Improved Compressive Temporal Imaging using a Shuffled Rolling Shutter

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Abstract: We propose a slight modification to the rolling shutter by shuffling the scanline mechanism to significantly improve its sampling ability to recover high speed videos from a single image using compressive reconstruction algorithms.

OCIS codes: 110.0110, 110.4234, 170.1630

1. Introduction

CMOS sensors are not only popular in cheap consumer cameras. Lately, they are also becoming the new standard in professional and scientific cameras as they started to offer higher quantum efficiencies and reduced noise levels even competitive to the most expensive EMCCDs. Nonetheless, the majority of CMOS sensor are designed with a column-parallel readout circuit known as Rolling Shutter (RS), which tend to generate unwanted distortions such a wobble, skew and other image artifacts [1] when imaging dynamic scenes. Some work has treated the RS as a nuissance and has focused on compensating this distortion by different means [2–5]. However, some research has also indicated that if we consider that each row is exposed at different times, then a single RS-shot has the potential to particularly sampling the space-time volume so dynamic information beyond the exposure time could be potentially extracted. For example, some recent efforts for compressive temporal imaging have been presented in [6] and [7] where spatial multiplexing is added to the RS deterministic spatio-temporal sampling through the use of diffusers at the imaging or pupil plane, respectively, achieving remarkable reconstruction frame rates from a single RS image. Nonetheless, additional multiplexing of light comes at the expense of optical calibration and a reduced signal-to-noise.

In this work, we tackle the inherent lack of sampling diversity provided by the RS by proposing a slight hardware-only modification to the RS scanline mechanism shuffling the position of the pixels being read. If feasible, this modification should be hardwired. We present elements for the coding design for the shuffle in order to boost the ability of the new RS design to recover several frames of the space-time datacube, while sharing some exciting preliminary results.

2. Shuffled Rolling Shutter Code Design

The main idea is to shuffle the position of the pixels being scanned. In this way, a scanline is not a single row anymore, but rather a collection of pixels at different column positions, but only one pixel per column to maintain the consistency with the original scanline and readout mechanism whereby a pixel is only sampled once during a frame. The new sampling scheme is illustrated in Fig. 1 where we can see that the first highlighted scanline (in red) is actually sampling different spatial pixels across the detector, but only one pixel is sampled per column.

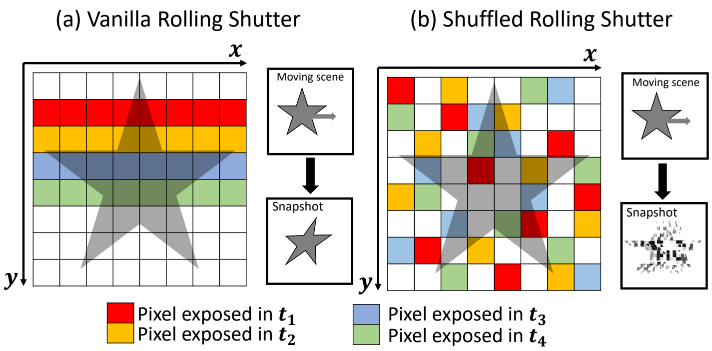

Fig. 1. Normal and shuffled rolling shutter acquisition scheme.

The question now is how to choose the shuffling mechanism to make the sampling of the space-time datacube as uniform as possible in either the spatial and temporal directions, avoiding clusters of contiguously pixels sampled such as in the case of the traditional RS scanline. If we leave it as a random permutation, we can still end up with solutions where two neighboring (or too close) pixels are being sampled. On the other hand, we have found that some solutions to the 3D N^2-Queens problem also provide with an uniform sampling of the datacube. We are currently mathematically and empirically studying the solutions to this combinatorial design problem that can maximize the spatial (and temporal) distance between sampled pixels within the space-time datacube, considering also that an extended exposure time will make the sampling for a given pixel persistent to the following frames.

In Fig. 2 we present preliminary simulation results of the proposed scheme for the shuffled RS when sampling a moving spatial scene of 256×256 and recovering 8 subframes by means of the ADMM-TV compressive reconstruction algorithm [8]. Notice the motion blur, which is expected given that the reconstructed sub-frames span 32 high-speed original sub-frames. Note also that this reconstruction is impossible using the traditional RS scheme.

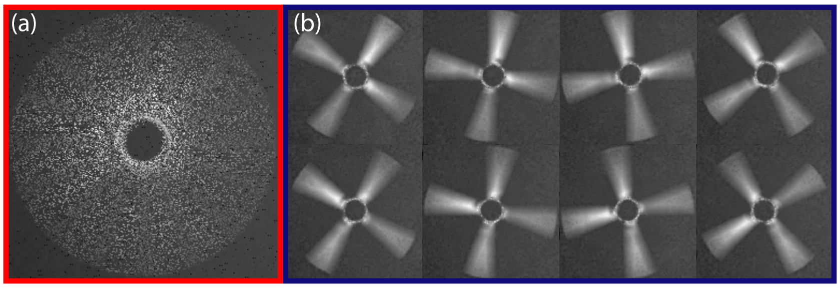

Fig. 2. Simulation of the `Fan` dataset at $256 \times 256 \times 256$. (a) Detector measurement considering a exposure time of $7\Delta t$; (b) Reconstructed frames with ADMM-TV using a compression of $8\times$ (mean PSNR = 29.77 dB).

3. Conclusion

We propose a modification to the RS scanline mechanism to better sample the space-time datacube for compressive temporal imaging, showing promising results. Future work will consider the design of the best sampling lattices given the RS restrictions and a set of experimental demonstrations.

Funding

This work was supported by Fondo Nacional de Ciencia y Tecnologia (FONDECYT) (1181943) and Air Force Office of Scientfic Research (AFOSR) (FA9550-19-1-0293)

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