High-Speed Imaging using CMOS Image Sensor with Quasi Pixel-Wise Exposure

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Abstract Recent studies based on the concept of compressive sensing have been realized scene capture beyond the trade-off limit between spatial resolution and temporal resolution, but the feasibility is low. We proposed co-designed CMOS sensor architecture and its controlling method that performs high-speed imaging with sufficient feasibility. We fabricated a prototype camera and demonstrated the realization.

Keywords: high speed imaging, compressive sensing, sparse optimization, pixel-coding imaging

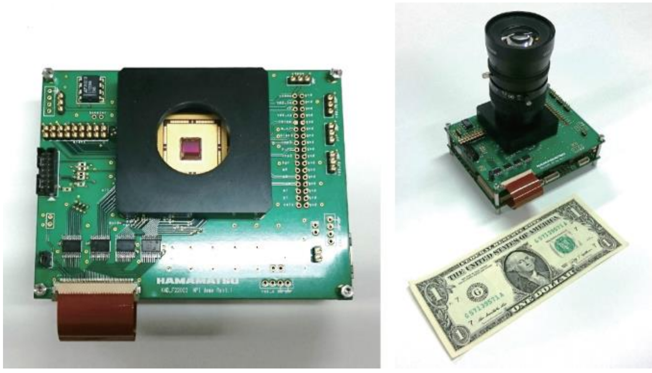

Fig. 1. Prototype CMOS sensor with quasi pixel-wise exposure.

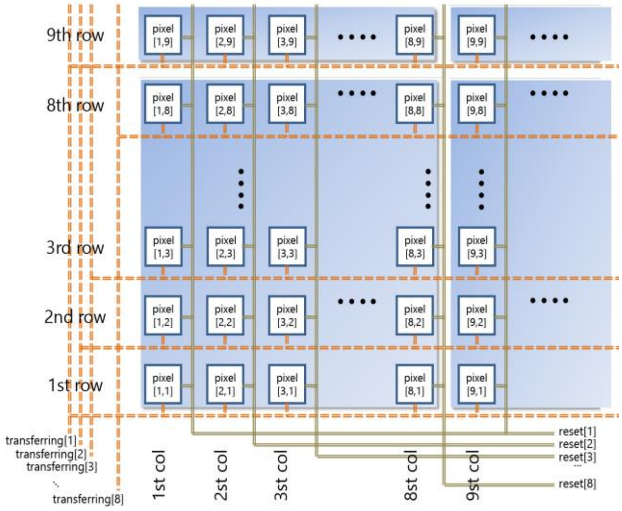

Fig. 2. Architecture diagram of CMOS image sensor with quasi pixel-wise exposure capability.

Table 1. Specifications of prototype QPE sensor

Pixel size	7.4×7.4 *μm*
Number of pixels	672×512 pixels
Number of effective pixels	656×496 pixels
Frame rate	15 fps
Size of light receiving area	4.8544×3.6704 *mm*

1. Introduction

Digital image sensors have a fundamental problem in the form of a trade-off between the spatial resolution and the temporal resolution of the captured video, because the sensor bandwidth and the analog-to-digital conversion stage act as process bottlenecks. Several recent studies [1] used random sampling methods to obtain multiplexed space-time information in the form of a single image, and then decoded it into multiple image frames. Most of these methods demonstrated their feasibility through simulation experiments or using optically simulated implementations (e.g., a combination of a standard image sensor and spatial light modulators), because there is no commercially available image sensor with pixel-wise exposure capability for compressive sensing at present.

In this paper, we proposed co-designed method using a CMOS image sensor design [2] and its nontrivial usage that realizes quasi pixel-wise exposure and a method for high speed video reconstruction [3]. The proposed CMOS image sensor is based on the addition of control lines to every pixel, as shown in Fig. 2. The proposed sensor can control the exposure reset and transfer signals within a specific capture frame. The prototype sensor shown in Fig. 1. has eight independent resetting lines and eight transferring lines for an 8 × 8 block, and shares the lines for each 8 × 8 block. Therefore, we can control the exposures of all pixels in the block, although every block of the pattern is the same and is repeated in an image. This simple sensor modification for quasi pixel-wise exposure is easier than that which would be required for full pixel-wise exposure. We also avoid the need for large numbers of pixel control lines corresponding to the number of pixels required for a full pixel-wise CMOS sensor. The simple design modification maintains high fill factor of the photodiode, and produces similar sensitivity to that of a regular CMOS sensor. We propose the nontrivial signal pattern to realize pseudo-random sampling via the limited controls of quasi pixel-wise exposure. We used an over-complete dictionary to reconstruct a high-frame-rate video without the rolling shutter effect from the images captured by the CMOS sensor.

This paper is shrunk version of our work [3]. Our tackling to solve the rolling shutter effect on our sensor and further experiment results can be found in this full version.

2. Experiments

In Fig. 3, we demonstrated the quality of the reconstructed

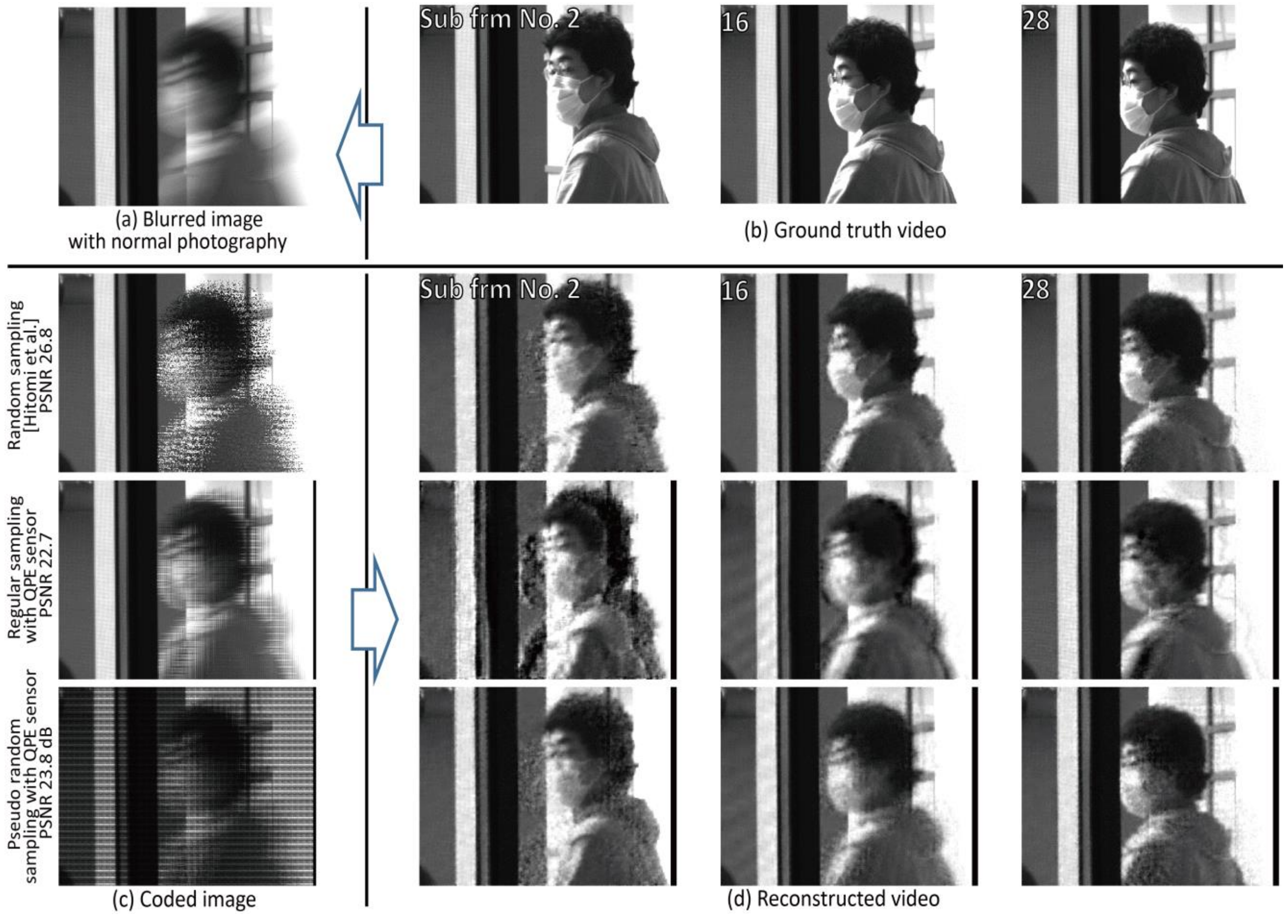

Fig. 3. **Simulation experiment**. (b) We captured the ground truth video using a high-speed camera with high spatial and temporal resolution. Only three frames of the 32 captured frames are shown. We obtain (a) by integrating all 32 frames. (a) can be considered to be an image captured using a normal still camera that has high spatial resolution but low temporal resolution. (c) shows a simulated coded image with random sampling [8], regular sampling with the QPE sensor, and pseudo-random sampling with the QPE sensor. (d) reconstructed video (sub-) frames. The frames corresponding to the ground truth are shown.

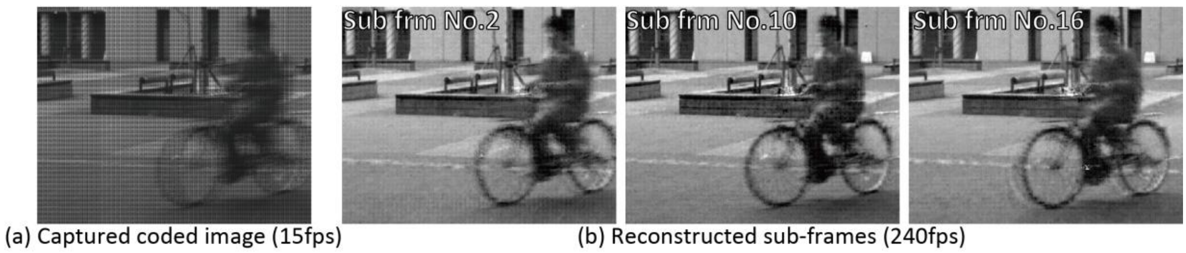

Fig. 4. **Real experiment**. the target scene is a cycling man. (a) shows the frame captured by the prototype QPE sensor (15fps). (b) shows three sub-frames from the reconstructed video (240fps).

video sub-frames that were obtained using our pseudo-random sampling process with the QPE sensor. We compared our results with those obtained by random sampling using pixel-wise exposure and those obtained by regular sampling using the QPE sensor. The random sampling process can recover the scene because it has sufficient randomness. The results of regular sampling using the QPE sensor can also be used to recover the scene; however, some artifacts corresponding to the inverse motion of a walking man appeared, unlike the random sampling case. In contrast, pseudo-random sampling performs the operation with similar quality to that of random sampling. These results show that the pseudo-random sampling process has sufficient randomness for scene reconstruction.

We demonstrated the feasibility of the proposed method using a prototype CMOS sensor and quasi pixel-wise exposure in Fig. 4. We can see that the motion is recovered through the calculation in spite of the captured frames are acquired in low temporal resolution.

References

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