Object Tracking and Image Reconstruction from Compressive Sensing Cameras

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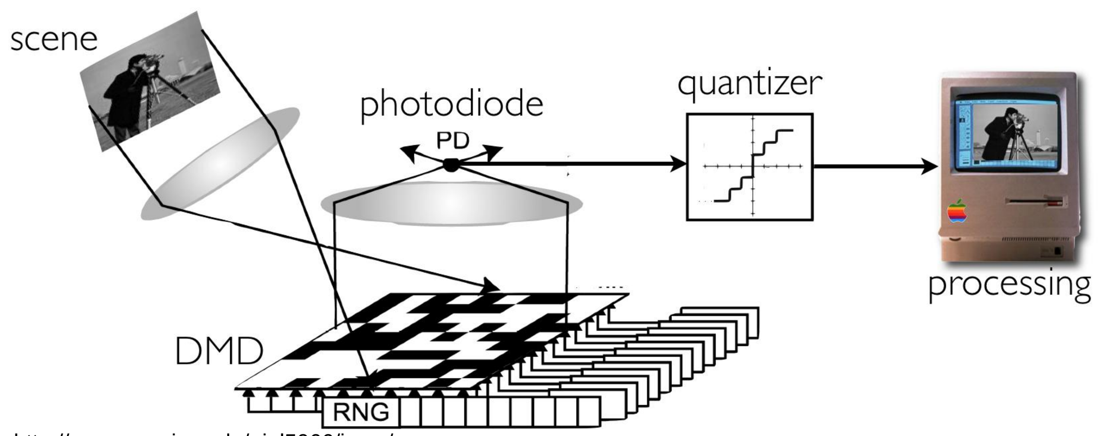
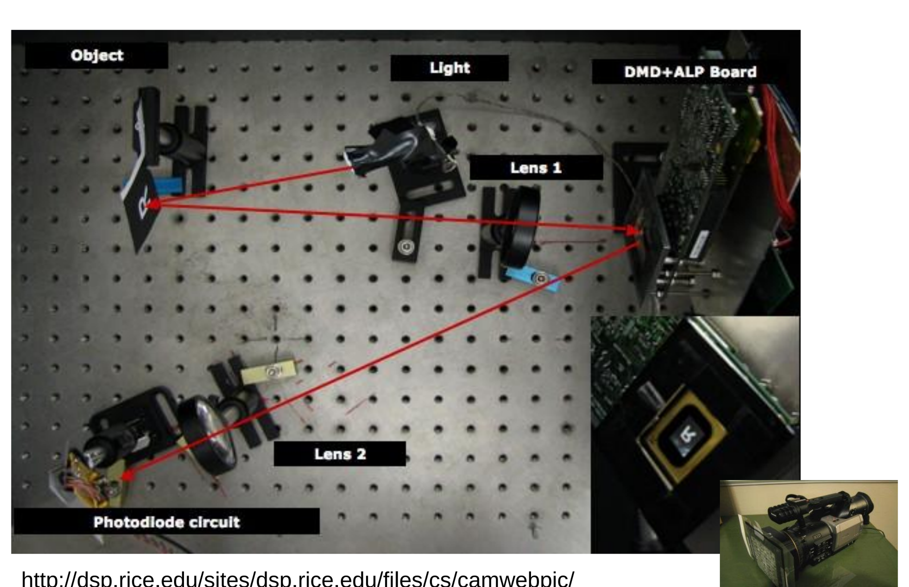


http://www.ece.rice.edu/~jnl5066/imgs/cscamera.png

Summary

Compressive imaging is a novel sensing paradigm which promises lower data rates and lower cost sensing hardware, particularly in non-visible wavelengths where per-pixel costs are high. However, current methods for reconstructing compressively sensed videos do not fully exploit prior knowledge of motion and frame-to-frame correlations. We have extended typical l_1 reconstruction to incorporate optical flow information when simultaneously reconstructing multiple frames of video. Although estimating generalized dense optical flow from compressively sensed data is a difficult and unsolved problem, we demonstrate the usefulness of this approach for two special cases: known optical flow and unknown but constant optical flow. In both cases, a clear perceptual improvement in reconstructed frames is evident, as is an increase in Peak Signal-to-Noise Ratio (PSNR).



http://dsp.rice.edu/sites/dsp.rice.edu/files/cs/camwebpic/cscamerasetup.jpg

http://cs.uky.edu/~jacobs/projects/integral-pixel-motion/camera_with_arrays_small.jpg

Compressive Sensing Camera Architecture

•Rather than sensing a grid of m small pixels, take a series of linear measurements $\mathbf{y}$ over the whole image using n different pseudorandom masks.

•$n << m$, hence the signal is *compressively sensed.*

•The original image is known to be sparse (i.e. compressible) using some basis B, for example a wavelet basis:

$$\mathbf{y} = \mathrm{M}\mathbf{x} = \mathrm{MB}\boldsymbol{\theta}$$

Compressive measurement

Sparse image vector

Measurement matrix

Image vector

Basis matrix

Video Reconstruction Incorporating Optical Flow

•Modern video codecs exploit correlations between neighboring frames when encoding video from conventional cameras – how can we do the same when reconstructing compressively sensed video sequences?

•If we know the optical flow vectors u and v between two frames, we can reconstruct by solving the following optimization problem:

$$\hat{\boldsymbol{\theta}},\hat{\boldsymbol{\eta}} = \underset{\boldsymbol{\theta},\boldsymbol{\eta}}{\mathrm{argmin}} \left\| \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \end{bmatrix} - \begin{bmatrix} \mathrm{MB} & 0 \\ \mathrm{MF}_{\mathbf{u},\mathbf{v}}\mathrm{B} & \mathrm{M} \end{bmatrix} \begin{bmatrix} \boldsymbol{\theta} \\ \boldsymbol{\eta} \end{bmatrix} \right\|_2 + \tau \left\| \begin{bmatrix} \boldsymbol{\theta} \\ \boldsymbol{\eta} \end{bmatrix} \right\|_1$$

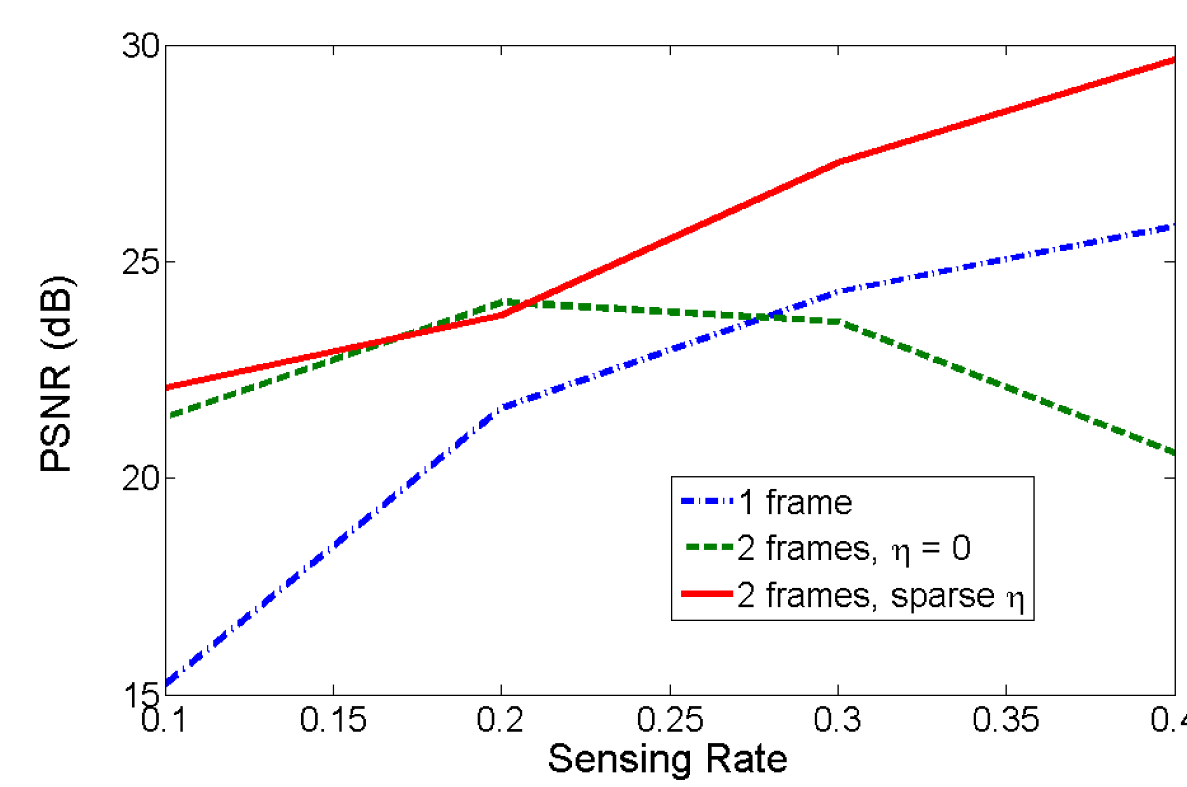
•If optical flow is known to be constant across the image, we can perform single-frame reconstruction to estimate the shift between frames, and use this shift as before to perform 2-frame reconstruction.

Results

Reconstruction with known motion

- The reconstruction algorithm above was tested using the Middlebury optical flow dataset, which includes known optical flow data.
- Clear improvements in both perceptual quality and PSNR across a wide range of sensing rates.

Ground Truth | Single-frame reconstruction | 2-frame reconstruction with optical flow



Reconstruction with constant shift

- The algorithm was tested on a single cropped frame from the PETS2000 dataset, with a shift introduced to simulate a moving camera.

Ground Truth | Single-frame reconstruction PSNR = 24.4 dB | 2-frame reconstruction with optical flow PSNR = 27.21 dB

Conclusion

This work is an important first step toward fully incorporating temporal information in compressively sensed video. Relative to single-frame reconstruction, the algorithm described here shows clear benefits in the quality of reconstructed compressively sensed images. This knowledge may speed the commercialization of cost-effective imaging systems in a variety of wavelengths beyond the visible range.

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