High Quality Structure from Small Motion for Rolling Shutter Cameras

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Motivation

- Depth from accidental motion
  - Mobile phone camera (or) DSLR
    - Off-the-shelf Camera
    - Handshaking (Inevitable motion)
    - Narrow-baseline
    - 3sec (100 frames)

User-friendly

- Depth Applications
  - Refocusing
  - Background stylization

- Contribution
  - High quality depth map is estimated from popularized cameras
  - Feature extraction — remove features on moving objects using Essential matrices
  - Accurately estimate depth of sparse 3D points with handing the rolling shutter artifacts
  - Geometry guidance term assists to get high quality depth map

Sparse 3D reconstruction

- Feature extraction
  - Harris corner & KLT tracker
  - Outlier removal — Essential matrices from 5-pts algorithm
  - Fundamental matrix from Essential matrices & pre-calibrated camera intrinsic parameters

$$\mathbf{l}_2 = \mathbf{F}\mathbf{x}_1,\ \ \mathbf{l}_1 = \mathbf{F}^{\mathsf{T}}\mathbf{x}_2,\ \ \mathbf{l}^{\mathsf{T}}{}_1\mathbf{x}_1 = 0,\ \ \mathbf{l}^{\mathsf{T}}{}_2\mathbf{x}_2 = 0$$

- Bundle adjustment
  - LM optimization
  - With camera pose from decomposition of Fundamental matrix
  - Without depth information - Random depth initialization

$$C(\mathbf{r},\mathbf{t},\mathbf{X}) = \sum_{i=1}^{N_I}\sum_{j=1}^{N_J} ||\mathbf{x}_{ij} - \varphi(\mathbf{K}\mathbf{P}_{ij}\mathbf{X}_j)||^2$$

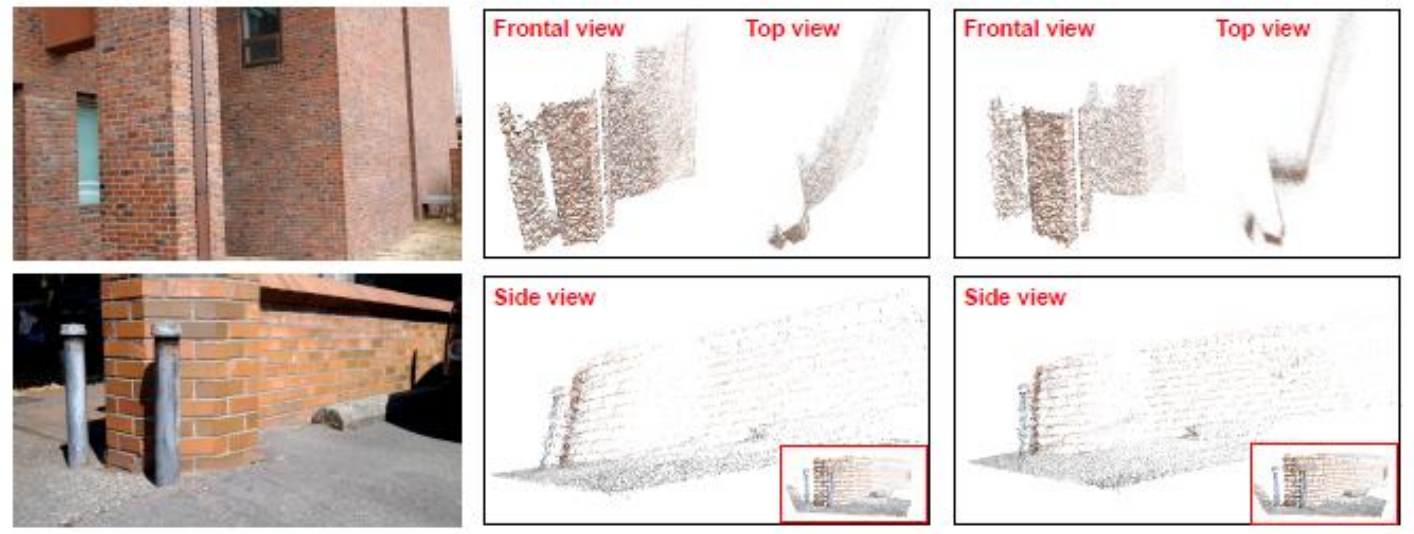
- Geometric model for small motion
  - Rotation matrix - Small angle approximation
  - Key to estimate pose and depth without any prior depth information [1]

$$\mathbf{P} = [R(\mathbf{r})|\,\mathbf{t}],\ where\ R(\mathbf{r}) = \begin{bmatrix} 1 & -r^z & r^y \\ r^z & 1 & -r^x \\ -r^y & r^x & 1 \end{bmatrix}$$

- Rolling shutter effect handling
  - Rotation, Translation vector - Linear Interpolation

$$\mathbf{r}_{ij} = \mathbf{r}_i + \frac{ak_{ij}}{h}(\mathbf{r}_{i+1} - \mathbf{r}_i) \qquad \mathbf{t}_{ij} = \mathbf{t}_i + \frac{ak_{ij}}{h}(\mathbf{t}_{i+1} - \mathbf{t}_i)$$

- Structure from Small Motion result with/without Rolling Shutter handling



Reference | SfSM without RS handling | SfSM with RS handling

Dense 3D reconstruction

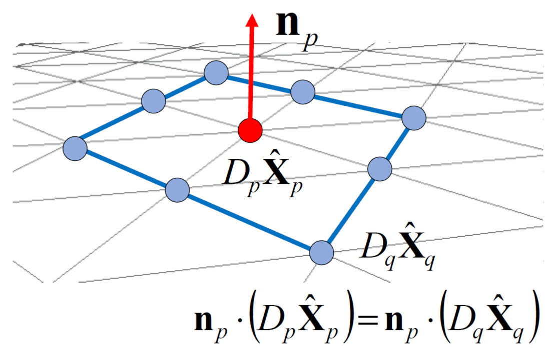
- Objective function

$$E(\mathbf{D}) = E_d(\mathbf{D}) + \lambda_c E_c(\mathbf{D}) + \lambda_g E_g(\mathbf{D})$$

- Data term & Color smoothness term
  - Data term - Sparse 3D point cloud
  - Color term — Neighboring pixel with similar color have similar depth

$$E_d(\mathbf{D}) = \sum_j \left(D_j - Z_j\right)^2 \qquad E_c(\mathbf{D}) = \sum_p \sum_{q\in W_p} \left(D_p - \frac{w^c_{pq}}{\sum_q w^c_{pq}} D_q\right)^2$$

- Geometry guidance term
  - Low spatial resolution
  - Normal should be pre-calculated

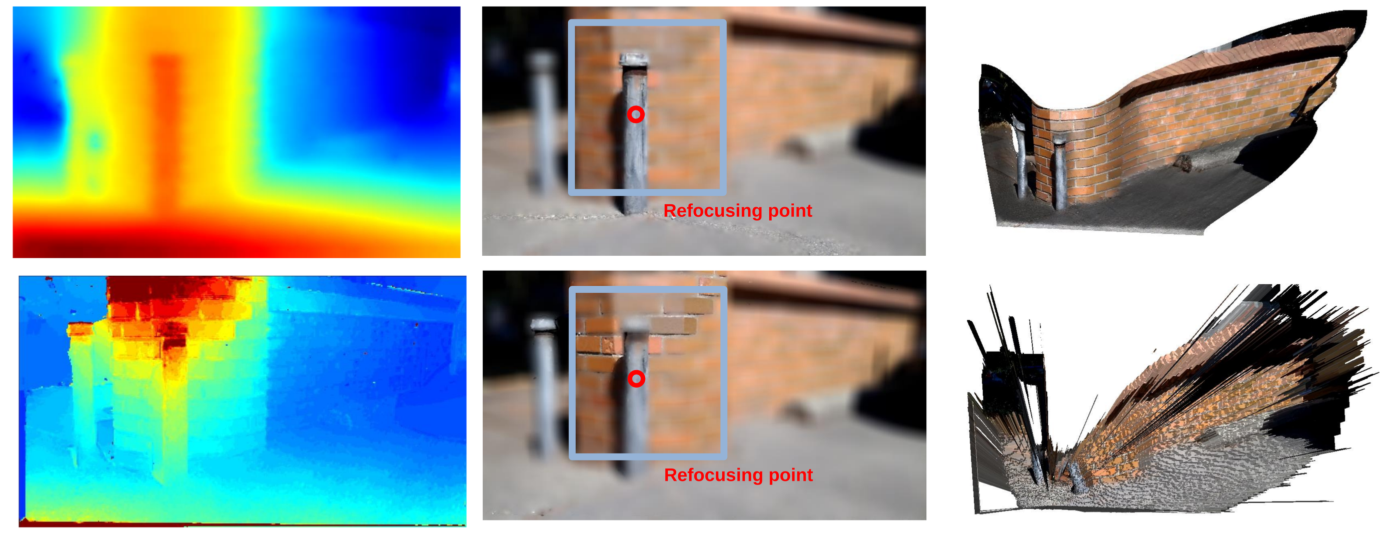


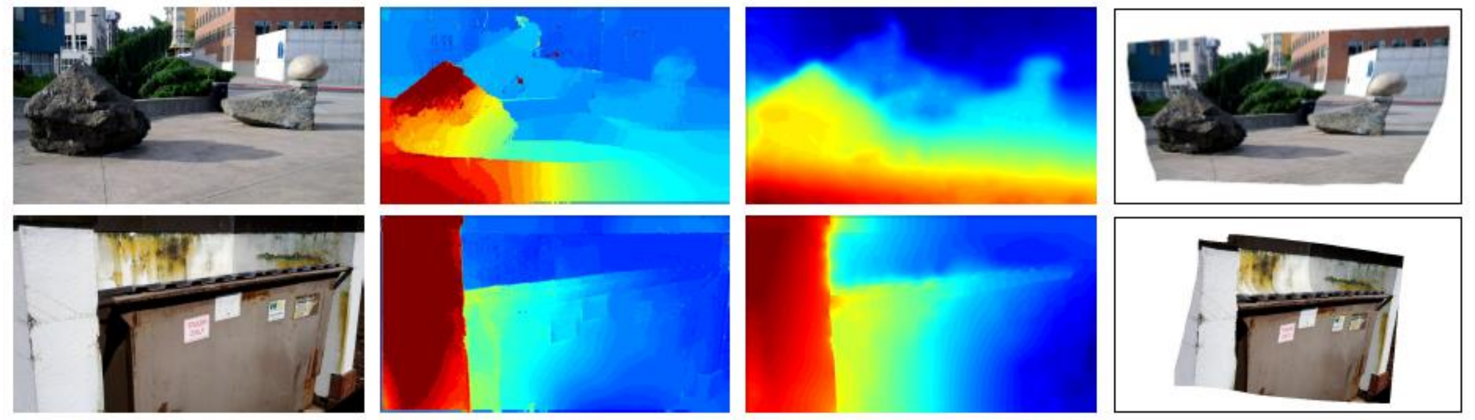
$$E_g(\mathbf{D}) = \sum_p \sum_{q\in W_p} w^g_p \left(D_p - \frac{\mathbf{n}_p\cdot\hat{\mathbf{X}}_q}{\mathbf{n}_p\cdot\hat{\mathbf{X}}_p} D_q\right)^2$$

- Normal estimation
  - Using local plane fitting
  - Color-based propagation

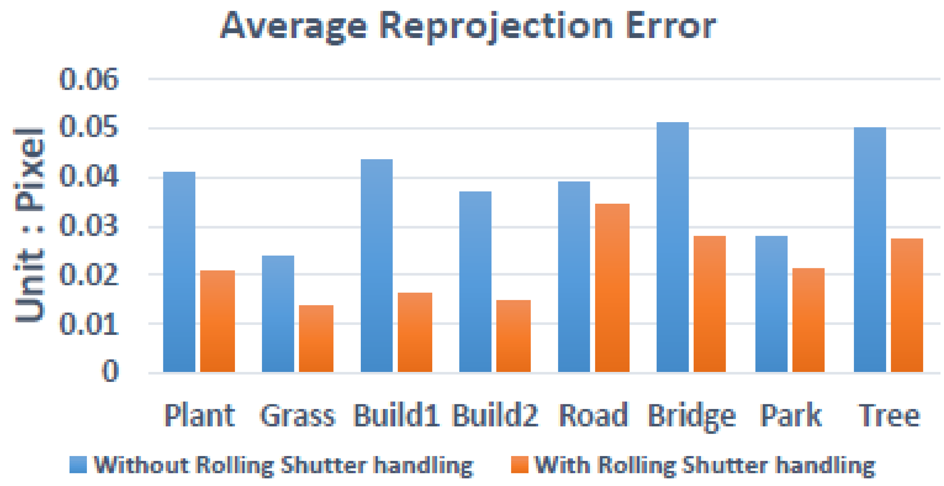
Experiments

- Comparison with state-of-the-art [1] (Captured by Goole Galaxy Nexus)

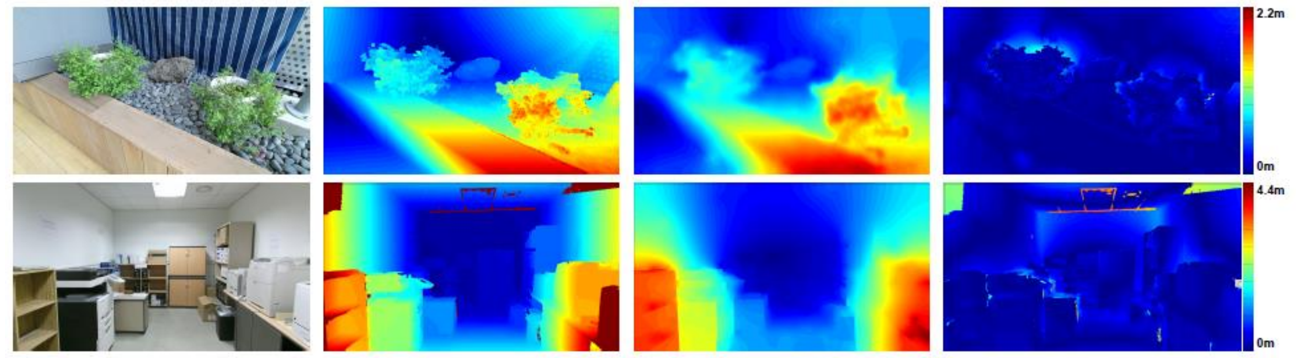




- Structure from Small Motion result with/without Rolling Shutter handling



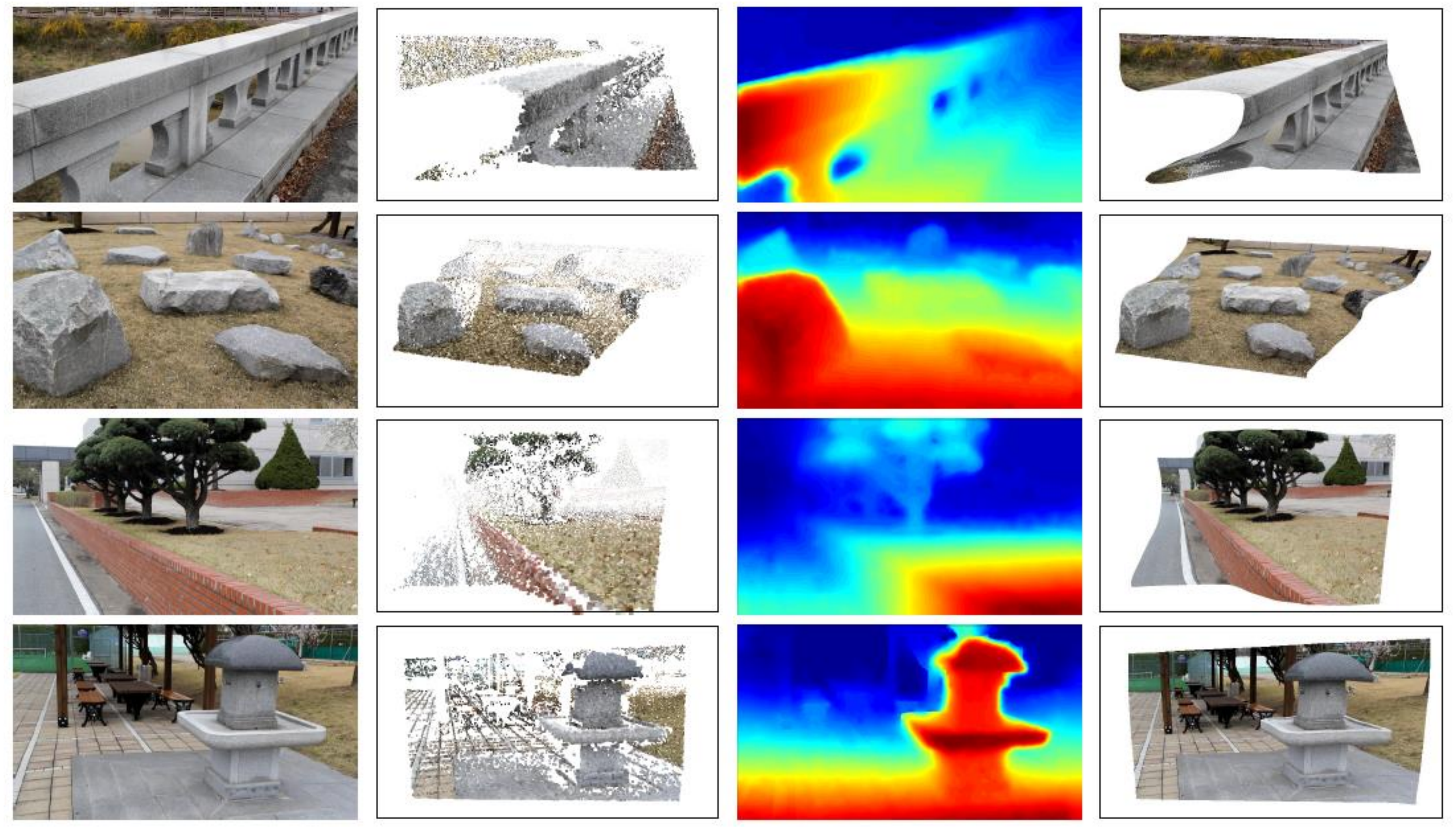
- Result comparison with the depth from Kinect (Captured by Kinect RGB sensor)



Dataset	*Max. depth*	R10	R20
Pot	2.2*m*	94.14%	99.07%
Room	4.4*m*	85.50%	96.31%

R10 : The percentage of pixels that have distance error less than 10% of the maximum depth value in the scene

- Our final results (Captured by Canon EOS60D)



- Applications
  - Refocusing

- Stylization

- Face Reconstruction

References

[1] Yu, Fisher, and David Gallup. "3D Reconstruction from Accidental Motion. "*Computer Vision and Pattern Recognition (CVPR), 2014 IEEE Conference on*. 2014.

[2] N. Joshi and C. L. Zitnick. Micro-baseline stereo. Microsoft Research Technical Report MSR-TR-2014-73, 2014.

[3] J. Hedborg, P.-E. Forssen, M. Felsberg, and E. Ringaby. ´ Rolling shutter bundle adjustment. In Proc. of Comp. Vis. and Pattern Rec. (CVPR), 2012.

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https://sites.google.com/site/shimrcv/