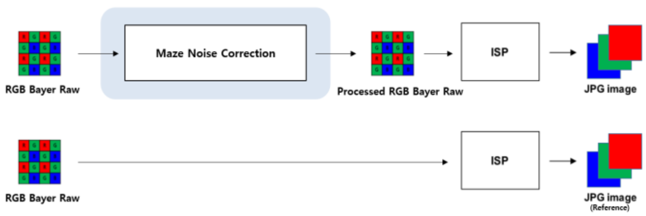


Figure 9. Simulation Process

## Result

In the image where the Gr, Gb Difference is corrected to 2% compared to the original image, the Maze Noise is barely visible. The result is the best. Maze Noise is visible at the 4%. 3% is an intermediate result. It is necessary to manage the Gr, Gb difference within 2% in the Bayer raw of sensor as shown in Figure 10 and 11.

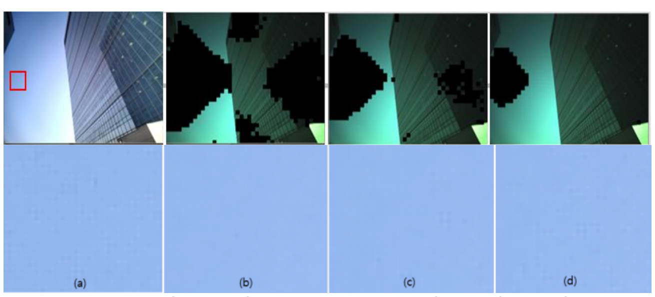


Figure 10. (a) Original, Correction within (b) 2%, (c) 3%, (d) 4%


Figure 11. (a) Original, Correction within (b) 2%

The result of calculating the texture by capturing the TE42 chart is judged to be at a similar level and an equivalent level without texture deterioration as shown in table 1[5] [6]. The equation used for normalization is as follows (3).

| | | Normalization | Apsolute Value | |
|---|---|---|---|---|
| Items | Sub Items | Direct Lightsource | Correction | Ref(Original) |
| General IQ Components | | Outdoor | After | before |
| Texture (high Contrast) | dl_hc_cross_acutance | 100.02% | 0.5643 | 0.5642 |
| | dl_hc_cross_mtf10 | 100.14% | 1143.5112 | 1141.9257 |
| | dl_hc_cross_mtf25 | 100.02% | 846.2176 | 846.0212 |
| | dl_hc_cross_mtf50 | 99.97% | 649.9987 | 650.1863 |
| Sub Score | | 100.04% | | |
| Texture (Low Contrast) | dl_lc_cross_acutance | 100.02% | 0.465 | 0.4649 |
| | dl_lc_cross_mtf10 | 100.06% | 1053.043 | 1052.4257 |
| | dl_lc_cross_mtf25 | 99.99% | 775.6299 | 775.7246 |
| | dl_lc_cross_mtf50 | 100.03% | 565.1122 | 564.9686 |
| Sub Score | | 100.02% | | |

Table 1.Texture Result Using TE42 Chart

$$Normalization\ (\%) = \frac{After_{\ absolute\ value}}{Before_{\ absolute\ value}} \cdot 100 \qquad (3)$$

Even when viewing the image with naked eye, no degradation in resolution or texture can be observed in terms of visibility as shown Figure 12 and 13.

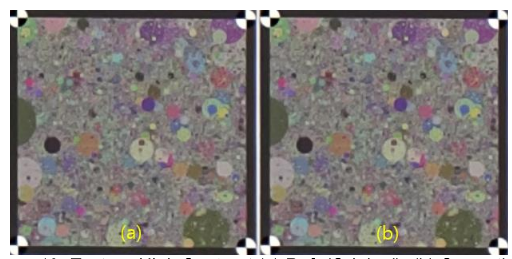


Figure 12. Texture High Contrast (a) Ref. (Original), (b) Correction

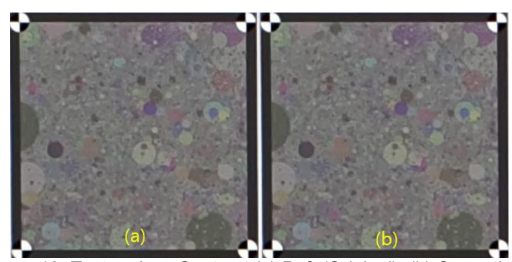


Figure 13. Texture Low Contrast (a) Ref. (Original), (b) Correction

## Conclusion

This study proposes a lightweight and applicable image quality enhancement framework to overcome the physical limitations of micro pixel sensors. The proposed technology has been implemented as a hardware IP block or a software library. By effectively controlling only Maze Noise and utilizing the existing Application Processor's Image Signal Processor for other aspects, it offers a low cost, high efficiency structure that enables image quality maximization through digital processing with a simple architecture. Furthermore, by ensuring versatility, it is possible to flexibly respond to various sensor models and customer specifications. This flexibility allows for immediate response to various sensor characteristics through correction blocks in the form of software libraries, instead of changing the sensor design according to customer requirements as shown in Figure 14.

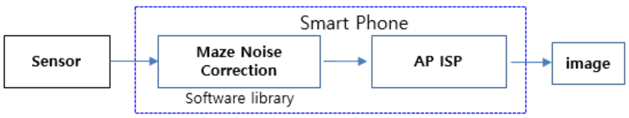

*Figure 14. Maze Noise Correction Methods for Software library*

Because it is simple and has a small logic size, it can also be implemented as a hardware IP block in the image sensor as shown in Figure 15

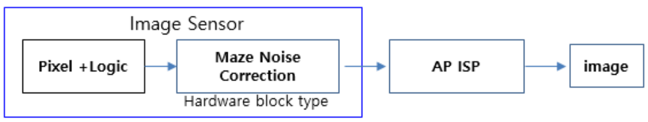

*Figure 15. Maze Noise Correction Methods for Hardware block of sensor*

If we secure various image quality improvement solutions, we can develop image sensors that reflect various customer needs [7] [8]. This can be a very advantageous position in the sensor business. In future research, we will consider expanding in to an intelligent algorithm that automatically sets the optimal threshold value in various lighting environments by incorporating artificial intelligence. In the future, we expect various image sensors that improve characteristics and reflect customer orders to be commercialized and that the sensor industry will prosper.

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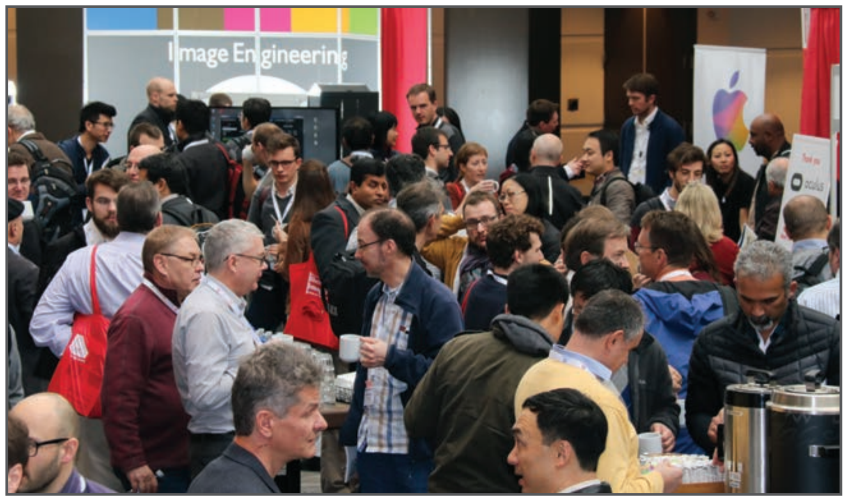



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