Feedback Control of a Block-Wise-Controlled Image Sensor Based on Brightness Distribution Analysis

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Abstract This study proposes an image sensor design implementing block-wise control that allows independent control of pixel binning and exposure time within each pixel block. This facilitates the flexible control of the frame rate, resolution, and dynamic range for better applicability to a shooting scene. A 1 K × 1 K prototype image sensor with 16 × 17 blocks (64 × 64 pixels in each block) is used to demonstrate the feedback control capability of the image sensor based on brightness distribution analysis.

I. INTRODUCTION

Tradeoffs between frame rate, resolution, noise performance, and dynamic range render the designing of high-pixel-rate image sensors [1] required for recent imaging systems such as 8 K [2], VR, and 360° video [3] difficult. To overcome these tradeoffs, this study proposed a scene-adaptive imaging system that facilitates local control of the imaging parameters based on individual areas according to the characteristics of the scene, such as object movement and brightness distribution. Therefore, imaging parameters such as the resolution and frame rate can be allocated according to the scene being recorded. In addition, since the exposure time can be controlled for each area, it is possible to increase the exposure time in dark areas to improve S/N, and shorten the exposure time in bright areas to expand the dynamic range. A key technology in this system is the proposed architecture for block-wise-controlled image sensors. This architecture divided the pixel array into blocks, wherein an external feedback signal is used to individually control pixel binning and exposure time. This feedback signal was obtained based on an external scene analysis and specified the appropriate imaging parameters for each area. This study demonstrated the feedback control of a block-wise-controlled image sensor, wherein the operation modes could be changed locally based on brightness distribution analysis.

II. BLOCK-WISE-CONTROLLED IMAGE SENSOR

Figure 1 shows a block diagram of the proposed system, which comprised a block-wise-controlled image sensor and a signal processor. The signal processor performs a brightness distribution analysis of the captured scene and determined the optimal operating mode for each block based on its brightness. Consequently, the result is fed back to the image sensor as a feedback signal. The image sensor operates under different modes for each block according to the feedback signal. In this system, analysis processing and feedback operations is performed within one frame period to facilitate real-time response to changes in the scene.

Figures 2 and 3 show the die image and pixel architecture of the image sensor, respectively. The prototype image sensor comprised a 1024 × 1088 pixel array, pixel driver, column-parallel ADCs, an output block, and a mode controller. The die dimensions are 6.5 mm (H) × 7.7 mm (V). A 1024 × 1088 pixel array is divided into 16 × 17 control blocks (64 × 64 pixels per block). Figure 3 (c) shows that every 2 × 2 pixel (depicted as *A*, *B*, *C*, and *D*) shares a pixel amplifier and receives readout pulses through the switches provided for each pixel. Therefore, a selected pixel or a pixel-binned signal of 2 × 2 pixels can be selectively read according to the control signal. These switches are independently controlled by the control signals specified by the mode controller for each block according to the externally received feedback signals. Further, the output block output the sensor data as an LVDS 4-ch signal.

Table 1 summarizes the four operational modes supported by the image sensor, and Fig. 4 shows the readout scanning method for these modes. Compared to the results presented in Ref. [4,5], the proposed image sensor facilitates control of the exposure time and frame rate for each area. The scanning method is as follows. (a) Normal mode: One selected pixel signal is read for each scan, thus enabling subframe readouts with 1/240 s periods in the order of A, B, C, and D. The exposure time is 1/60 s, and the resolution is 64 × 64 pixels per block. (b) Fast mode: Pixel-binning readout is performed for each scan. This enables high-speed readouts with a frame rate of 240 fps. However, the resolution deteriorates to 1/4 (32 × 32 pixels per block). (c) Bright mode: Sub-frame readout is performed in a manner similar to that in the normal mode; however, the exposure time is limited to 1/240 s using an electronic shutter. (d) Low-light mode: Sub-frame readout and 4-frame readout pauses are alternately performed, thereby extending the exposure time to 1/30 s.

III. BRIGHTNESS DISTRIBUTION ANALYSIS

The brightness distribution analysis and feedback signal generation processes are shown in Fig. 5. First, the signal of subframe A is averaged every 8 × 8 pixels, where averaged signal number in one block is 64. The averaged results is classified into low-light, normal, and bright modes using two thresholds (depicted as thresholds 1 and 2 in Fig. 5). Finally, the mode with the highest frequency of each of the three modes is determined for each of the 16 × 17 blocks using a mode filter. These operation modes are fed back to the image sensor as feedback signals. The output signal level varies depending on the mode. In particular, in low-light mode, the signal level is twice as high as normal mode; and in bright mode, it is 1/4 of the signal level of normal mode. To correct this signal-level difference in signal processor, the level correction factors (×1/2, ×1, ×4) are multiplied by the next subframe A, depending on each operating mode. These processes are implemented on an FPGA board. Further, processing for analysis and feedback signal generation is performed within 1/60 s. Therefore, each block of the image sensor can be operated in real-time in the optimal operating mode according to changes in the brightness distribution of the scene.

IV. EXPERIMENTAL RESULTS

To verify the block-wise control function, the operation modes are set using a specified external feedback signal. Fig. 6 shows images of the four operation modes set by the specified external feedback signal. The images in each mode correspond to their imaging parameters. In the fast mode, pixel binning results in an image with 1/4 resolution compared to the normal mode. In the bright mode, the signal value is 1/4 because of the exposure control of 1/240 s. Finally, in the low-light mode, the signal value is twice that in normal mode because the exposure time is extended to 1/30 s.

Figure 7 shows the video images and feedback signals captured by the proposed system. The upper row of the four images shows the captured video images, whereas the lower row of four images shows the color-coded results of the brightness distribution analysis. Depending on the brightness distribution, the three different modes: low-light, normal, and bright, are assigned. The area captured in low-light mode is changed to follow the area of the moving hand, whereas that where the LED light is captured is switched to high-brightness mode. Further, the region captured by the transmitted chart, which exhibits intermediate brightness, switches to normal mode. Thus, these results demonstrate the feedback control capability of the operation modes based on brightness distribution analysis.

V. CONCLUSION

This study proposes a scene-adaptive imaging system that facilitated local control of the imaging parameters based on individual areas according to the characteristics of the scene. The prototype image sensor demonstrates block-wise control of the resolution, frame rate, and exposure time using the specified external feedback signal. In addition, the proposed system demonstrates the feedback control capability of the operation modes based on a brightness distribution analysis. Thus, the results of this study indicate that the architecture of the prototype image sensor and the proposed system are suitable for realizing scene-adaptive imaging.

V. REFERENCES

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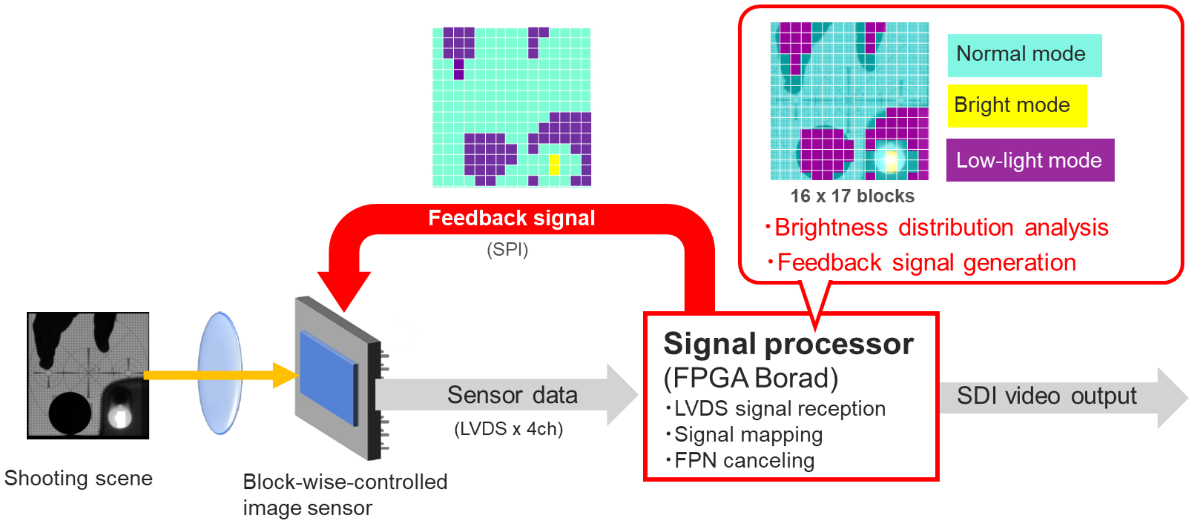

Fig. 1. Block diagram of the prototype scene-adaptive imaging system.

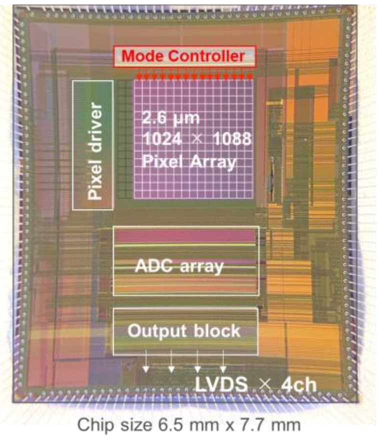

Fig. 2. Die image of the image sensor.

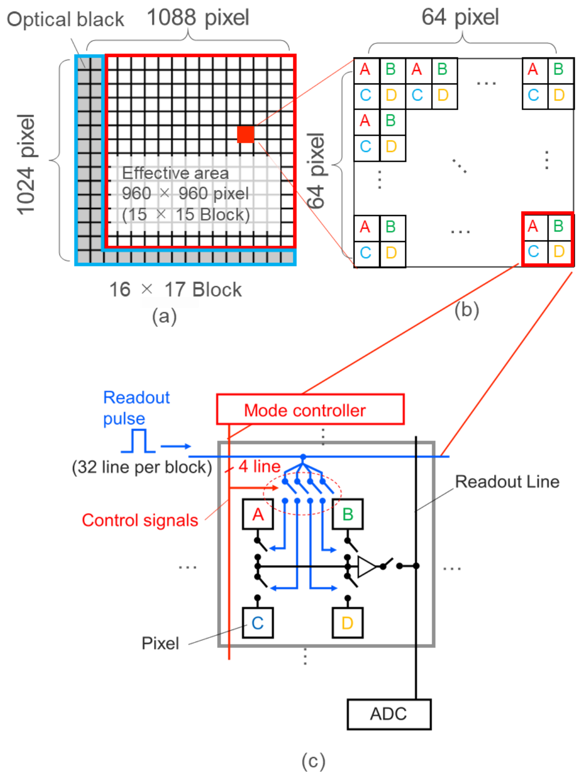

Fig. 3. Schematic of the pixel architecture: (a) pixel array, (b) pixel block, and (c) pixel readout circuit for 2 × 2 pixels.

Table 1. Operation modes implemented in the image sensor.

Mode	Resolution	Frame rate	Exposure time
Normal	64 × 64	60 fps	1/60 s
Fast	32 × 32	240 fps	1/240 s
Bright	64 × 64	60 fps	1/240 s

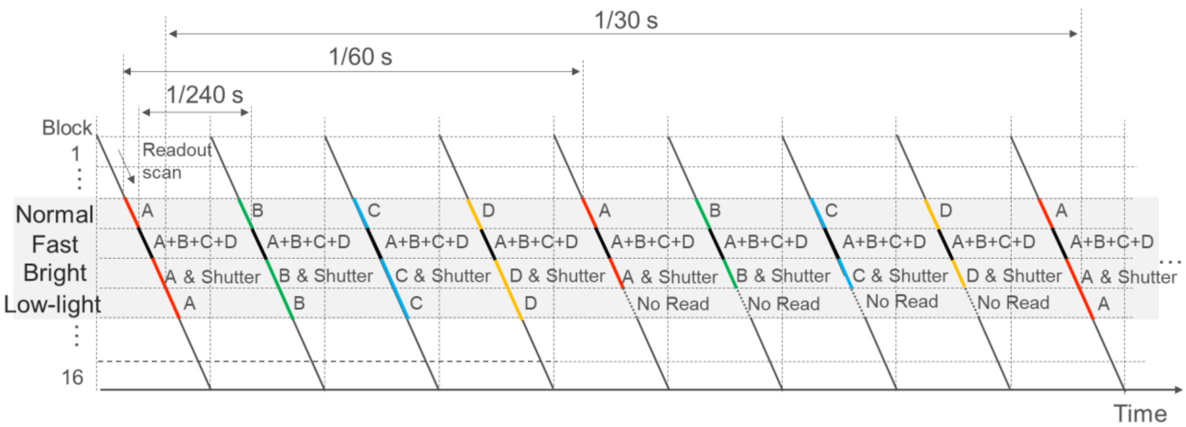

Fig. 4. Schematic of the readout scan method of the image sensor.

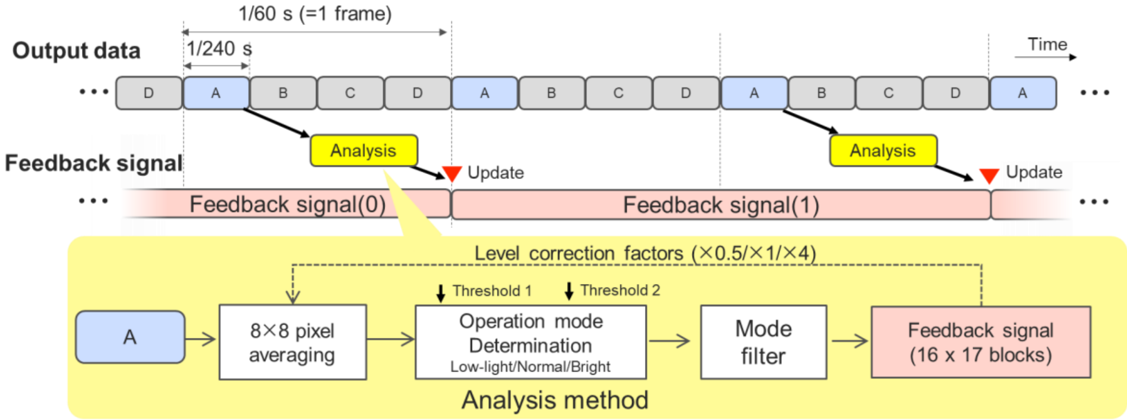

Fig. 5. Schematic of the brightness distribution analysis and feedback signal generation processes.

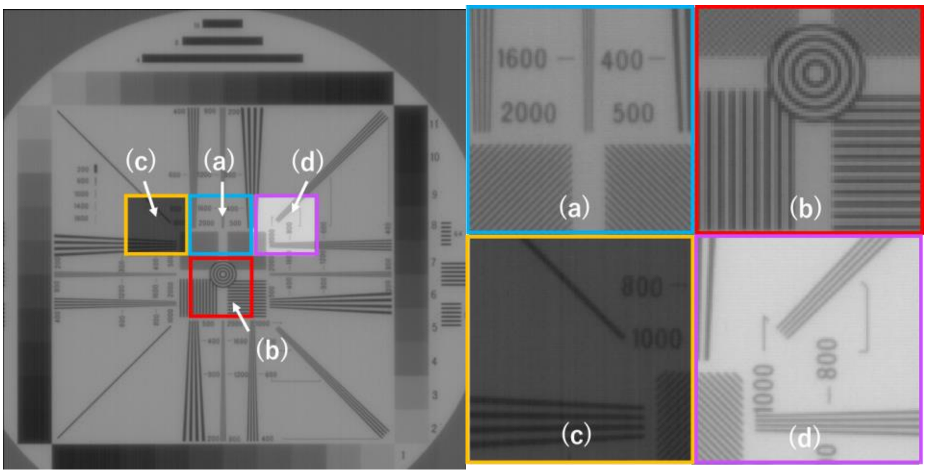

Fig. 6. Captured images by the prototype scene-adaptive imaging system with the operation mode set by external feedback signals: (a) normal, (b) fast, (c) bright, and (d) low-light modes.

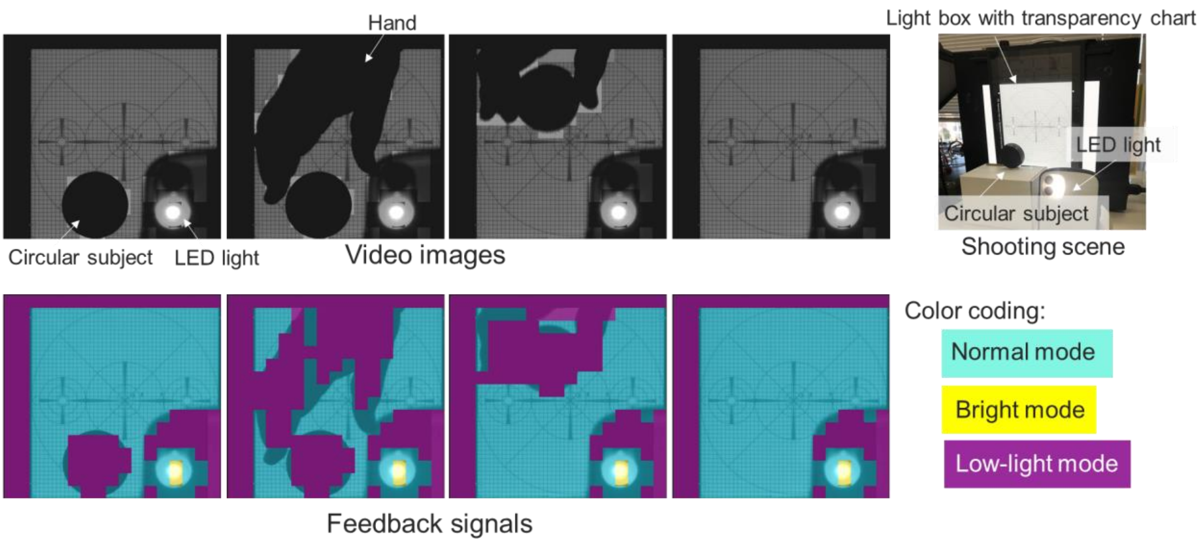

Fig. 7. Video images and feedback signals captured by the prototype scene-adaptive imaging system.