Fast Burst Images Denoising

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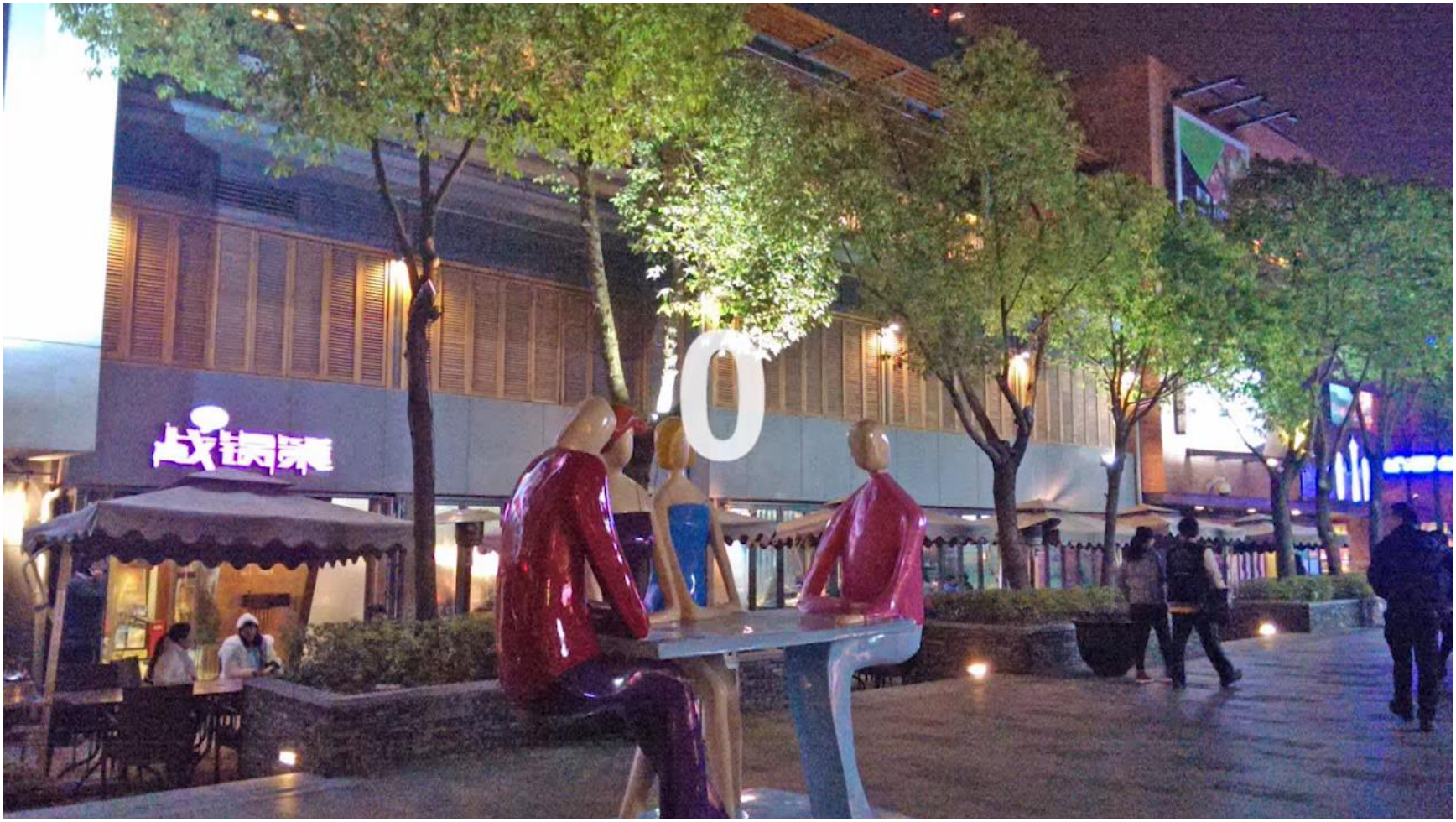
Image denoising

single image denoising

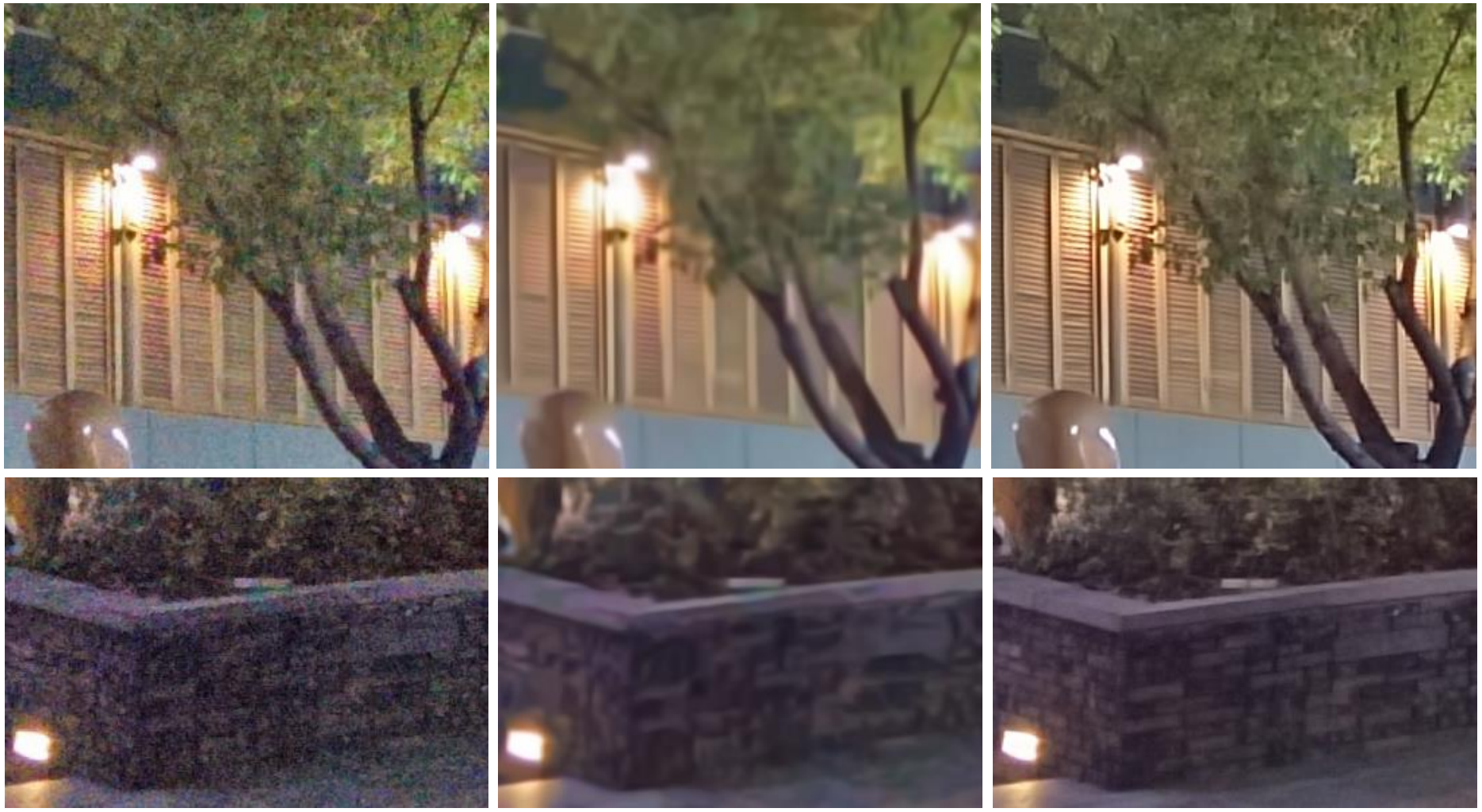
burst images denoising

video denoising

Burst images capturing

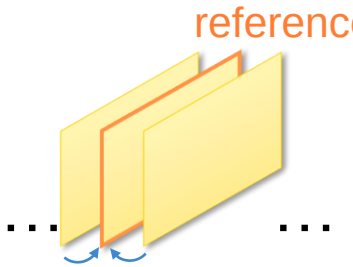


Single image *vs.* multiple images



original noisy frame | single image denoising (BM3D) | multiple images denoising (ours)

Basic pipeline of burst images denoising



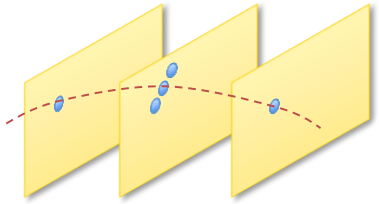
input images

motion estimation

images denoising

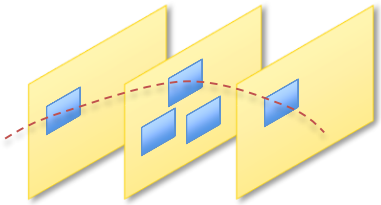
output image

- Camera motion
  - Point-wise



[Bennett and McMillan 2005]
[Joshi and Cohen 2010]

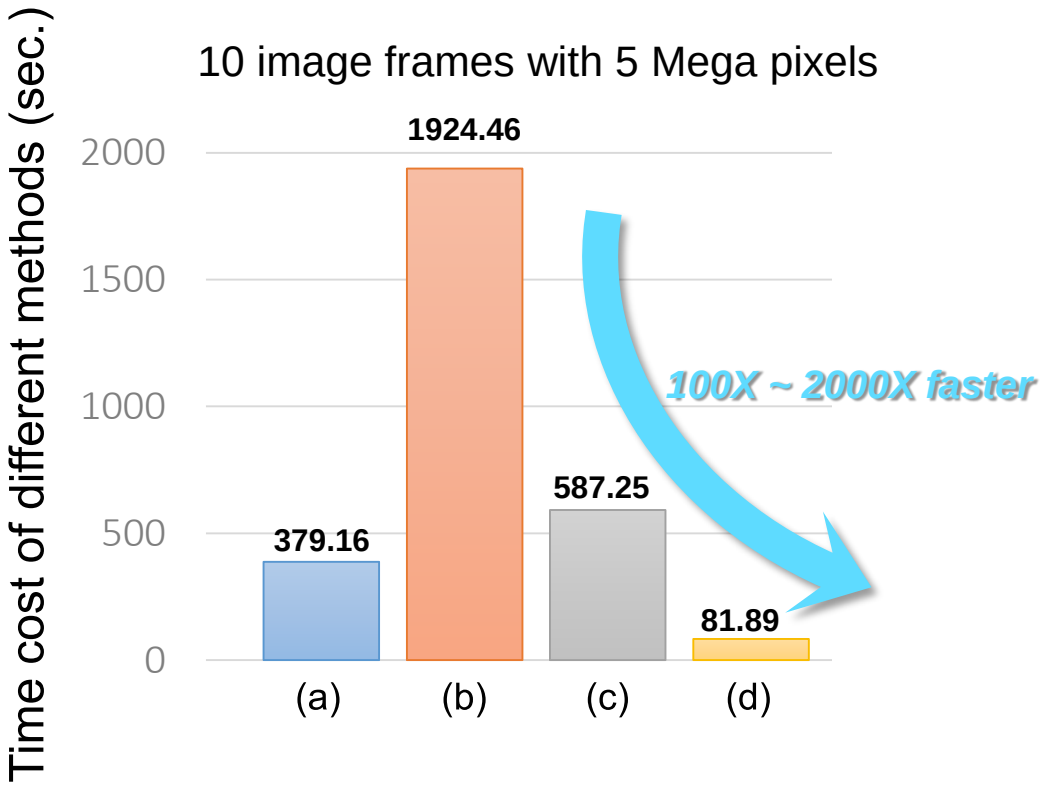
- Scene motion
  - Patch-wise



[Dabov et al. 2007]
[Maggioni et al.2013]

Challenges

- Speed



(a) Spatial-temporal filtering [Bennett and McMillan 2005]

(b) BM4D [Maggioni et al.2013]

(c) Optical flow [Liu 2009] + Median filtering

(d) Lucky imaging [Joshi and Cohen 2010]

(e) Our method

Challenges

- Quality: ***detail recovery***

(c) Optical flow [Liu 2009] + Median

(d) Lucky imaging [Joshi and Cohen 2010]

(e) Our method

Challenges

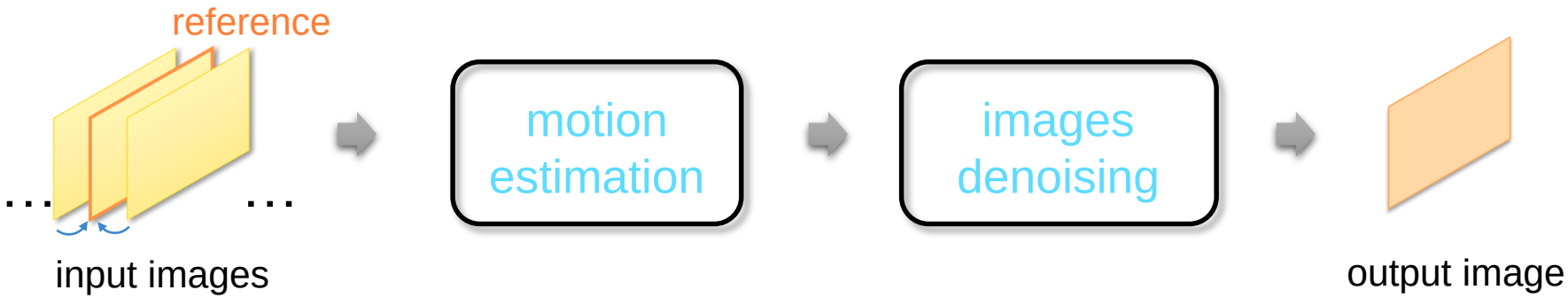
- Quality: ***ghost-free***

(c) Optical flow [Liu 2009] + Median

(d) Lucky imaging [Joshi and Cohen 2010]

(e) Our method

Our fast solution



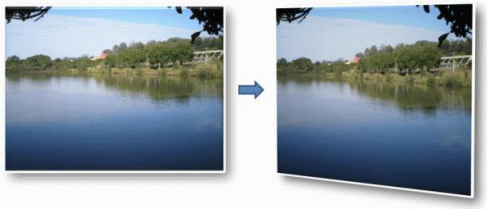
- Homography flow (*for* ***camera motion***)
- Consistent pixels selection (*for* ***scene motion***)
- Temporal & multiscale pixels fusion

Motion estimation

- Camera motion

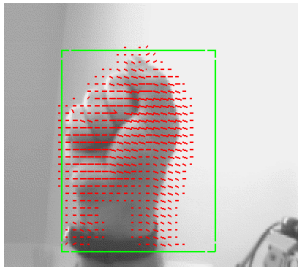
- Scene motion

Global homography registration



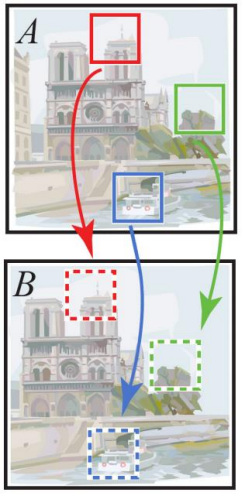
- ***Fast***
- ***Scene motion***
- ***Parallax issue***

Optical flow



[Brox et al. 2004]
[Liu 2009]

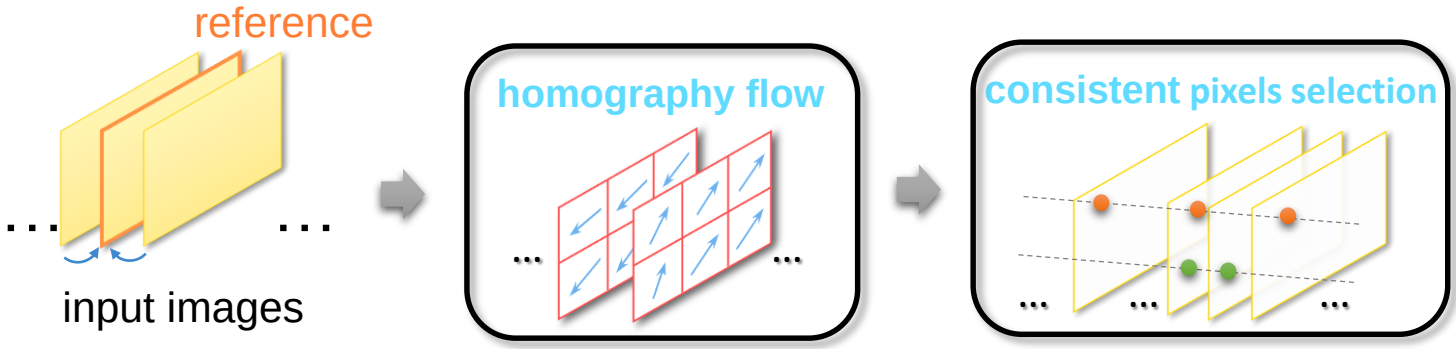
Patch matching



[Barbes et al. 2009]
[Buades et al.2005]

- ***Slow***
- ***Camera, Scene motion***
- ***Sensitive to noise***

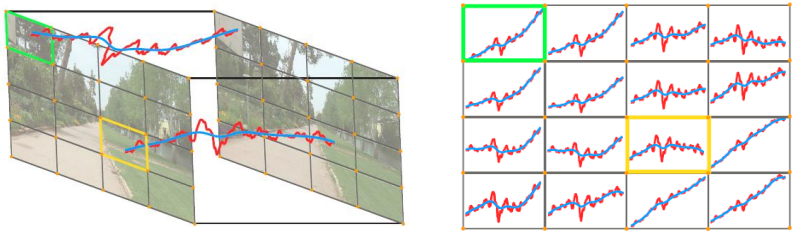
Motion estimation



- Homography flow (*for* ***camera motion***)
- Consistent pixels selection (*for* ***scene motion***)

Homography flow (*for* ***camera motion***)

- Mesh-based homographies (video stabilization)

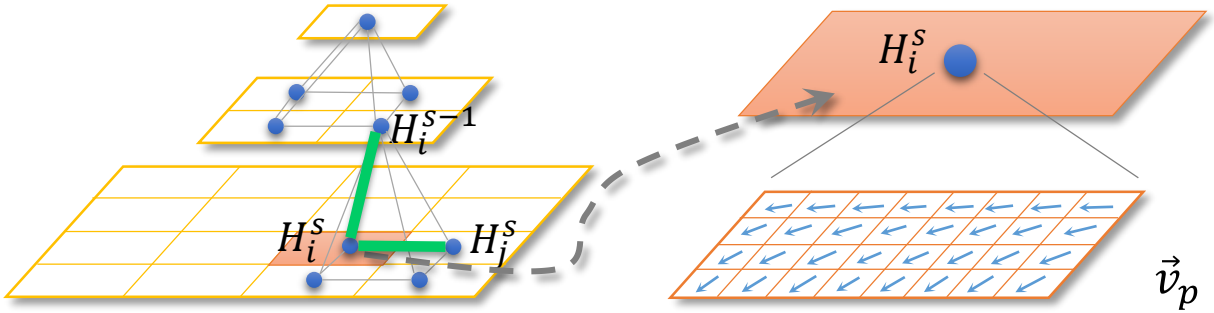


"as-similar-as-possible optimization"

[Liu et. al., SIGGRAPH 2013]

- Pyramid homography graph

$$\{\widehat{H}_i^s\} = argmin \sum_i \left(\left\| H_i^s - best(H_i^{s-1}, F_i^s) \right\|^2 + \lambda \sum_j \left\| H_i^s - H_j^s \right\|^2 \right)$$

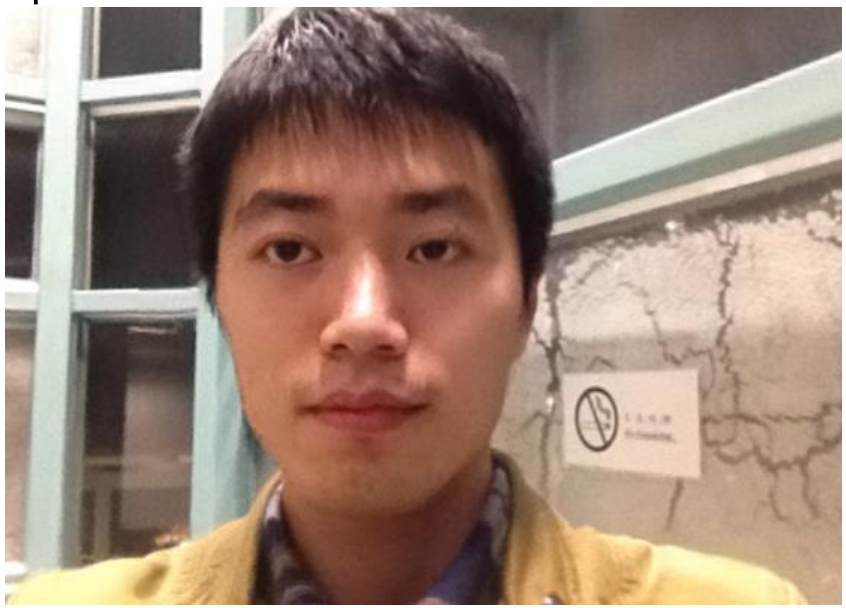


$$\vec{v}_p = H_i^s p - p$$

Global homography *vs.* homography flow

input sequence

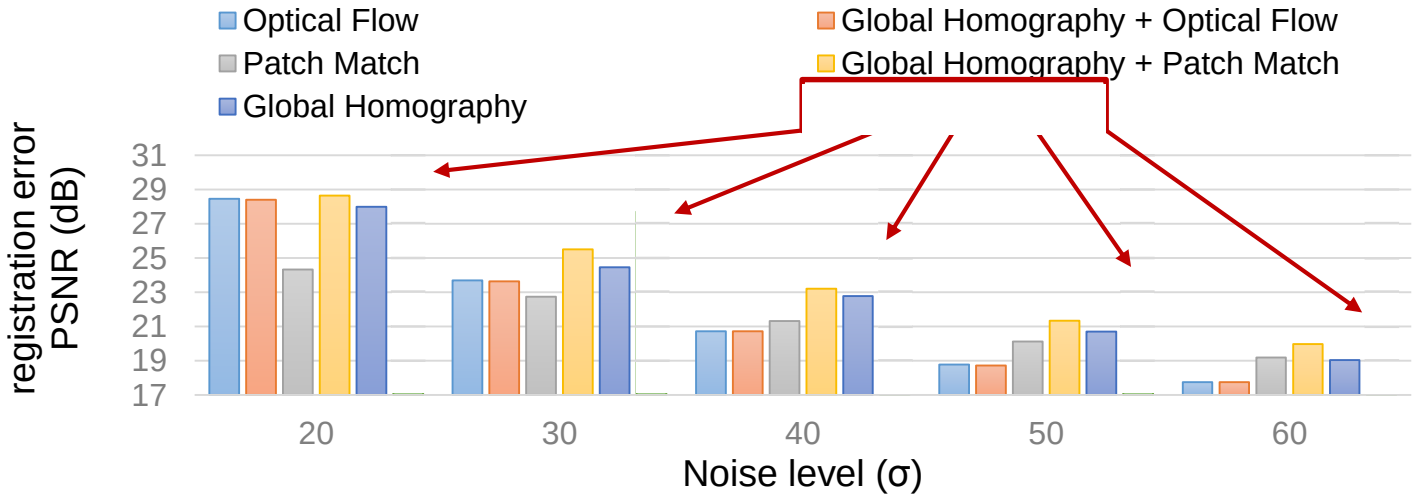
fusion result (global homography)



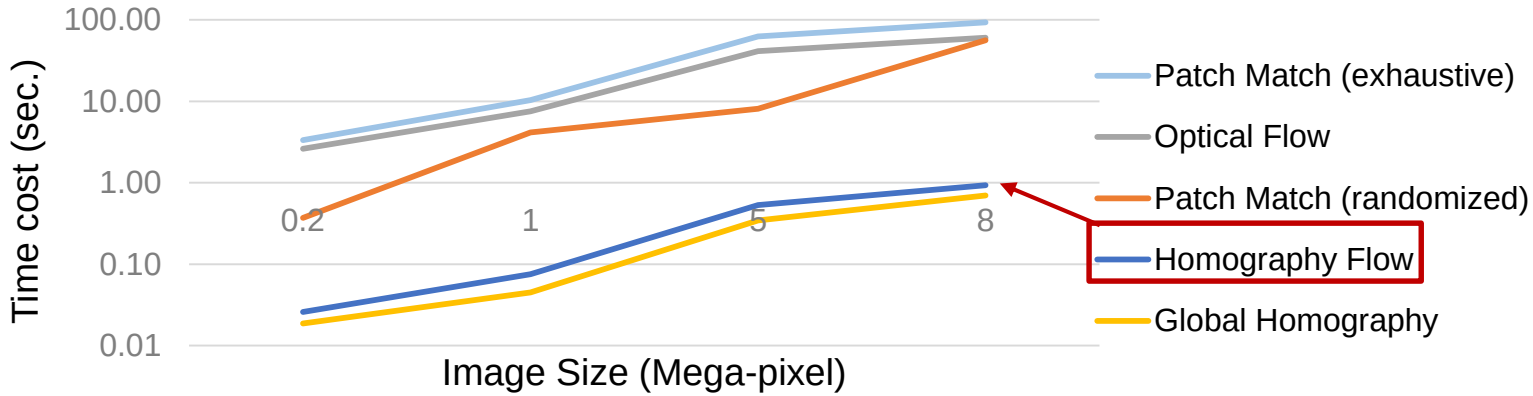
fusion result (homography flow)

Comparisons

- Registration error:

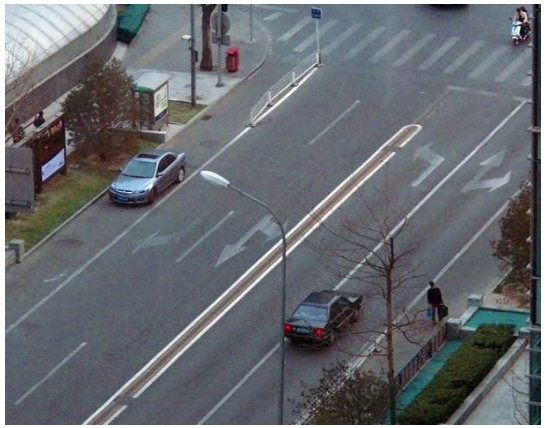


- Time cost:



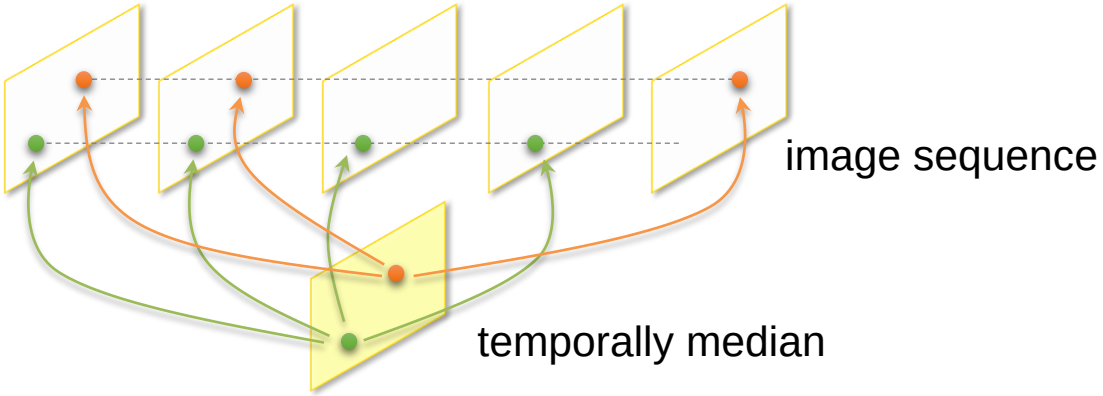
Consistent pixels selection (*for **scene motion***)

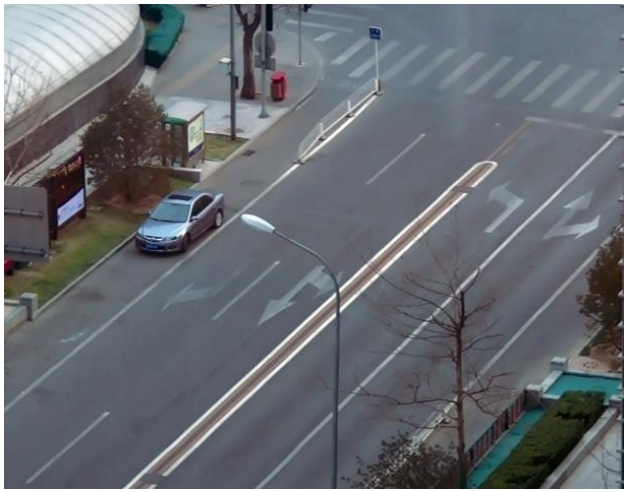
[Granados et al. 2013]



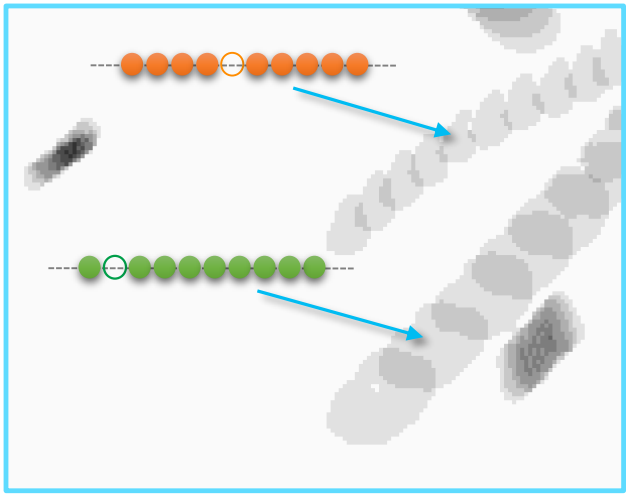
input images (fast motion)

- Median-based pixel selection:





fusion result

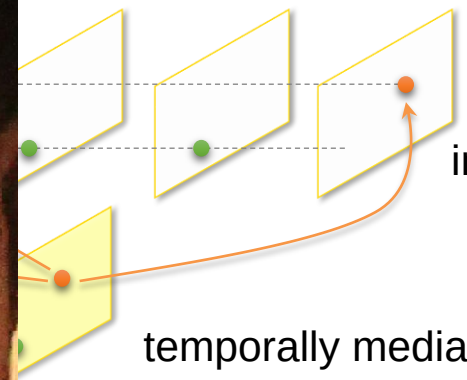


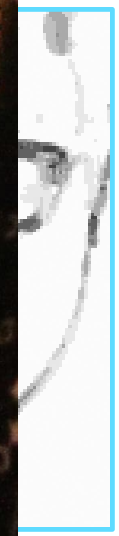
consistent pixels map

More samples for denoising!

Consistent pixels selection (*for **scene motion***)

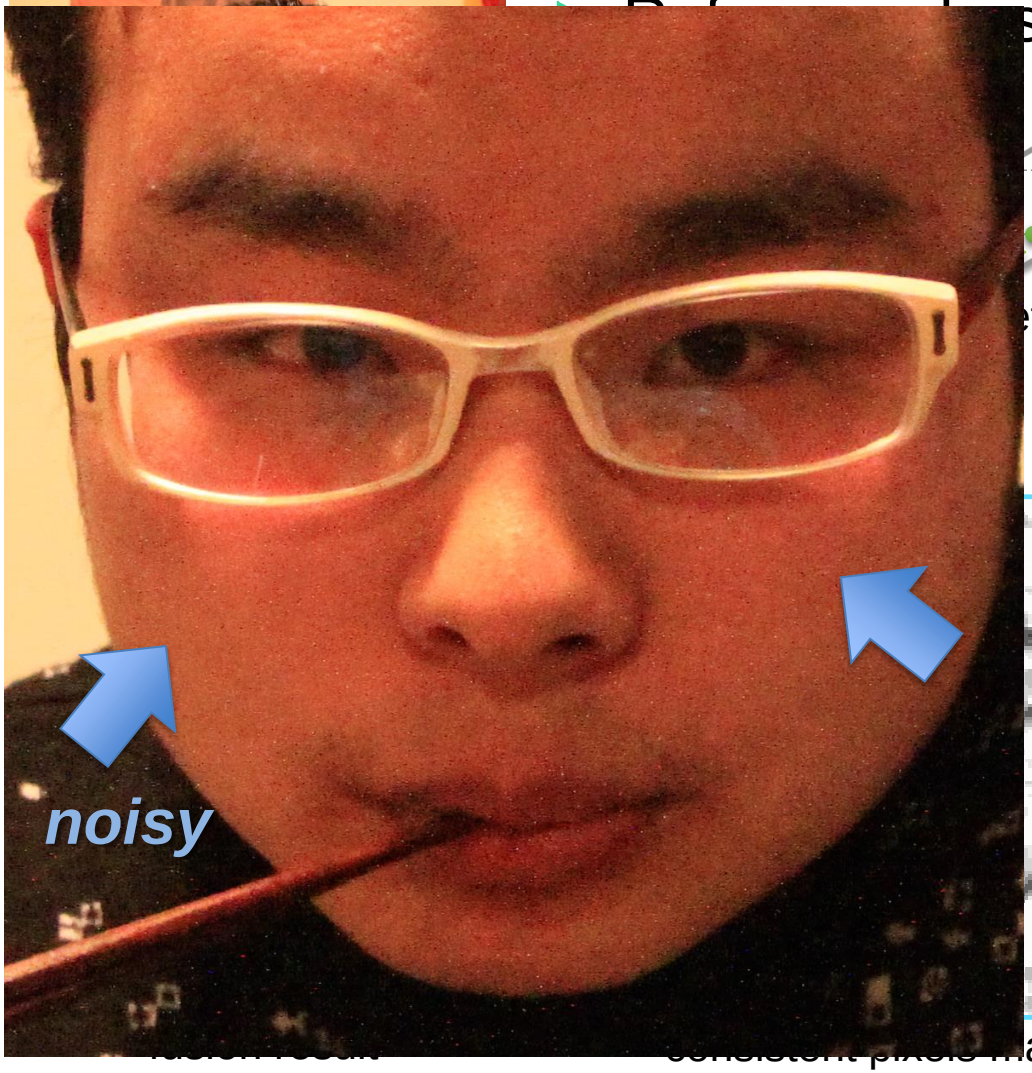
pixel selection:





- ***ghosts***
- ***more samples for denoising***

Consistent pixels selection (*for **scene motion***)



sed pixel selection:

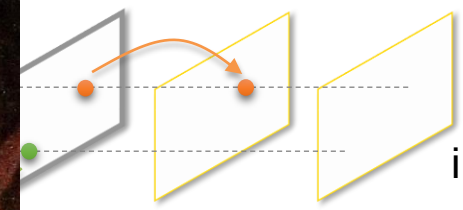


image sequence

eference

ap

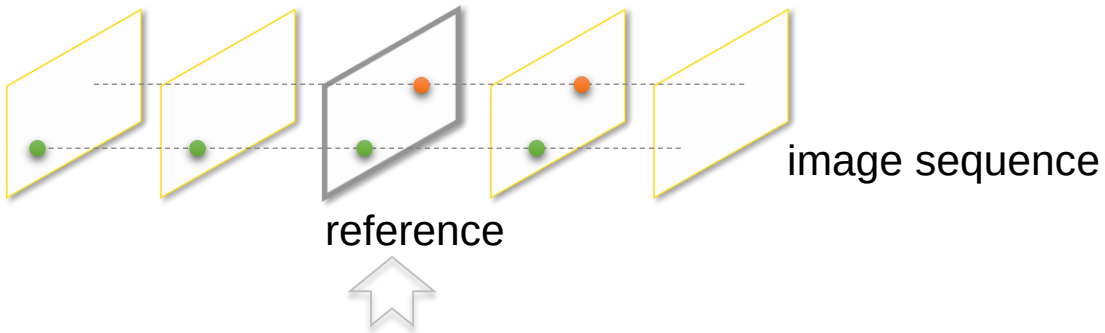
Avoid ghosts!

- ***ghost-free***
- ***less samples for denoising***

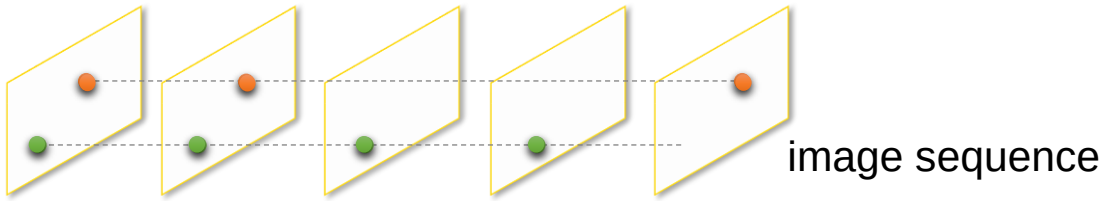
Consistent pixels selection (*for **scene motion***)

input images (slow motion)

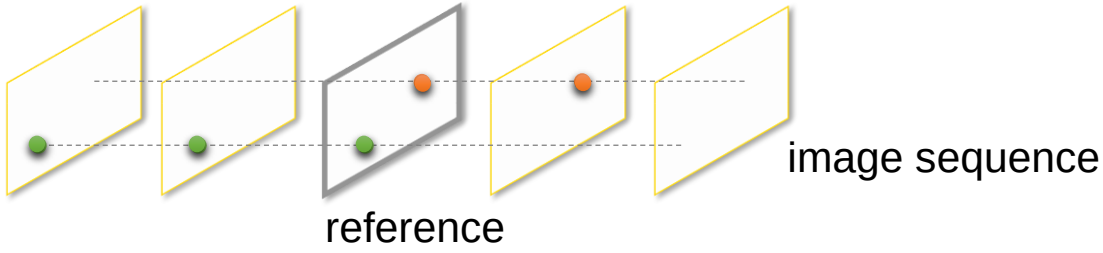
- Hybrid solution:



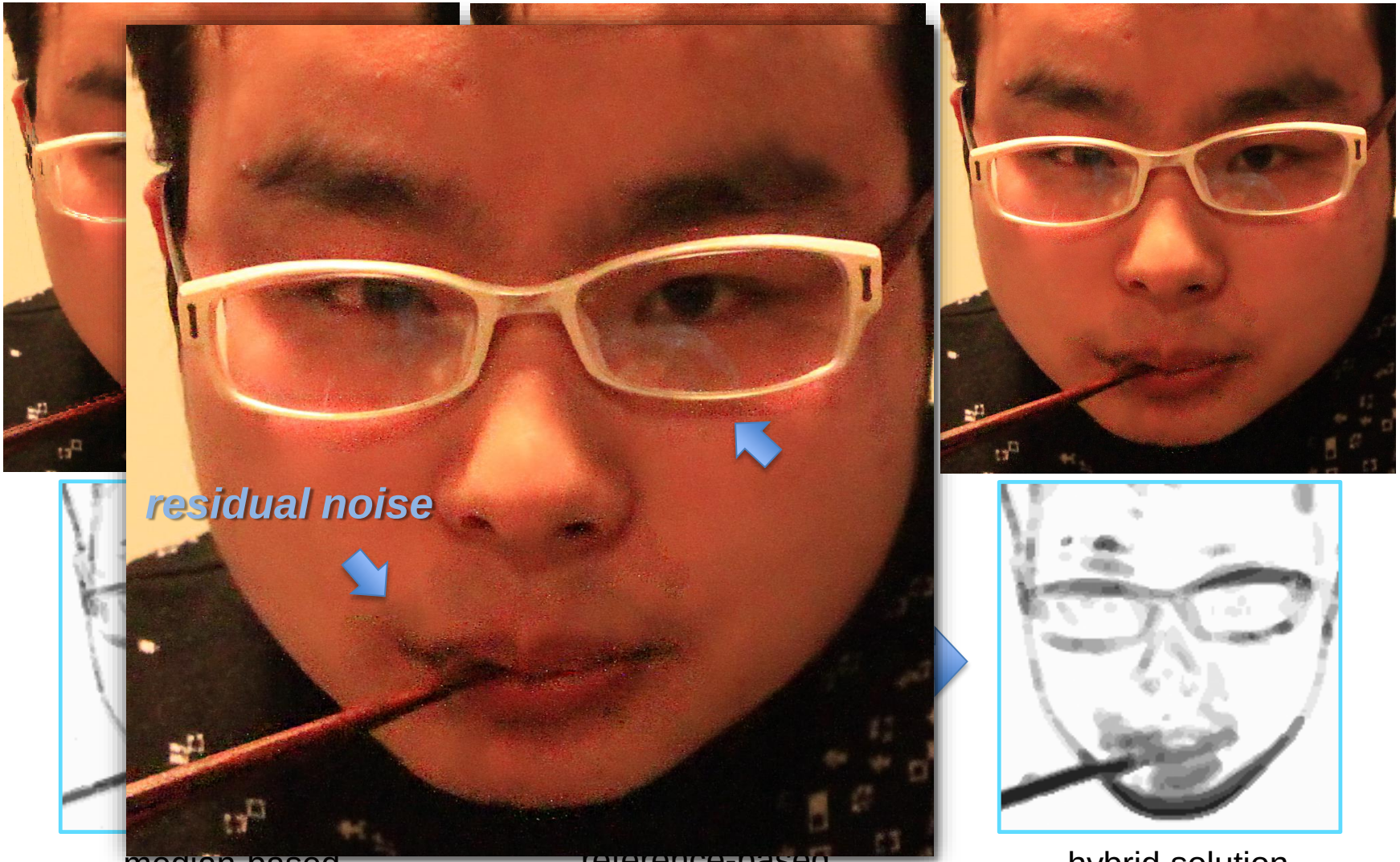
- Median-based pixel selection



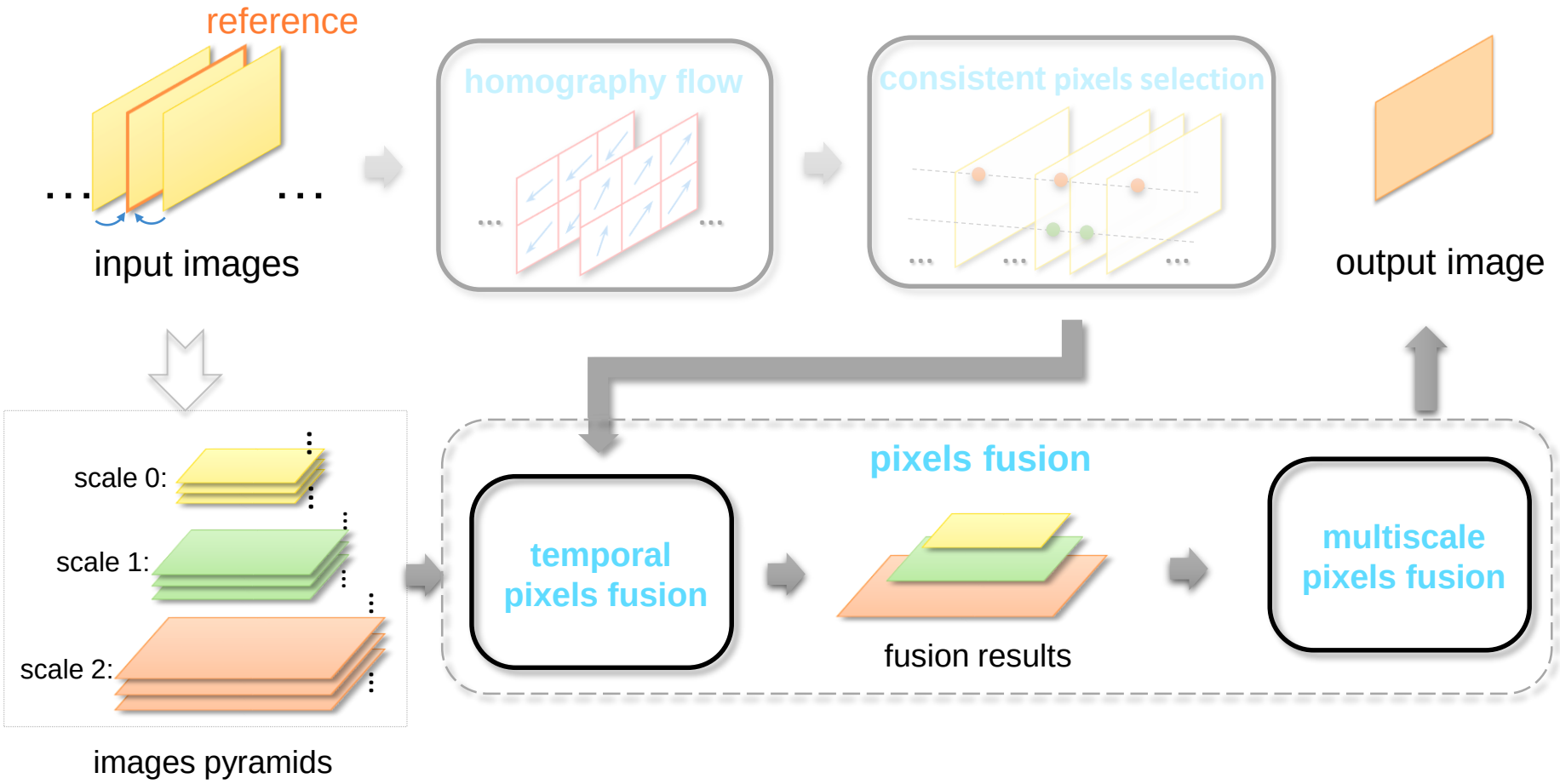
- Reference-based pixel selection



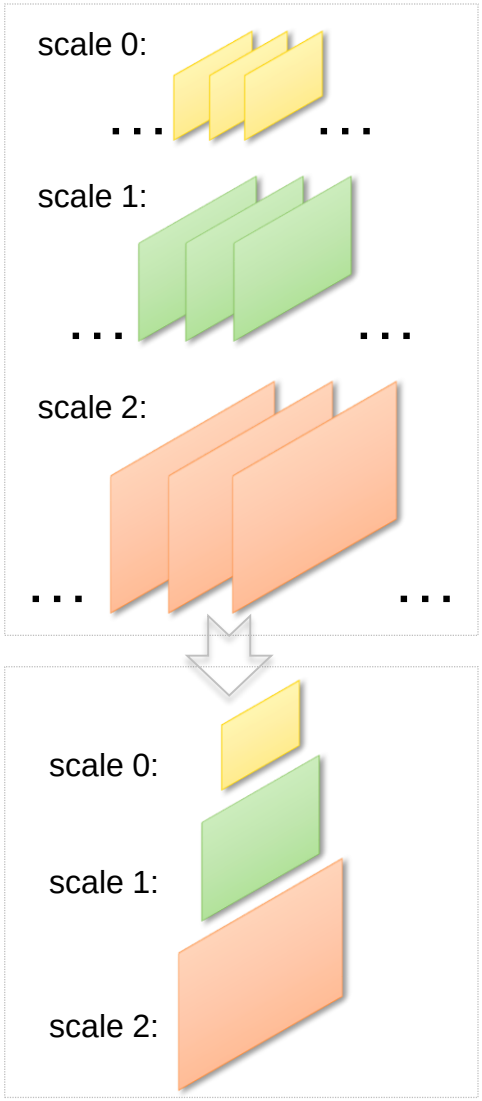
Consistent pixels selection (*for **scene motion***)



Pixels fusion



Temporal pixels fusion



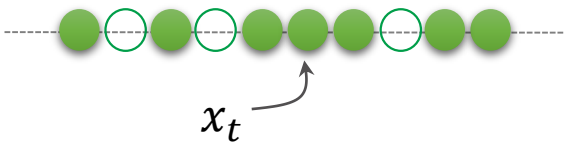
- Linear minimum mean square-error (LMMSE) estimator

$$\hat{x} = u + \frac{\sigma_t^2 - \sigma^2}{\sigma_t^2}(x_t - u)$$

$u: mean\ of\ \{x_t\}$

$\sigma_t: std.\ of\ \{x_t\}$

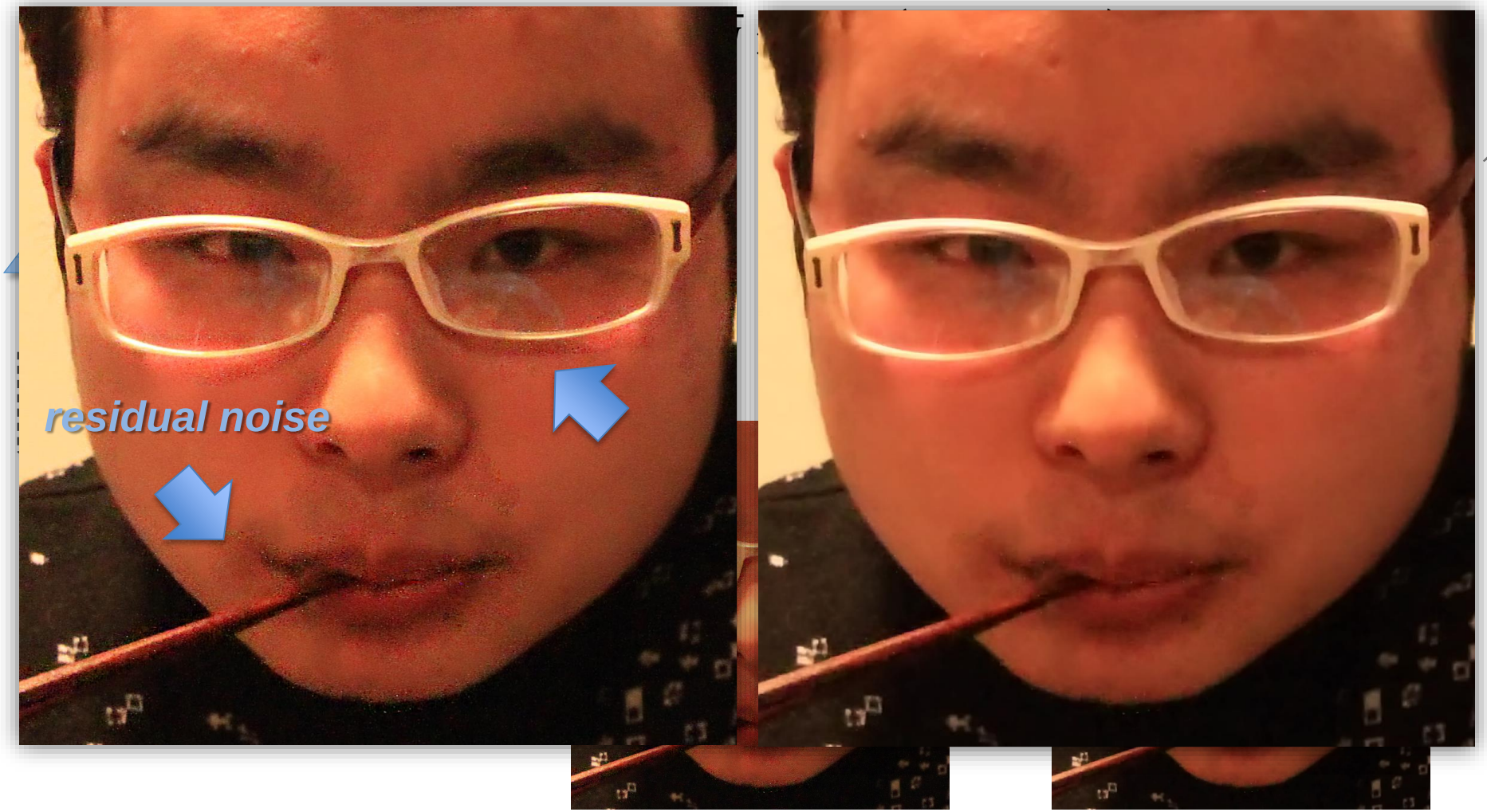
$\sigma: std.\ of\ noise$



- tiny moving structures

- discontinuities of depths

Multiscale pixels fusion

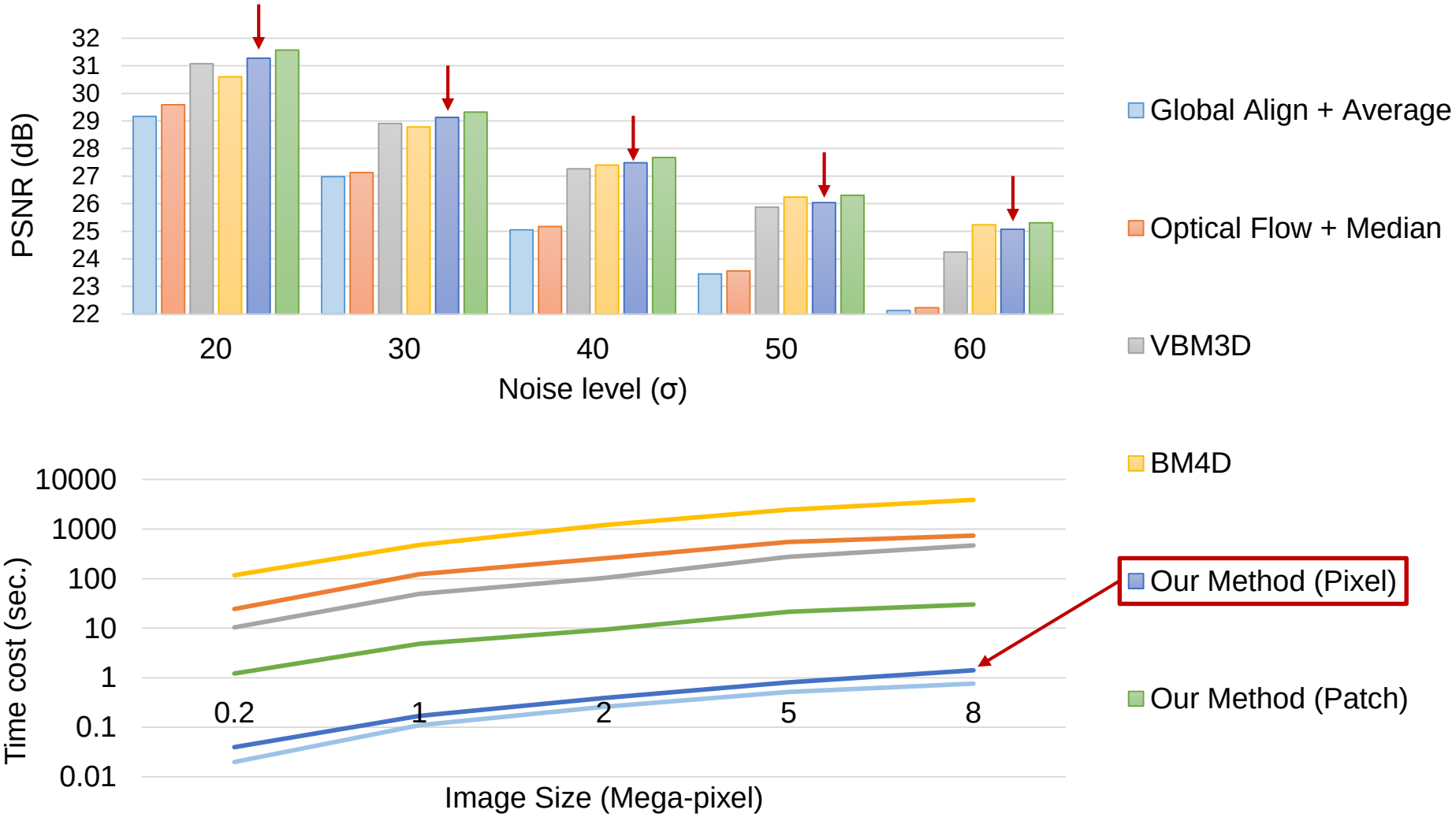


Evaluation of pixels fusion

- Clean image:
  - 68 images from Berkeley Segmentation Dataset [Martin et al. 2005]
- Synthesized noisy sequence:
  - Each sequence: 10 frames
  - Global homography (no parallax, static scene)
  - Additive Gaussian noise (σ = 20 ~ 60)

Berkeley Segmentation Dataset

Comparisons of fusion



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Comparisons on real examples

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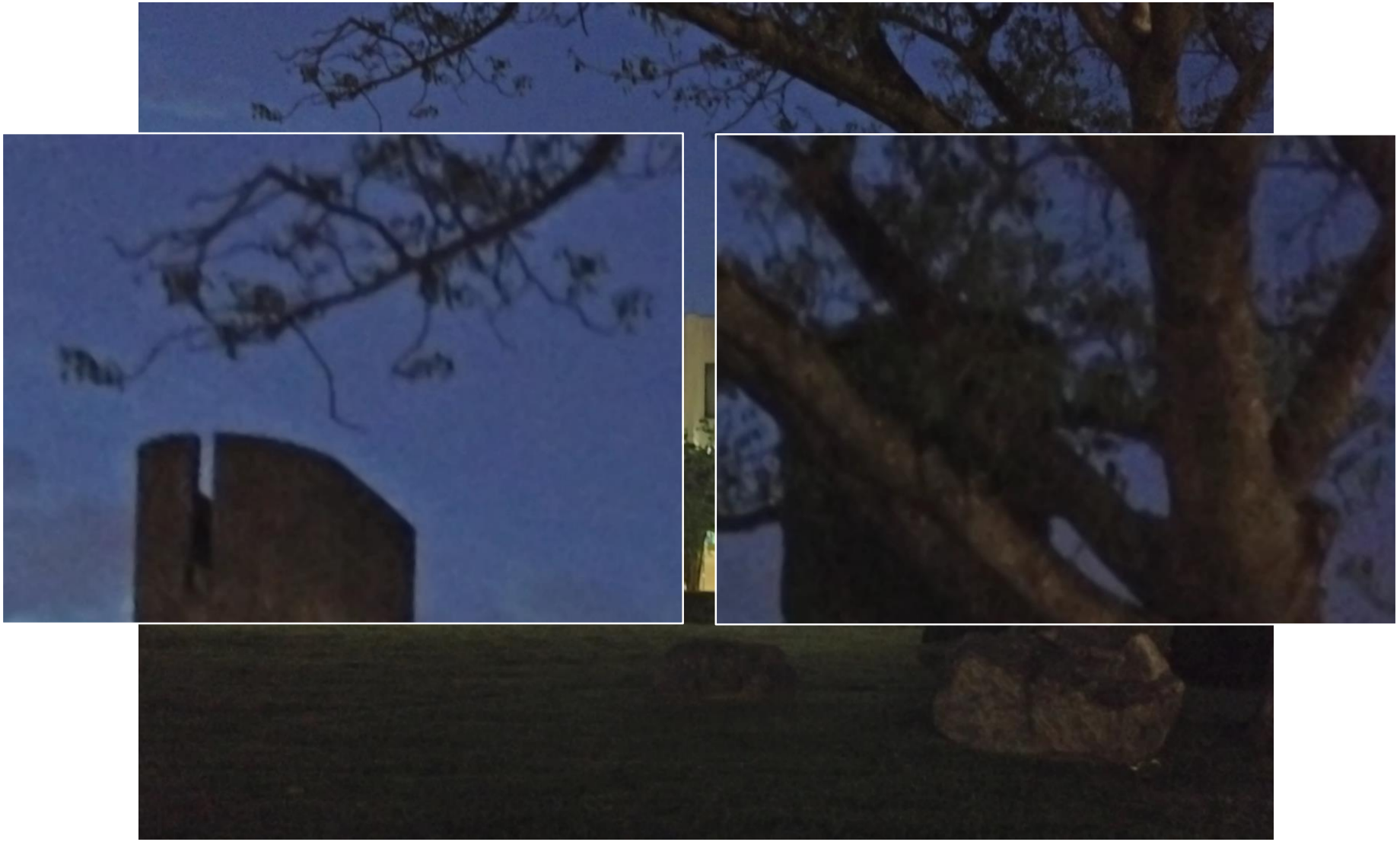
Static scene: 3264 X 2448, iPhone 5c

Reference frame

Our result

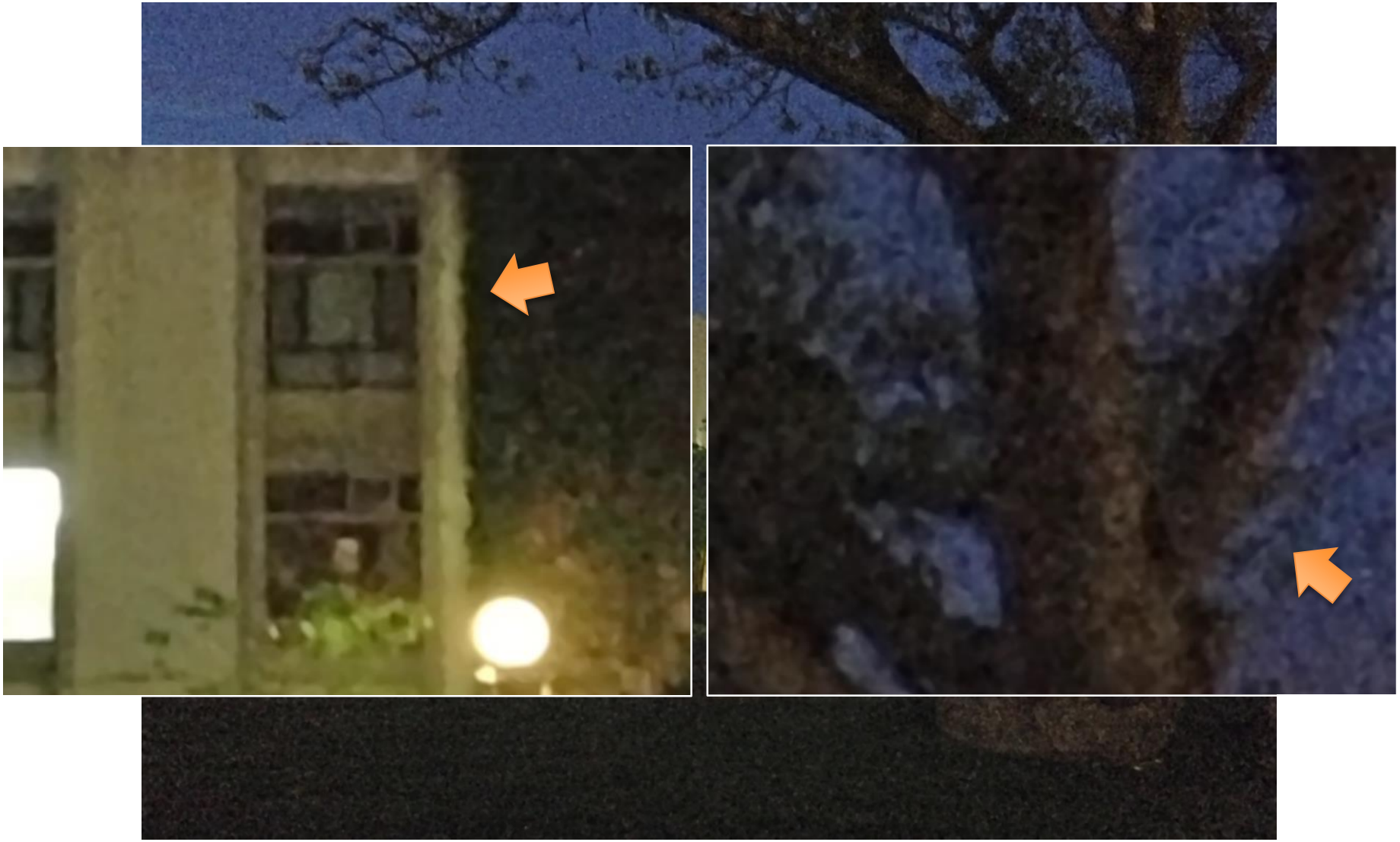
Spatial-temporal filtering [Bennett and McMillan 2005] *(644.82 sec.)*

Our result *(1.69 sec.)*

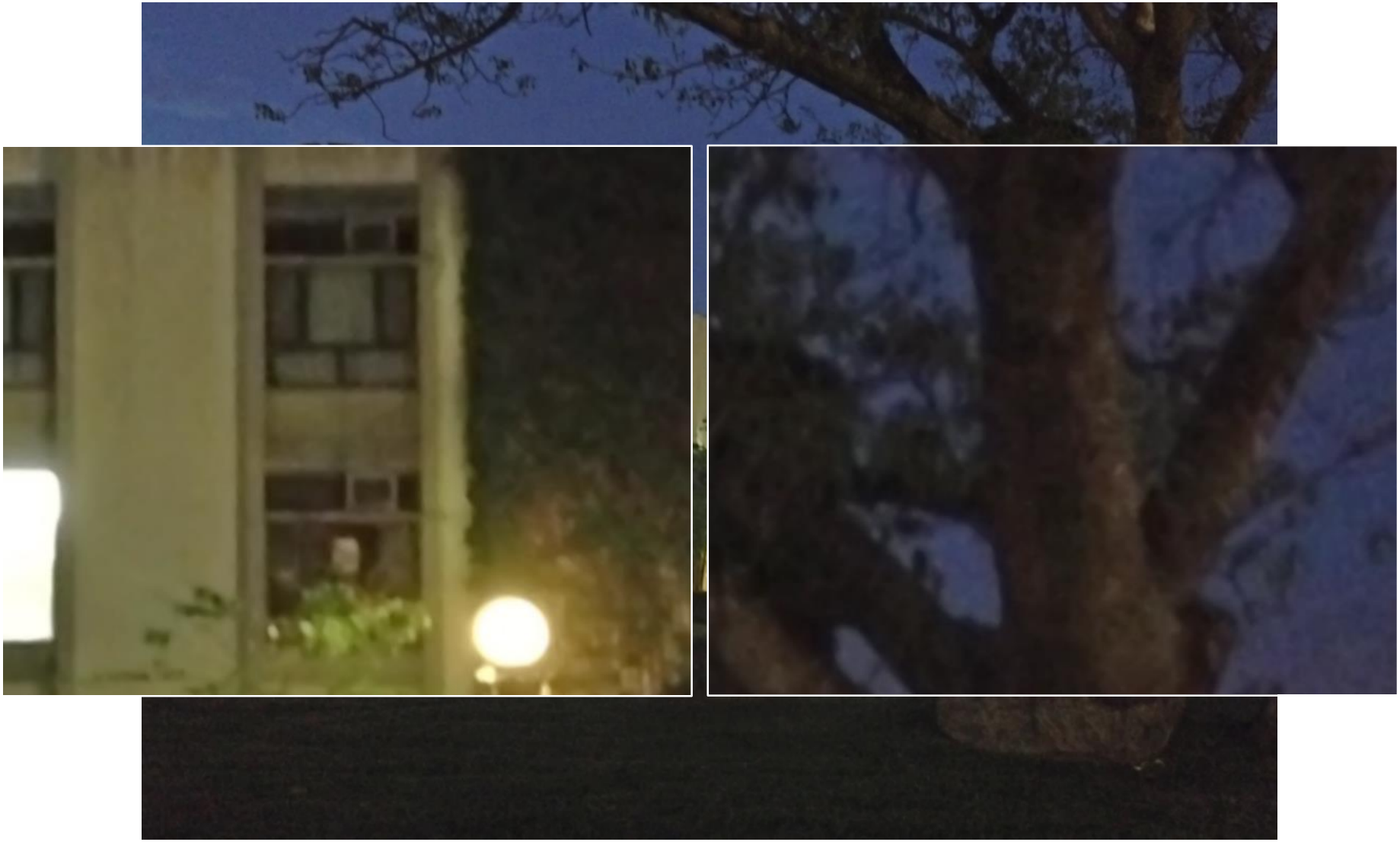


VBM3D [Dabov et al. 2007] *(442.68 sec.)*

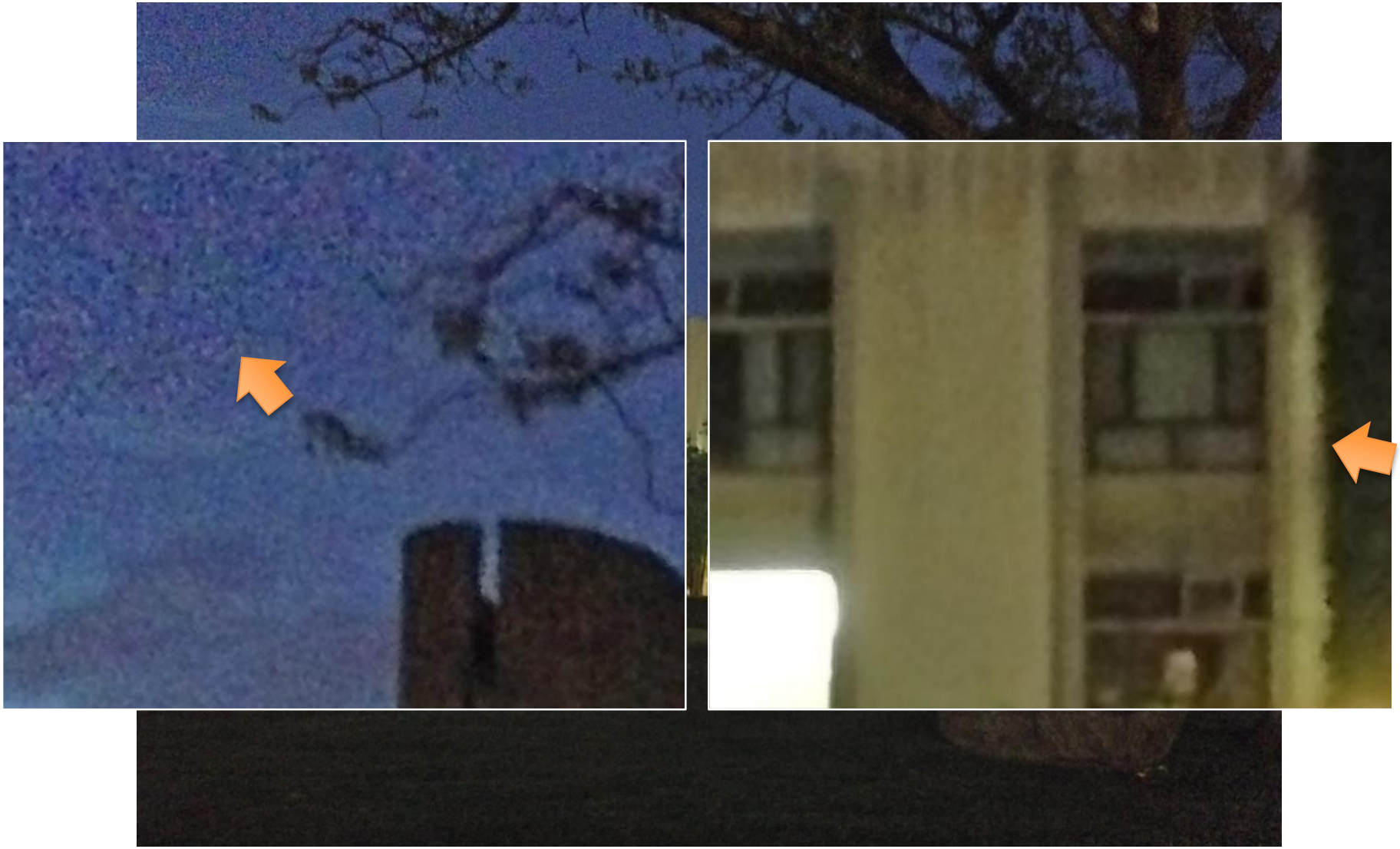
BM4D [Maggioni et al. 2013] *(3675.32 sec.)*



Our result *(1.69 sec.)*



Optical flow [Liu 2009] + Median filtering *(1166.57 sec.)*



Our result *(1.69 sec.)*

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Lucky imaging [Joshi and Cohen 2010] *(147.73 sec.)*

Our result *(1.69 sec.)*

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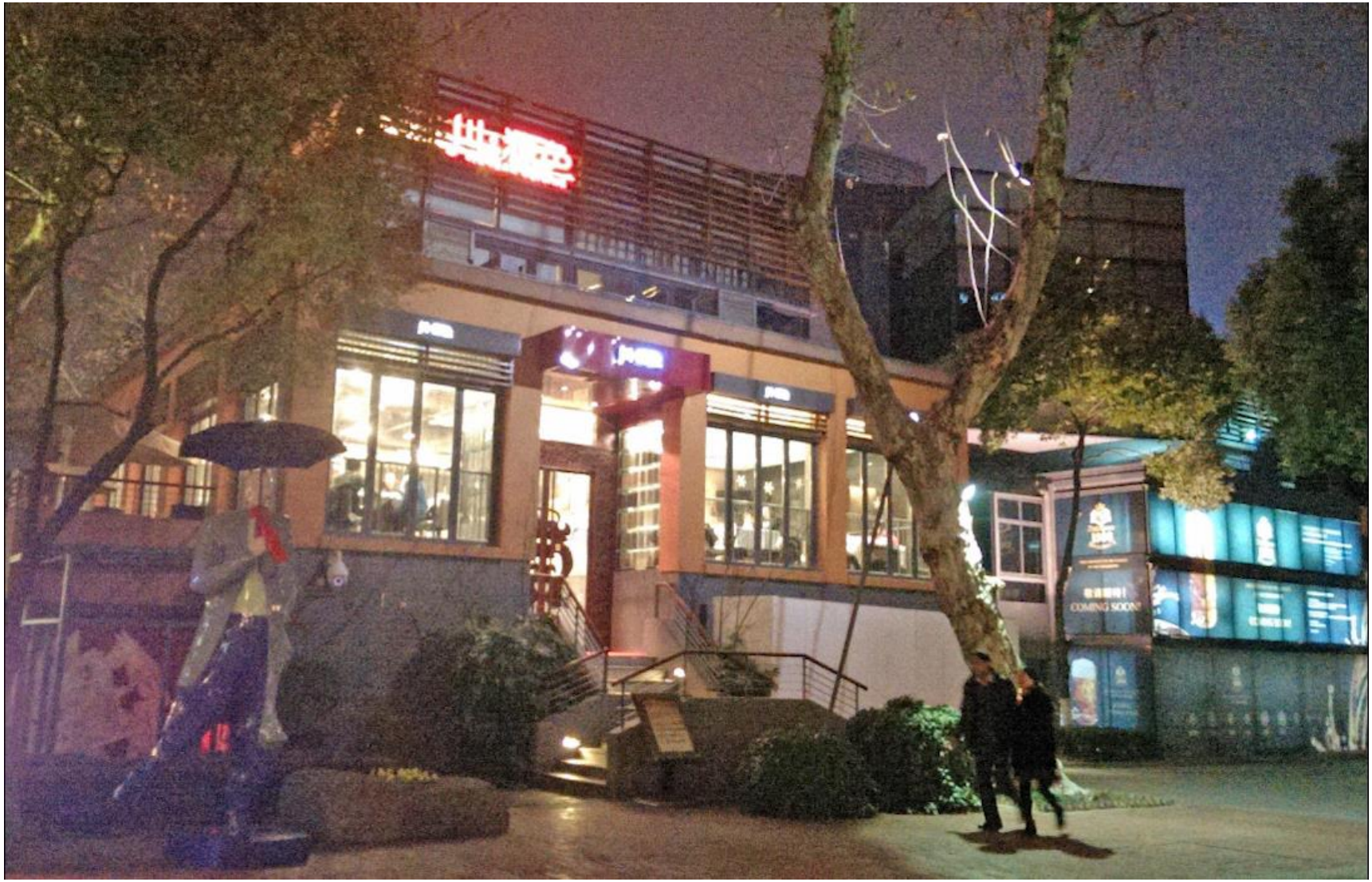
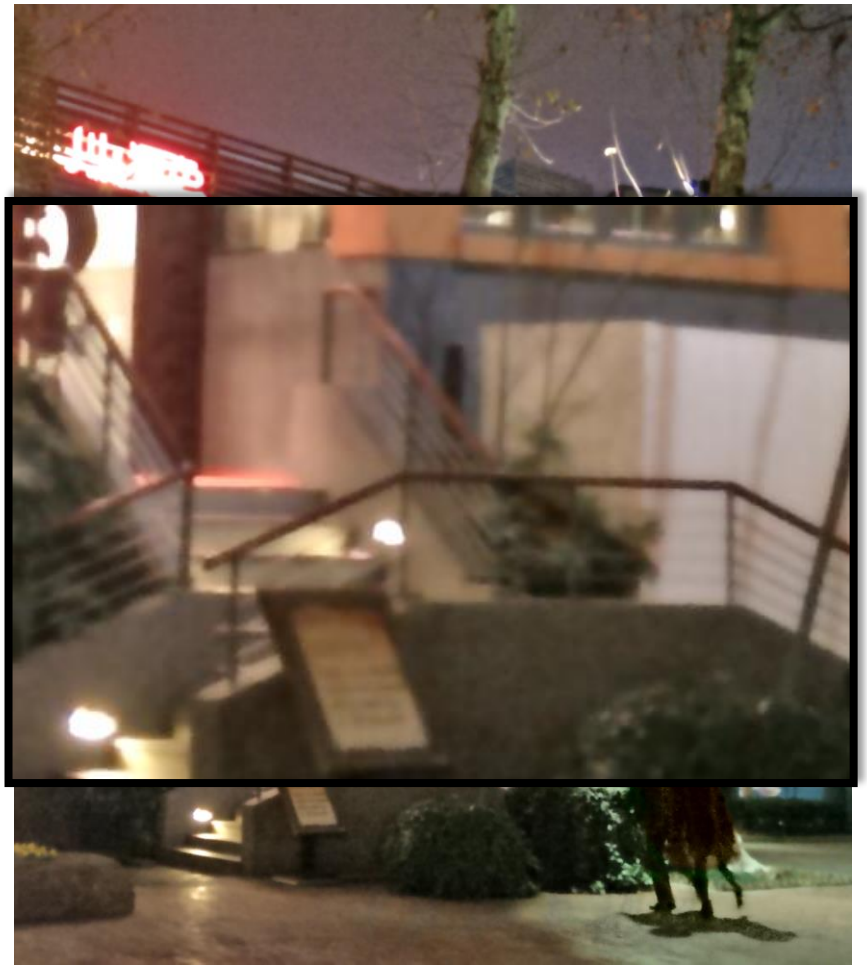
Dynamic scene: 3072 X 1728, HTC 802d



Reference frame

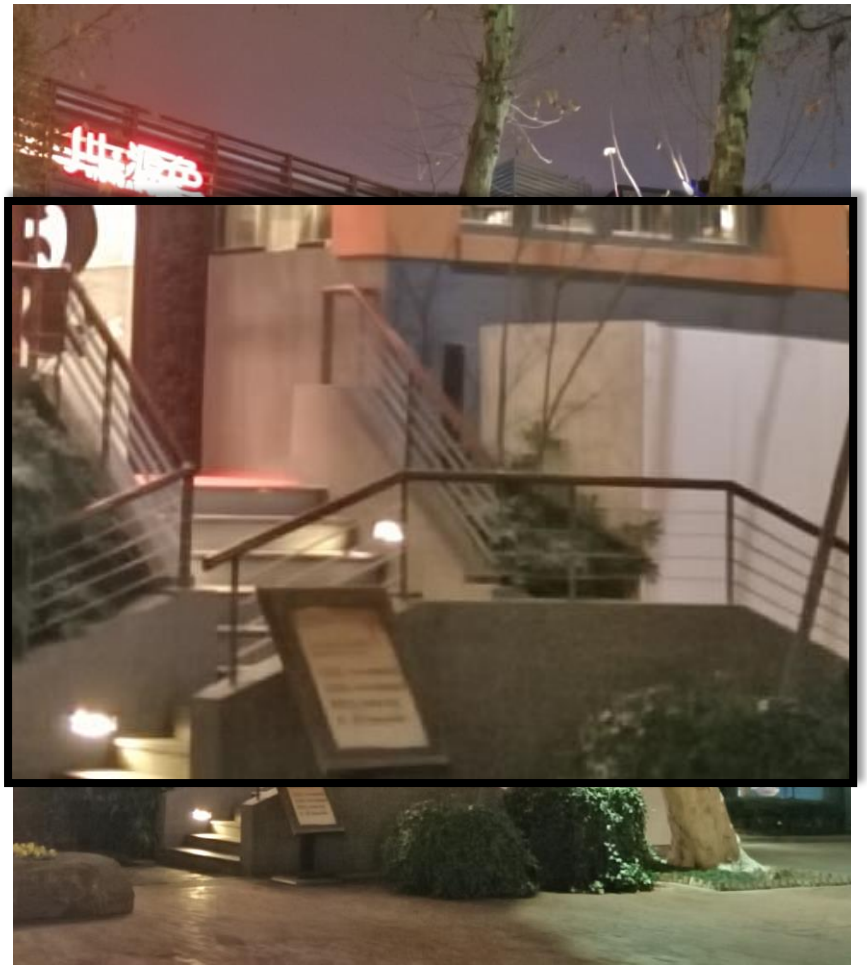
Our result

Comparison



Spatial-temporal filtering [Bennett and McMillan 2005]

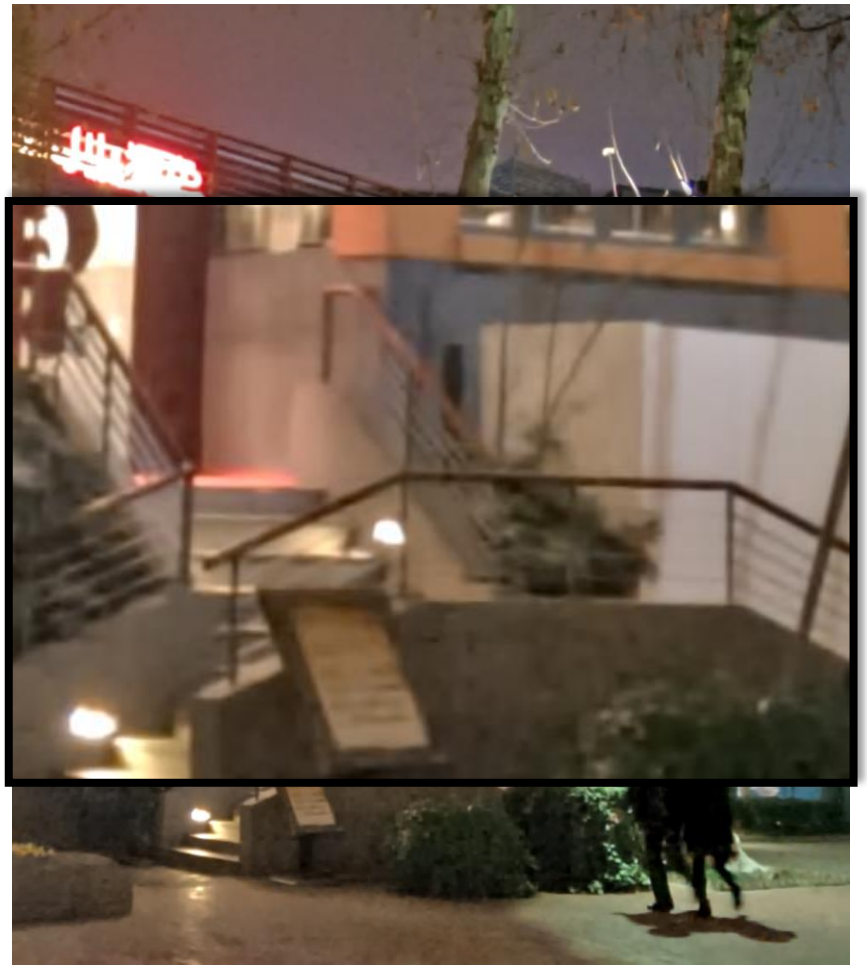
387.76 sec.



Our method

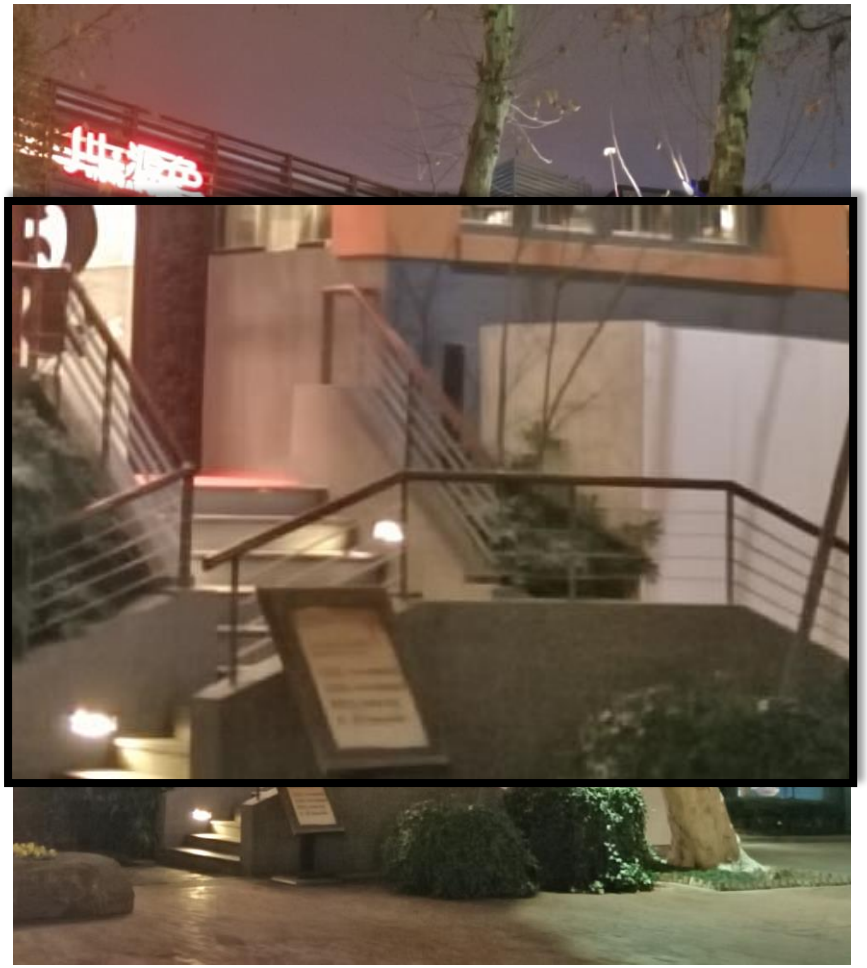
0.83 sec.

Comparison



VBM3D [Dabov et al. 2007]

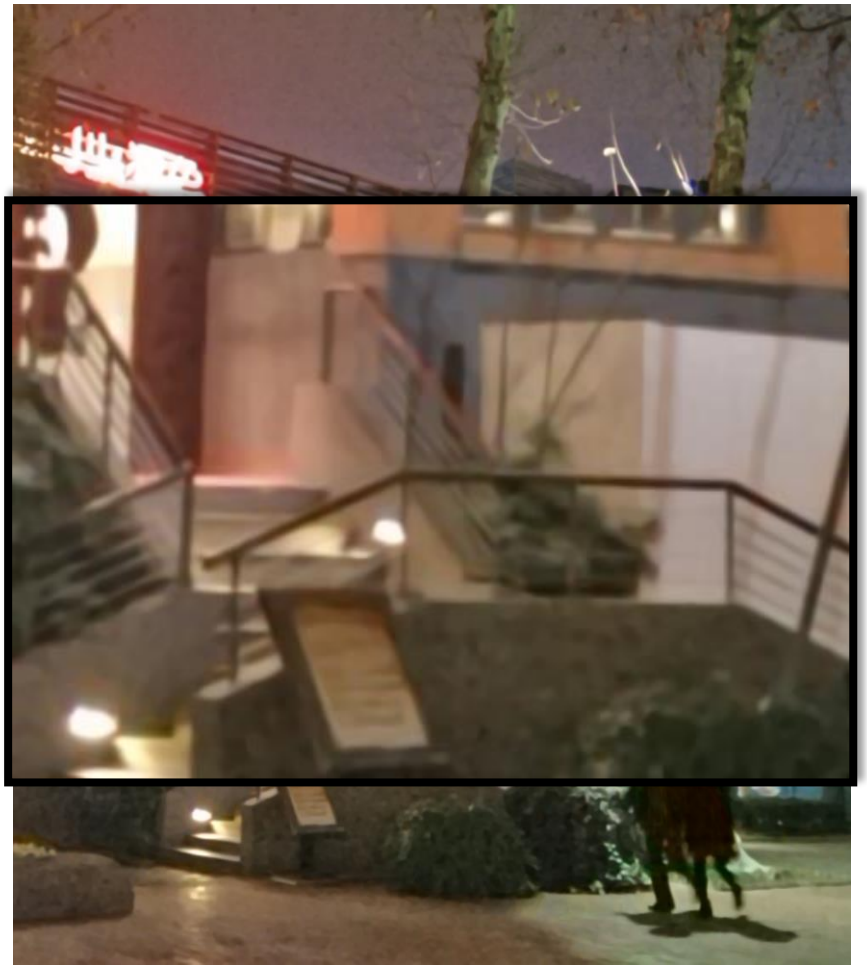
229.39 sec.



Our method

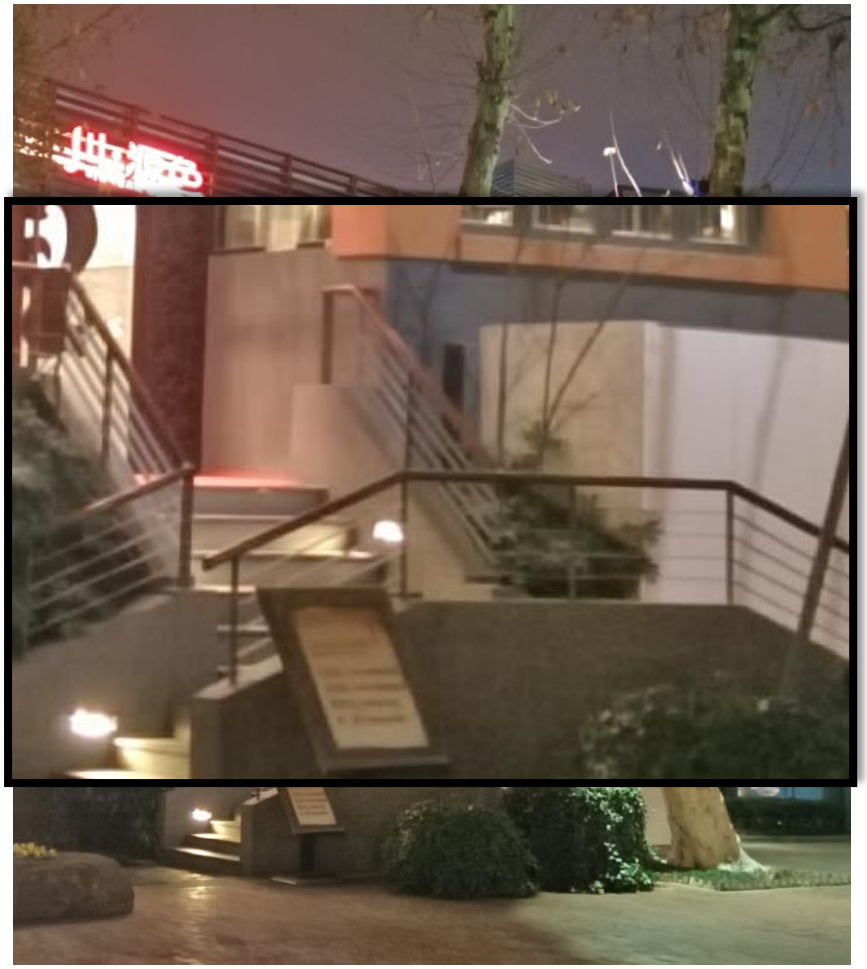
0.83 sec.

Comparison



BM4D [Maggioni et al. 2013]

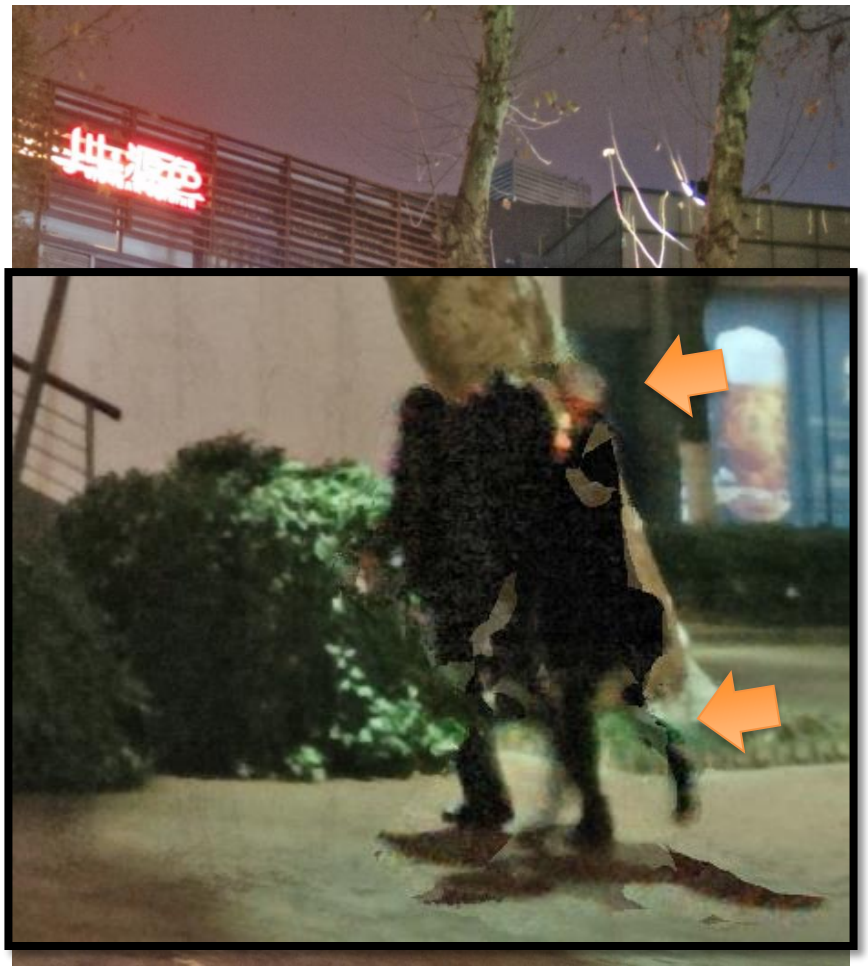
1938.14 sec.



Our method

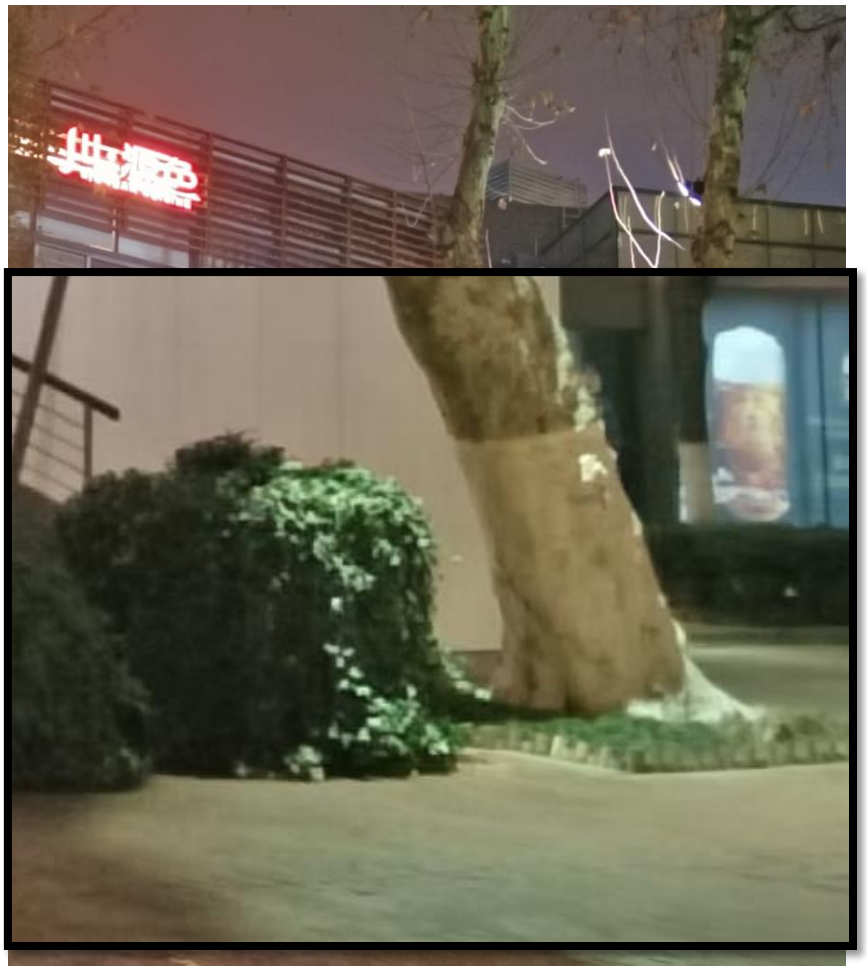
0.83 sec.

Comparison



Optical flow [Liu 2009] + Median filtering

591.32 sec.



Our method

0.83 sec.

Comparison

Lucky imaging [Joshi and Cohen 2010]

83.01 sec.

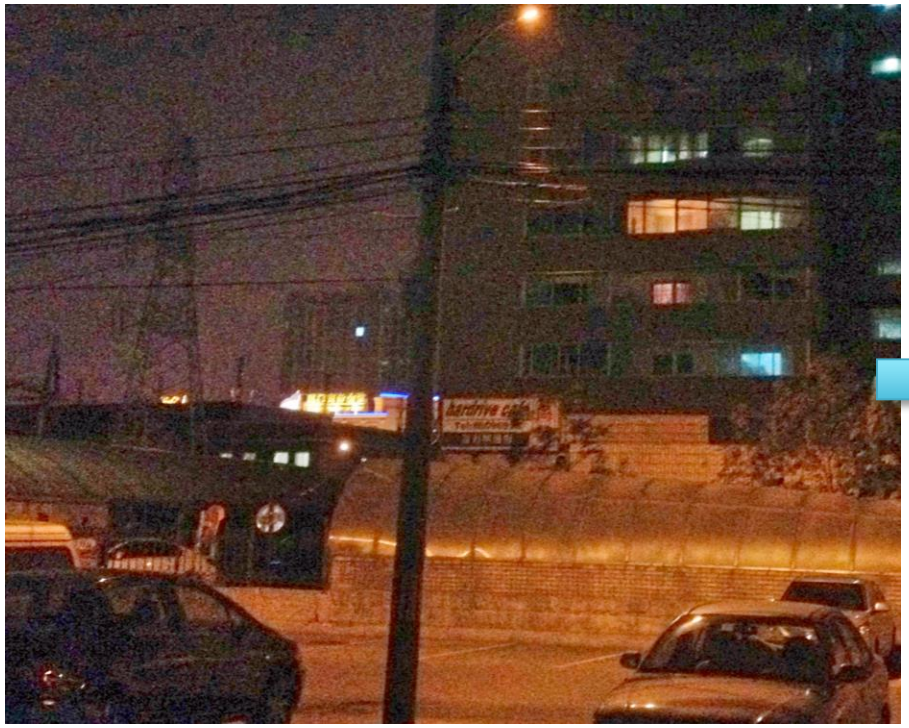
Our method

0.83 sec.

More results

Extreme low light (iPhone 4S)

Enhanced reference frame



enhanced reference frame

our result

original image

enhanced image

our result

Large occlusion (Canon EOS 500D)

Reference frame

Our result

Discussion & Limitation

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Discussion on reference frame

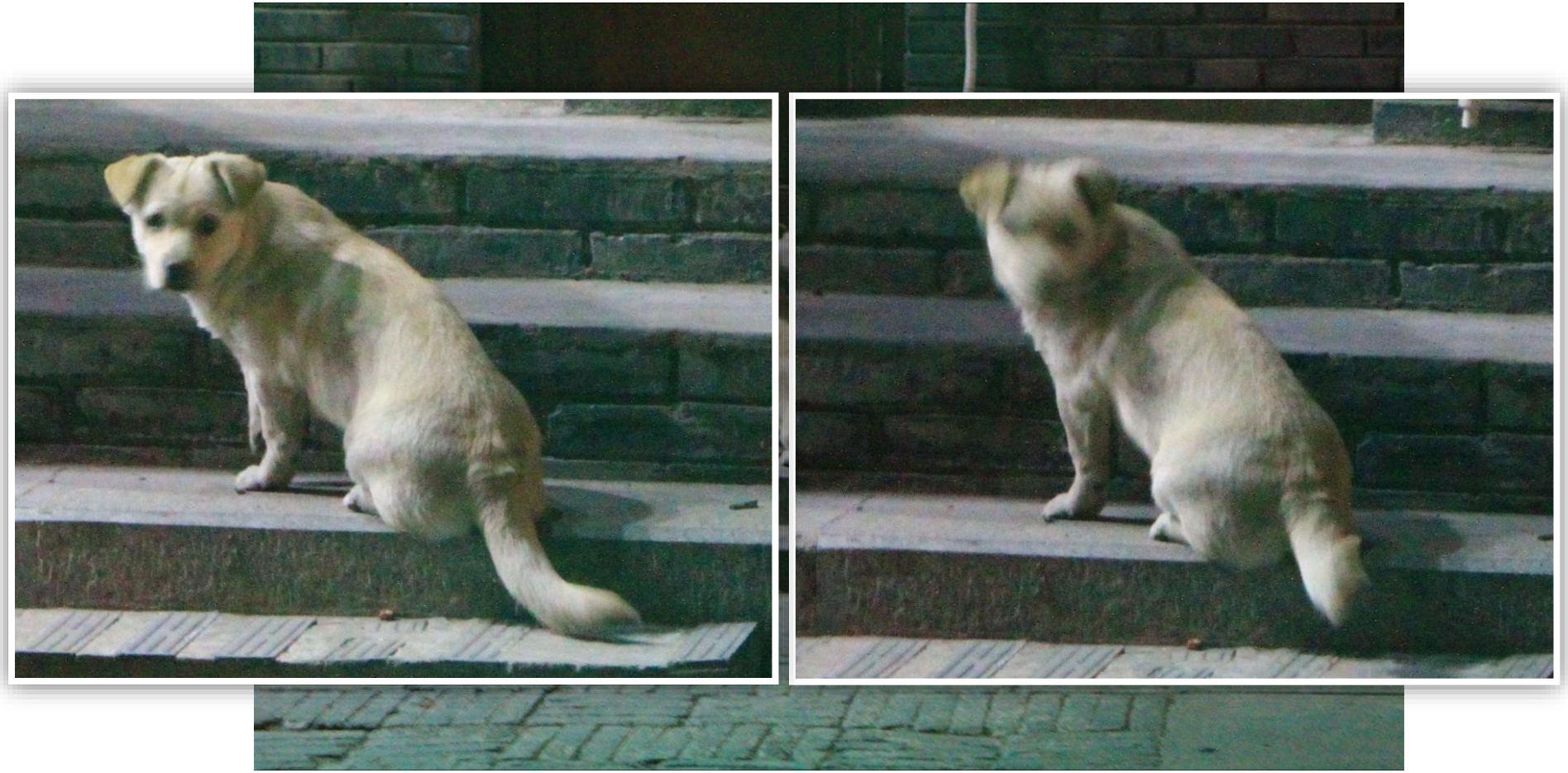
- Only several individual frames have blurs:

Discussion on reference frame

- ***NOT Sensitive*** to reference frame selection

Discussion on reference frame

- Majority frames have motion blurs:



Discussion on reference frame

- ***Sensitive*** to reference frame selection

Discussion on reference frame

- Fast moving objects:

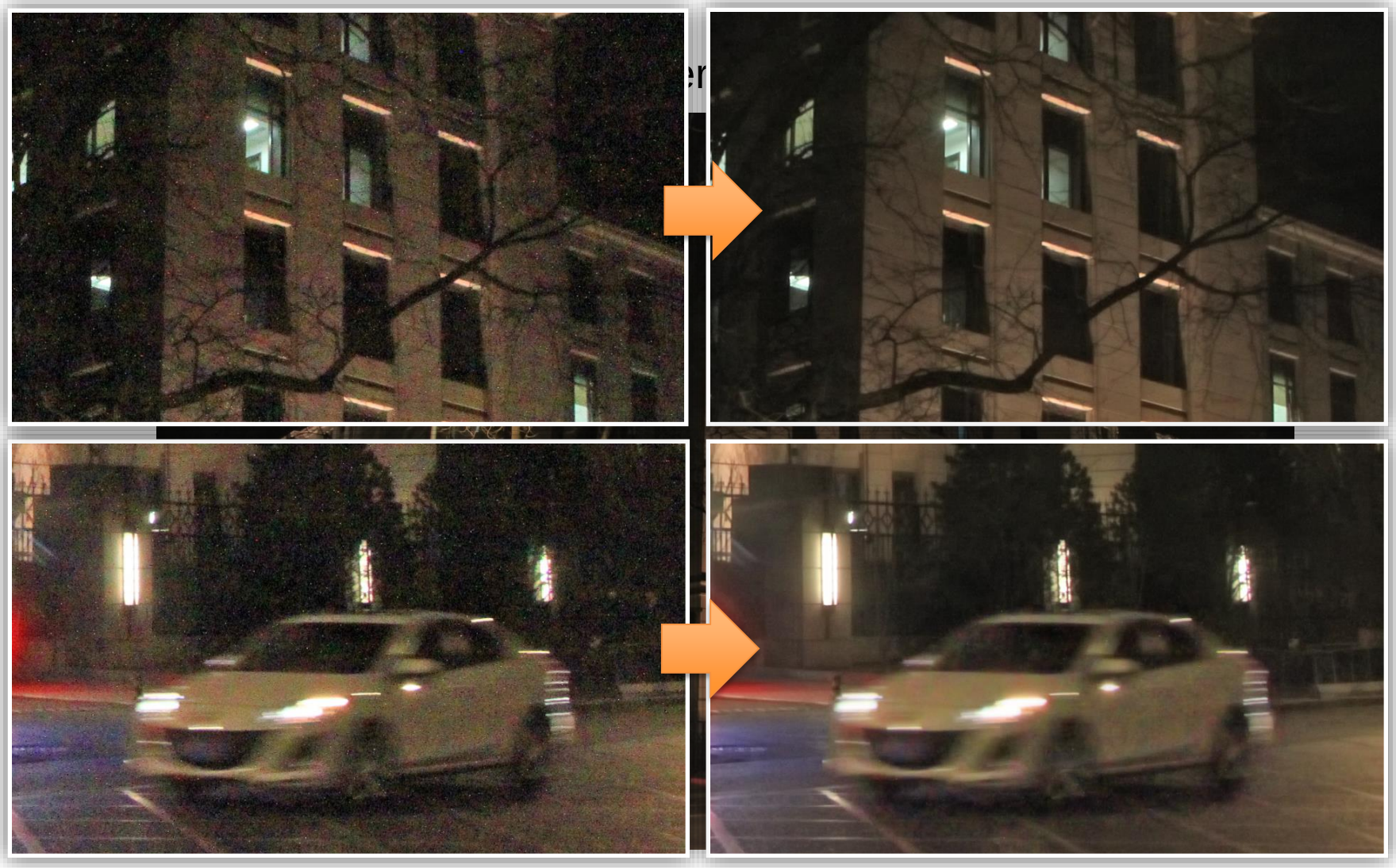
Discussion on reference frame

reference frame

Discussion on reference frame

our result

Discussion on reference frame



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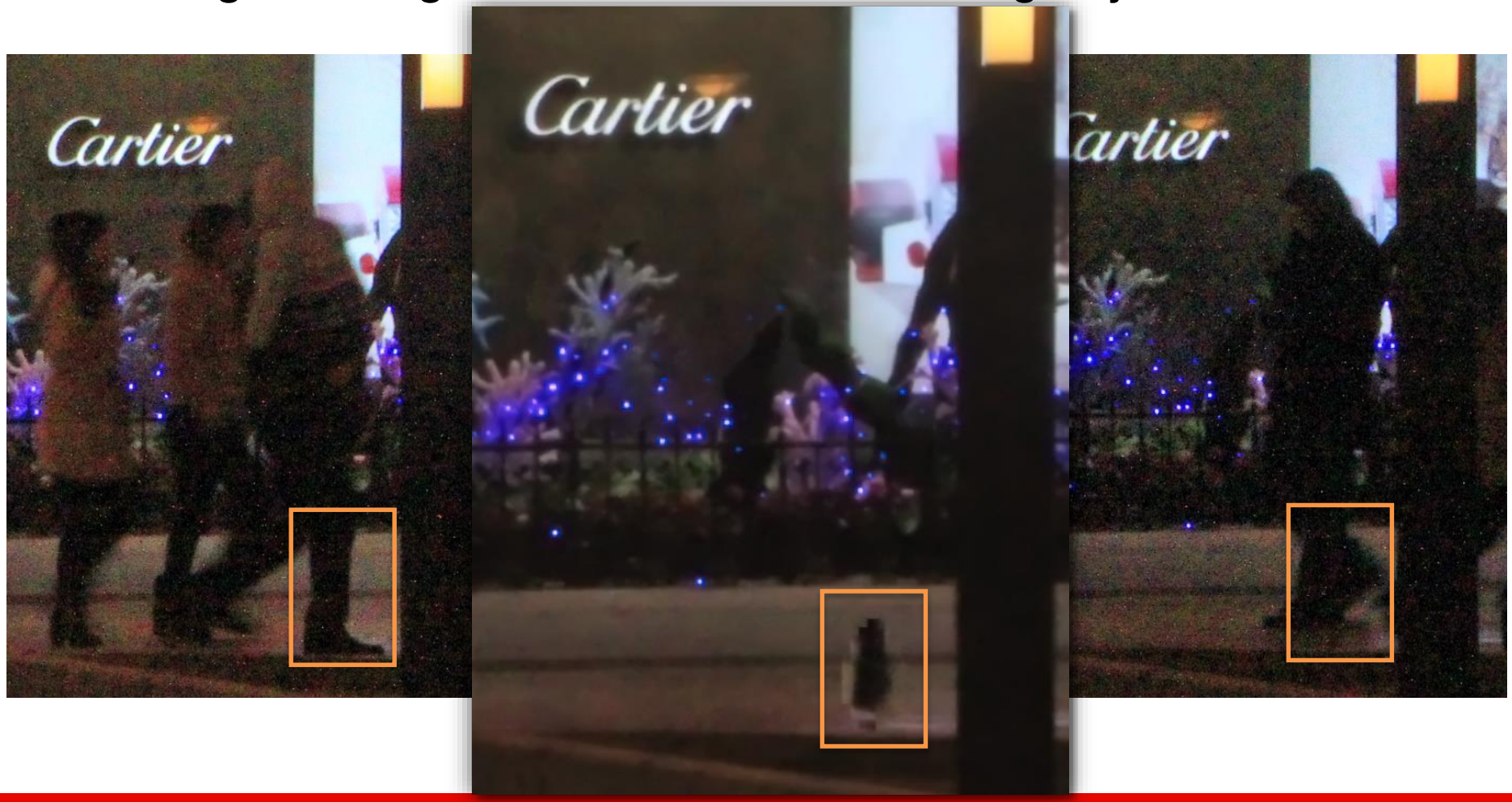
Failure case

- Ambiguous regions from different moving objects:



Released to BLINK app (WP store)

http://research.microsoft.com/en-us/um/redmond/projects/blink/

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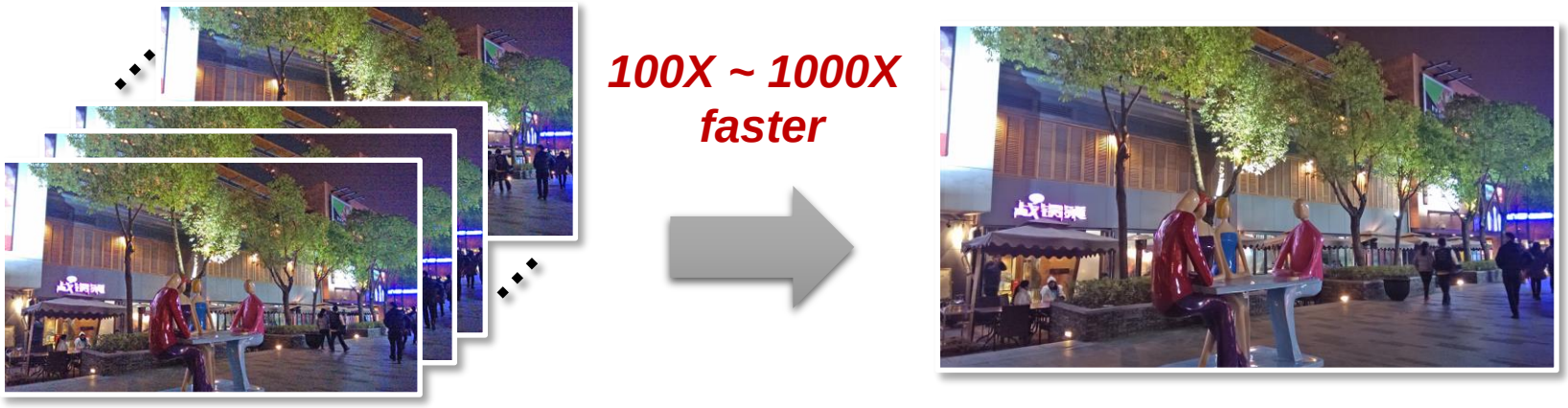
Conclusion

- Fast denoising for burst images:
  - Homography flow (*for* ***camera motion***)
  - Consistent pixels selection (*for* ***scene motion***)
  - Temporal & multiscale pixels fusion
- A practical solution to improve image quality



Thanks!