CMOS Image Sensor for Multi-Aperture Optics

A 15x9 Array sensor for low z-height 720p camera modules with depth information

Harald Neubauer, Thomas Schweiger
Fraunhofer Institute for Integrated Circuits (IIS)
Am Wolfsmantel 33, 91052 Erlangen, Germany

Abstract—This paper presents a 15x9=135 array sensor for wafer level multi-aperture micro optics intended for low z-height (<2mm) camera modules. The sensor acquires 1440x864 pixel for a 720p 30fps image and integrates image acquisition circuitry and digital reconstruction algorithms in-between the image arrays. The presented image sensor allows the computation of a depth map of the scene.

Keywords—Multi-aperture, computational imaging, CMOS image sensor

I. INTRODUCTION

Multi-Aperture systems see growing interest due to their ability to circumvent some of the current challenges in mobile device imaging. They enable lower z-height cameras with depth sensing capabilities. Due to the wafer level production of the optical elements these systems can be built at low cost. As currently pixels don’t shrink as fast as the resolution increases conventional single aperture optics can’t shrink the z-height due to geometrical optical considerations.

Apart from this, multi-aperture optics can enable additional features as depth information and refocus [1]. Multi-aperture optics project multiple images on the sensor. These images can’t be adjacent due to technology constrains of the production of the lenses. Therefore, there are gaps between these images, which cannot be used for light detection. The silicon area between the arrays is used for analog column circuits, the analog to digital converter, the digital timing circuit and the reconstruction algorithm. The lenses form partly overlapping projections of the scene, which is different from the super-resolution used in [1] and the described 16 focal plane sensor [2]. The reconstruction algorithms for the proposed method are less complex and therefore lower power consumption can be achieved.

II. SENSOR ARCHITECTURE

The implementation aims at a multi-aperture sensor with low area and the ability of computation between the individual image areas. To reduce overall area the analog to digital conversion, row selection, digital processing and output formatting is implemented between the image areas. The sensor consists of 15x9 image areas, each composed of 96x96 pinned pixels of 2.2µm in a 4-shared configuration as depicted in Fig. 1.

Fig. 1. Image area of sensor

The image areas are covered with a uniform RGB color filter, so there is no color crosstalk between adjacent pixels. A classical Bayer configuration is used as can be seen in Fig. 5. Each image area has a decoder for the selection and control of the necessary row signals. The column sample and hold (S&H) and comparator are in the lower 2 row-channels, the memory for the single slope converter is placed in the column-channel as shown in Fig. 2.

Fig. 2. Detailed view of lower left part of the sensor: Distribution of sample and hold and memory

The column-level, single-slope converter compares the column voltage with a globally generated ramp signal. It has a built-in correlated dark sampling (CDS) as depicted in Fig. 3.

Fig. 3. Column correlated dark sampling circuit

The correlated dark sampling is done by storing the column voltage on a capacitor after the pixel reset was done (dark signal) by setting the signal SD (sample dark) as can be seen in Fig. 4. Then the transfer of the charge corresponding to the information about the illumination in the pixel is done. The column voltage containing this information is sampled on a second capacitor by the signal SL (sample light). The sampling is done with the reference voltage set to the code 32 of the digital to analog converter. So with no signal (dark picture) the
code 32 (+ noise) will be digitized in the following analog to
digital conversion. This enables smoother pictures compared to
using the default value of 0 as the noise would be clipped in
half of the digitized signals.

After the sampling is done the global ramp shifts the
voltage at the input of the comparator. The comparator flips as
the voltage crosses the value of the “dark” sampled signal. The
digitized value is therefore the difference between the two
signals (dark and light) as desired. The corresponding digital
code is stored in a column-level digital memory of 10bit.

The digital circuitry in-between the image arrays controls
the sensor and integrates image processing algorithms as the
image reconstruction and black level correction. The sensor is
operated on a single clock and can be configured via an SPI.
The sensor output is a 10bit/pixel serial data stream, which can
be directly connected to the video interface of an OMAP-
processor.

III. SENSOR IMPLEMENTATION

The sensor is implemented in a 4 metal 180nm CIS process. Key challenge was the efficient implementation of the analog
processing and the digital algorithms within the image area. An
algorithm with electronic focus for the reconstruction of the
segmented picture with different depths is built into the sensor.
The implementation is done with little memory usage and is
therefore very area efficient. Several other algorithms are in the
image processing pipeline (ex. black level correction). As the
good of this sensor is not an integration of a complete image
processing chain, some algorithms (ex. demosaicing) are not
yet included but can be done in a later extension as there is still
enough area for digital algorithms.

IV. RESULTS

The sensor was fabricated and assembled with the micro
optical array (Fig. 5 and Fig. 6).

First images could be successfully taken from the sensor. It
could be proved that the algorithms needed for picture
reconstruction can be implemented in the silicon area between
the pixels even if some of the algorithms need improvements
for better picture quality in the next stage.

Key parameters are listed in Table 1.

<table>
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<th>TABLE I. KEY PARAMETERS</th>
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<td><strong>Process</strong></td>
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<td><strong>Pixel</strong></td>
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<td><strong>Image Area</strong></td>
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| **ADC** | 10bit single slope converter with column-wise correlated
dark sampling; configurable gain setting |
| **Die size** | 6400x4250um |
| **Framerate** | 30fps |
| **Processing** | Exposure control, image reconstruction, depth focus,
black level correction, quadrupel correction, |
| **Interface** | Single clock input; SPI configuration,
10bit serial 36MPix/s output; output format compatible
with OMAP video interface |

V. SUMMARY

We demonstrate an array sensor tailored to a multi-aperture
optical system for a very low z-height 720p camera module
with 3D capabilities. The area between the optical sensitive
arrays is used for the analog column circuitry, the digitization
and digital processing chain including an image reconstruction
algorithm.

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REFERENCES

Monolithic Camera Array”, ACM Transactions on Graphics (Proc.
SIGGRAPH Asia), 32(5), 2013.
with 1.75um Pixel: Architecture and Implementation,” International
Image Sensor Workshop, 2013
Wippermann, F., “Ultra-thin wafer-level camera with 720p resolution