Improved Compressive Temporal Imaging using a Shuffled Rolling Shutter

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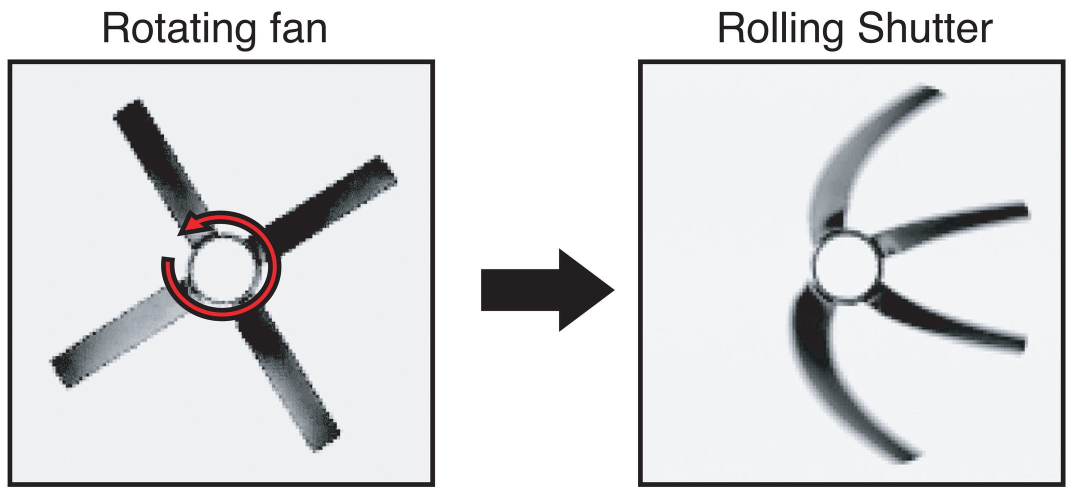
Abstract

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.

Introduction

Most CMOS sensors are designed with a column-parallel readout circuit known as Rolling Shutter (RS), which tend to generate unwanted distortions such a wobble [1], skew and other image artifacts [2] when imaging dynamic scenes.

Rotating fan   Rolling Shutter



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.

Background

The discrete model of the Rolling Shutter (RS):

$$\mathbf{Y} = \sum_{l=1}^{N_t} \mathbf{X}_l \odot \mathbf{C}_l + \mathbf{\Omega} \quad (1)$$

such that N_t is the total number of subframes within acquisition cycle, $\mathbf{X}_l \in \mathbf{R}^{N_x \times N_y}$ is the l^{th} frame with $N_x \times N_y$ number of pixels, $\mathbf{C}_l \in \mathbf{R}^{N_x \times N_y}$ is the l^{th} coded aperture, $\odot$ is the Hadamard product, and $\mathbf{\Omega}$ is the Gaussian noise. The discrete model is similar to the sensing model of CACTI presented in [3].

Coded Apertures Optimization

The design of the coded aperture for RS is equivalent to pack spheres in cubic container [4]. Exploiting the solution to $3DN_x^2$ Queens Problem ($3DN_x^2$QP), it is possible to find a solution to RS sensing:

$$I_{i,j} = (ai + bj) \mod N_x \quad (2)$$

where $i \in \{1, \dots, N_x\}$, $j \in \{1, \dots, N_y\}$, then the resulting coded aperture is:

$$C_{i,j,l} = \begin{cases} 1 & \text{if } l \in I_{i,j} \\ 0 & \text{if } l \notin I_{i,j} \end{cases}$$

where $l \in \{1, \dots, N_t\}$. The approach maximize the minimal distance between the center of the spheres $\max \quad d^*(n)$, where $n = N_x N_y$, and $d^*(n) = \min_{1 \le i < j \le n} \|\mathbf{p}_i - \mathbf{p}_j\|_2$, $\mathbf{p}_i$ and $\mathbf{p}_j$ are the centers of the spheres

$$d^*(n) = 2\sqrt[3]{\frac{(\sqrt{n}+1)^3}{4n\sqrt{2}}} \quad (3)$$

density $\rho = 0.7405 = \frac{\pi}{\sqrt{18}} = \frac{4n\pi r^3}{3(\sqrt{n}+1)^3}$.

References

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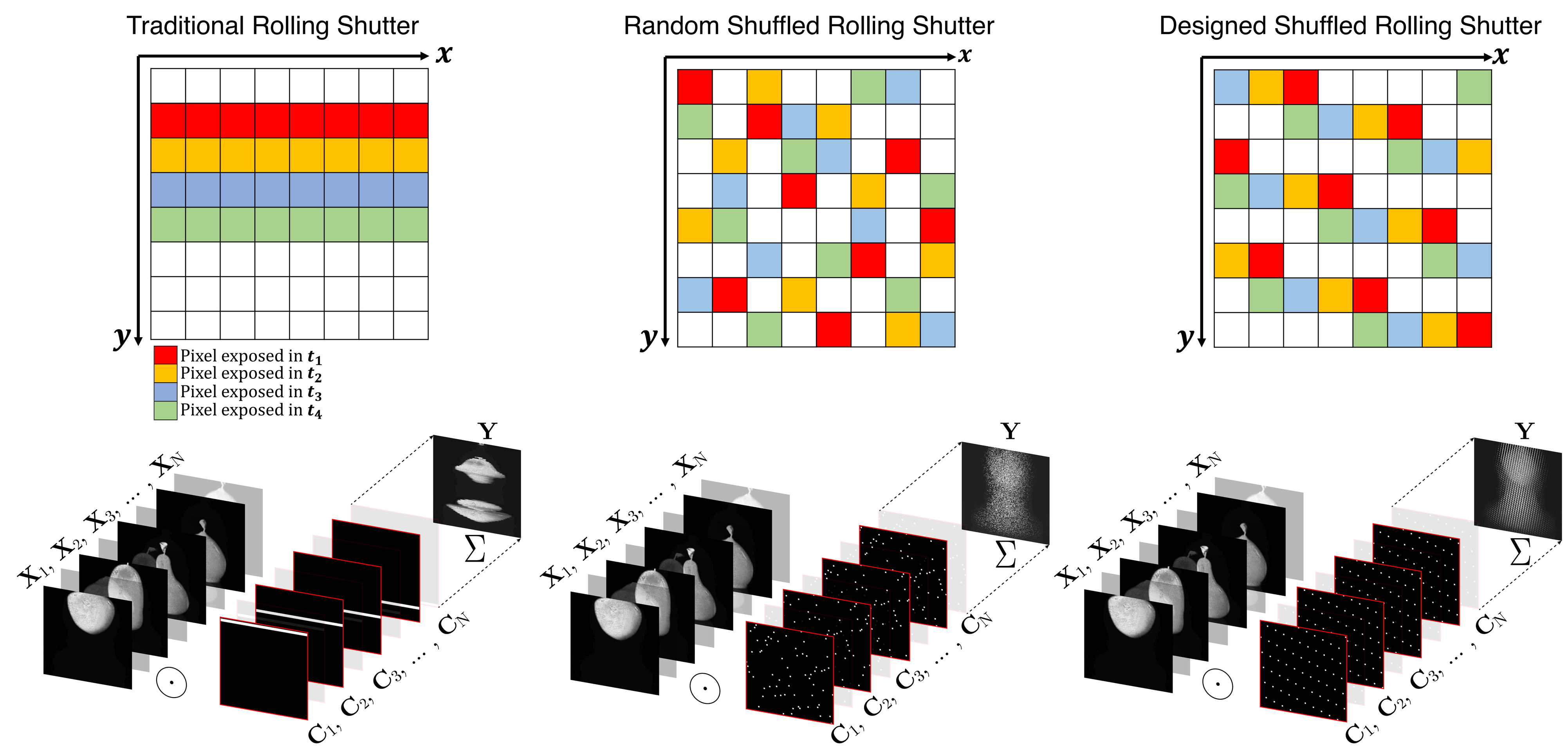
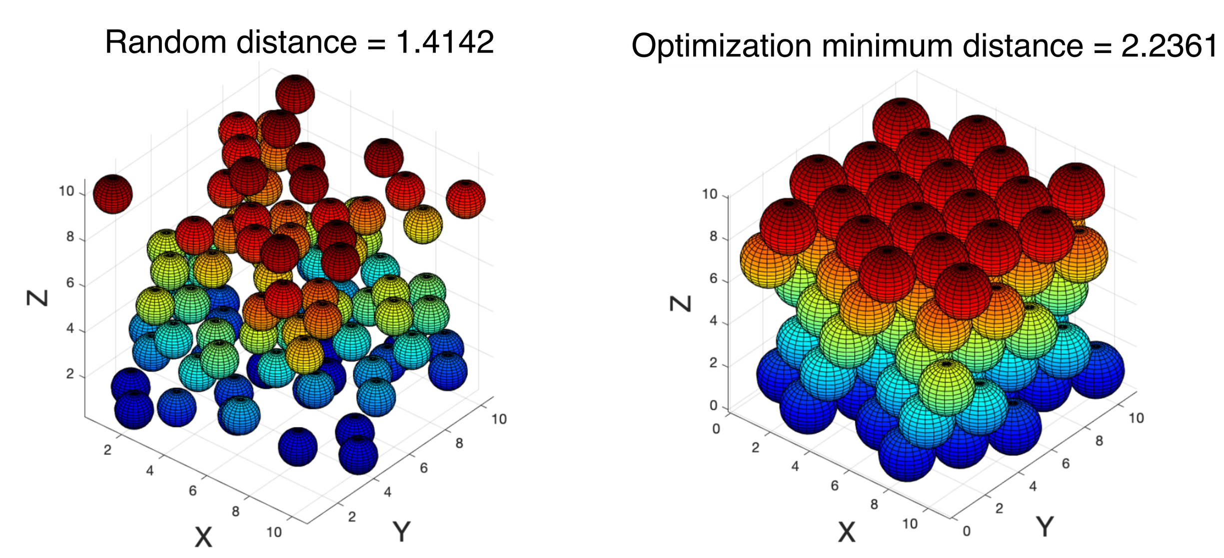
Methods

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.

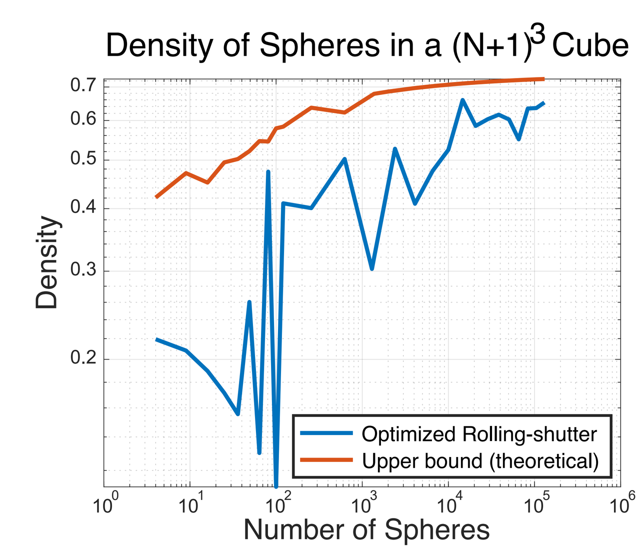
Sampling strategies



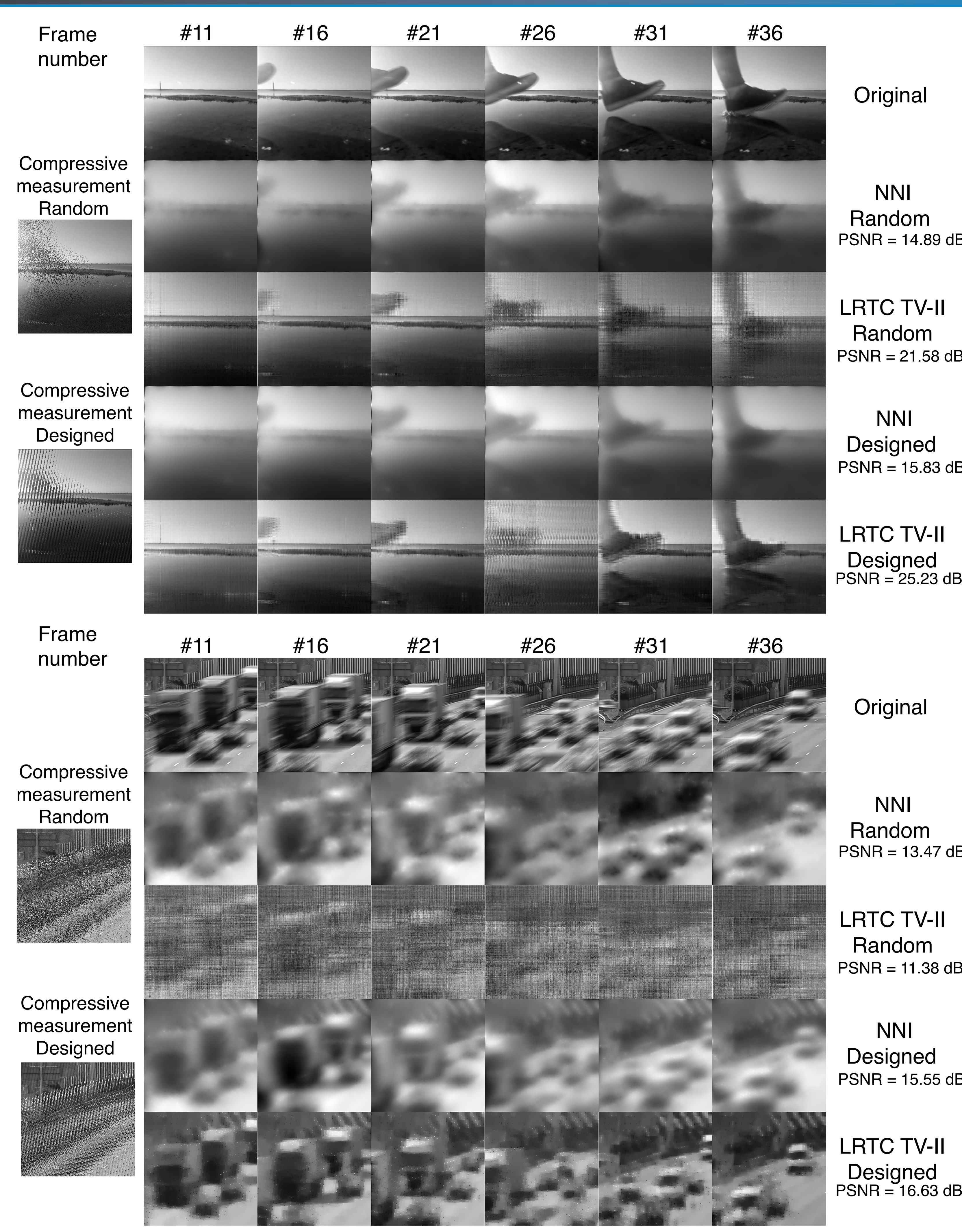
Sphere distance



Upper bound density



Results



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.

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