Velocity-Dependent Shutter Sequences for Motion De-blurring

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Abstract

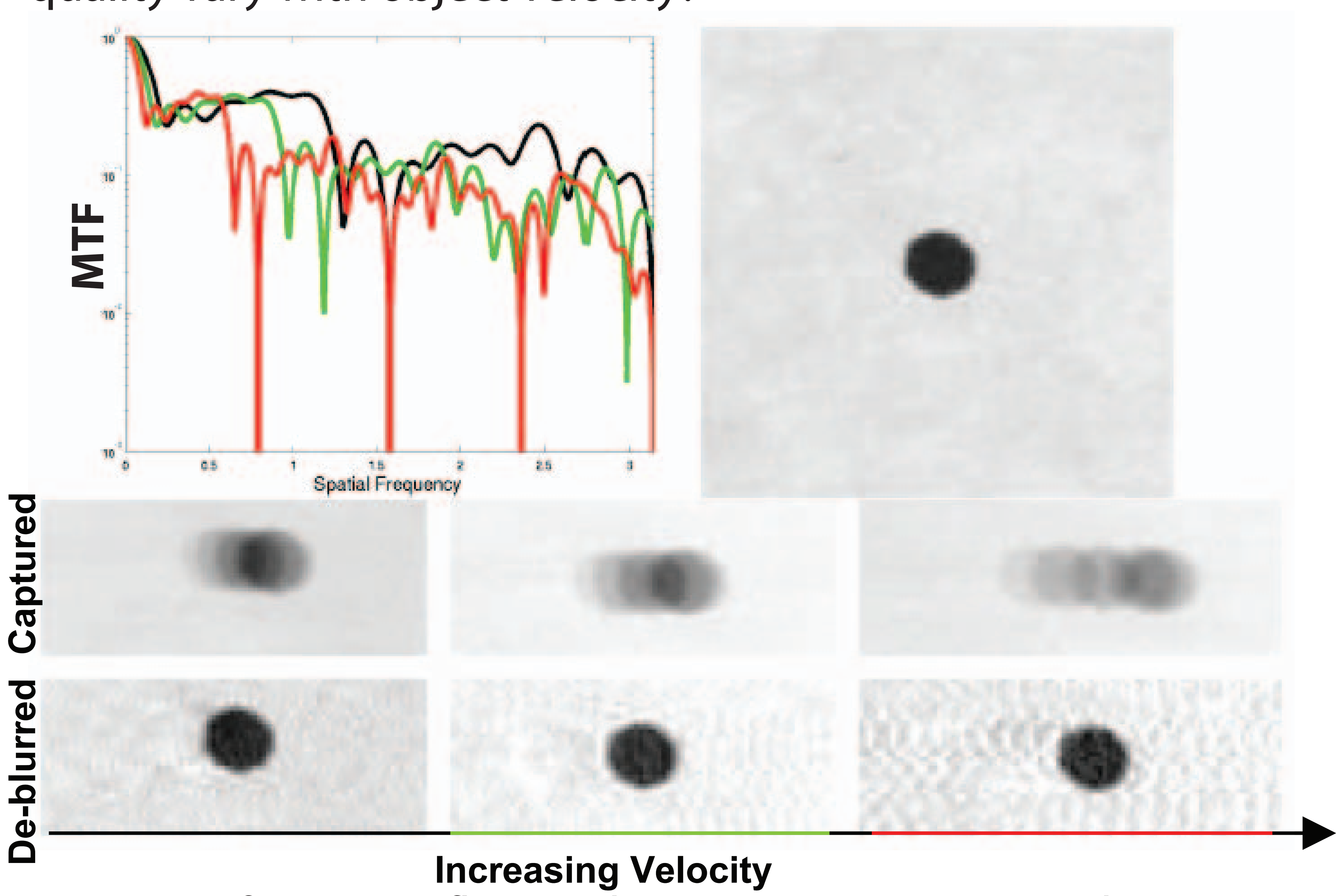
We extend the flutter shutter method of Raskar et al. [1] to fast-moving objects by first demonstrating that no coded exposure sequence yields an invertible point spread function for all velocities. Thus, the shutter sequence must depend on object velocity, and we propose a method to compute such velocity-dependent sequences. We demonstrate improved image quality from velocity dependent sequences on fast moving objects.

Velocity-Dependence

The objective of exposure coding is to choose a shutter timing sequence that produces an invertible Point Spread Function (PSF), i.e. one whose MTF does not go to zero.

But, the effective PSF depends on *both* the shutter sequence *and* the object's velocity.

For a given sequence, how does reconstructed image quality vary with object velocity?

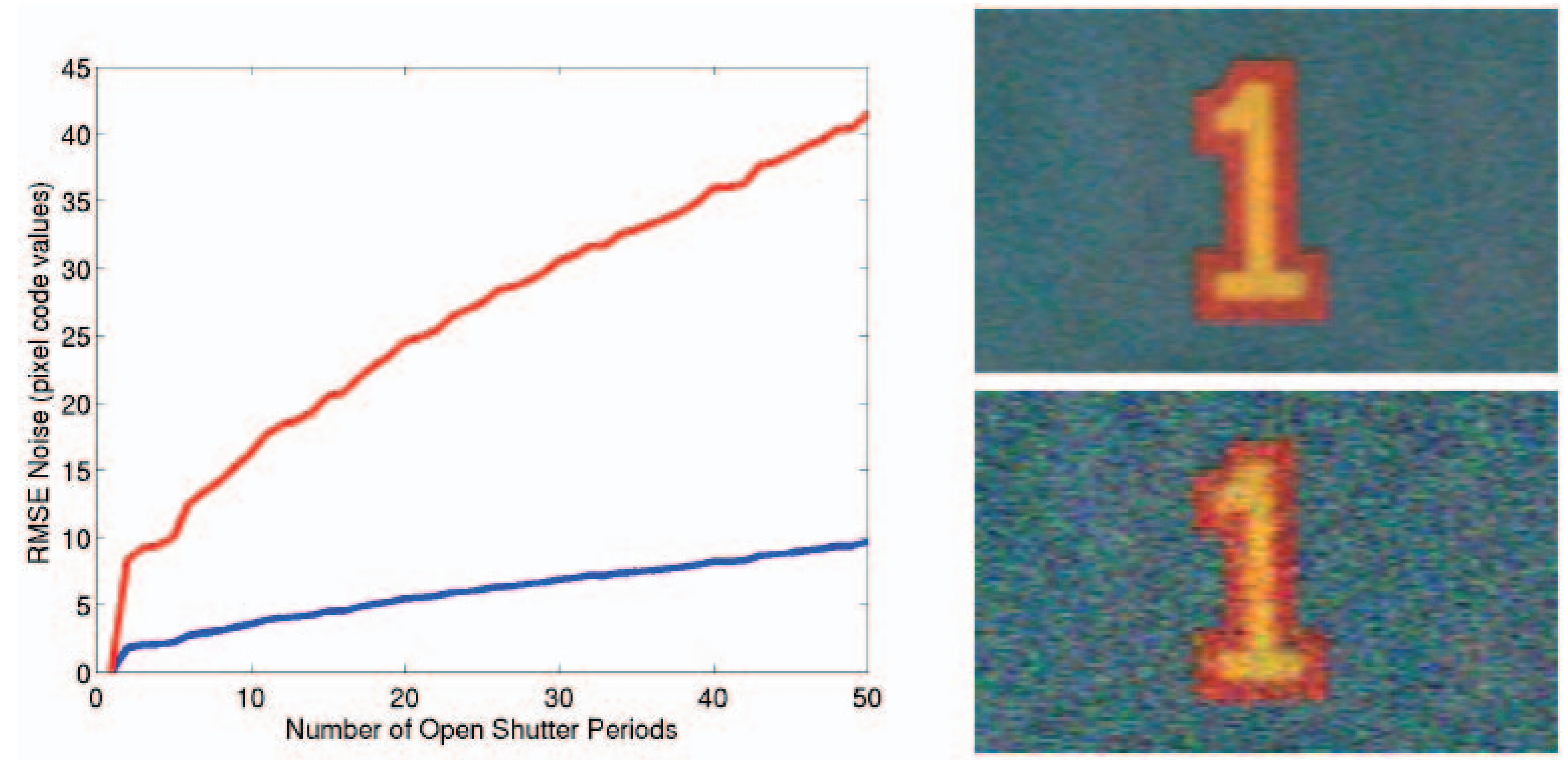


Lemma: If a given flutter shutter sequence S produces an invertible PSF for velocity V, inversion of the PSF produced by S under velocity $\geq 2V$ will be ill-posed at the Nyquist frequency.

Proof: In the paper.

Implication: Shutter sequences need to be designed for specific object velocities.

Shutter Sequence Design: Noise



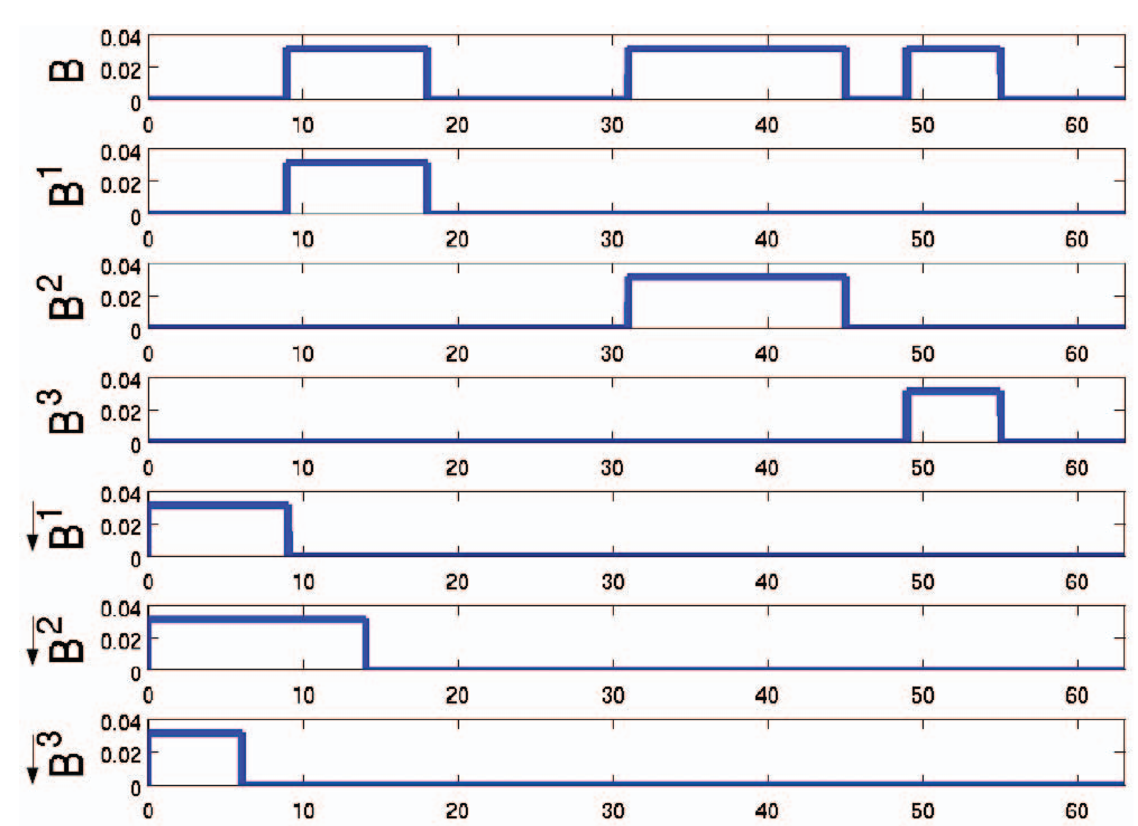
When using an electronic shutter (e.g., Point Grey Flea/Dragonfly) to capture a coded exposure image, read-out noise is proportional to the number of open shutter periods (blue curve). This noise is amplified by de-blurring (red curve).

Implication: When designing sequences for electronic shutter cameras, favor those with fewer open shutter periods.

Shutter Sequence Design: Algorithm

We represent a shutter sequence as a combination of:
(1) A number of open shutter durations and
(2) the start times of each open shutter duration.

We note that (1) imposes an upper bound on the MTF.



Algorithm Overview:

Step 1: Enumerate all partitions of exposure time into open shutter durations.

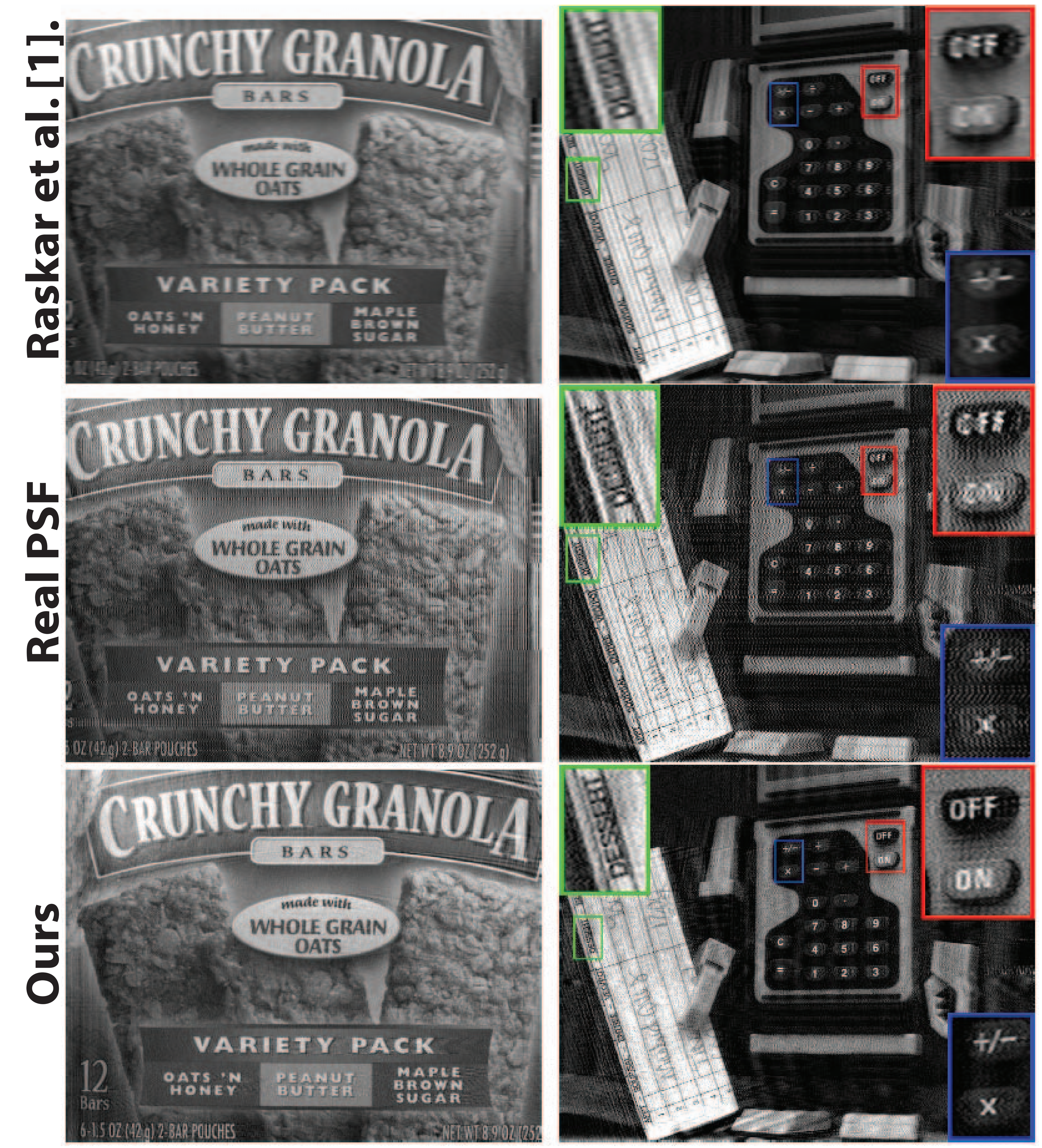
Step 2: Rank each partition by the upper bound of the MTF.

Step 3: Rank order search, determining start times until...

End condition: The upper bound MTF of the next best partition is worse than the current best MTF.

Full algorithm details can be found in the paper.

Experimental Results



Summary

We characterize the performance of shutter timing sequences for coded exposure de-blurring, and show that a unique timing sequence is needed for different object velocities. We also demonstrate and characterize a previously undocumented noise effect in coded exposure with electronic shutters. Based on these findings, we present an algorithm to find velocity-dependent sequences and demonstrate their utility on real images.

Key References

[1] Ramesh Raskar, Amit Agrawal, and Jack Tumblin. *Coded Exposure Photography: Motion Deblurring using a Fluttered Shutter.* In Proceedings of SIGGRAPH 2006.