CVPR 2023 Tutorial on
Rolling Shutter Camera

New trends with combination of hardware features and deep learning

Zhixiang Wang / Zhihang Zhong

Outline

- **Novel Feature I:** Global Reset
- **Novel Feature II:** Dual Reversed Rolling Shutter

Feature I:
Global Reset

Zhixiang Wang, UTokyo

https://lightchaserx.github.io/

Collaboration

Zhixiang
UTokyo / RIISE / NII

Xiang
UTokyo

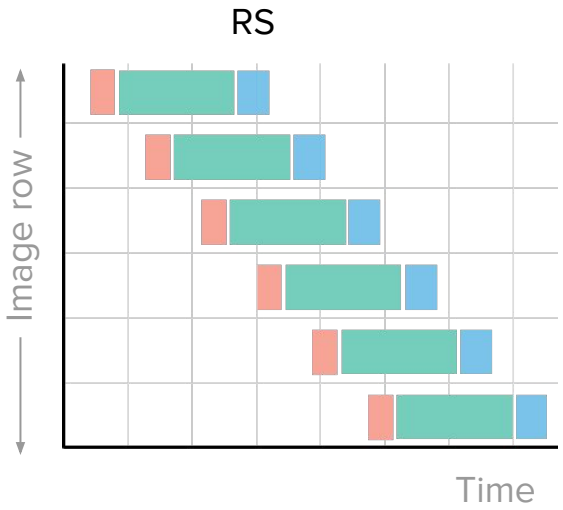
Jia-Bin
UMD

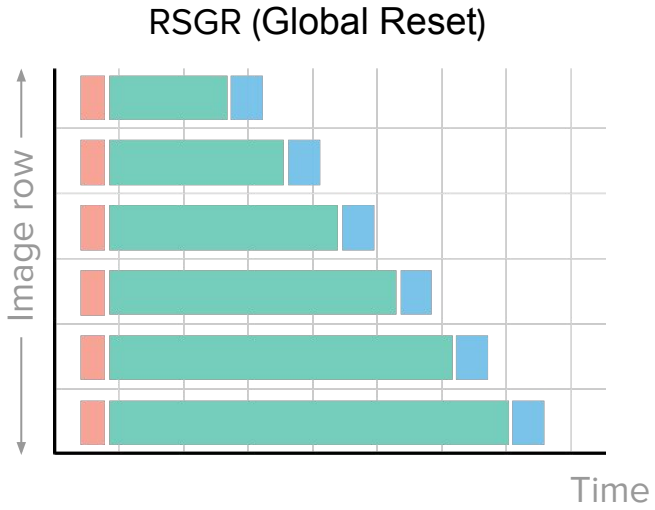
Yinqiang
UTokyo

Project leader

Shin’ichi
NII / UTokyo

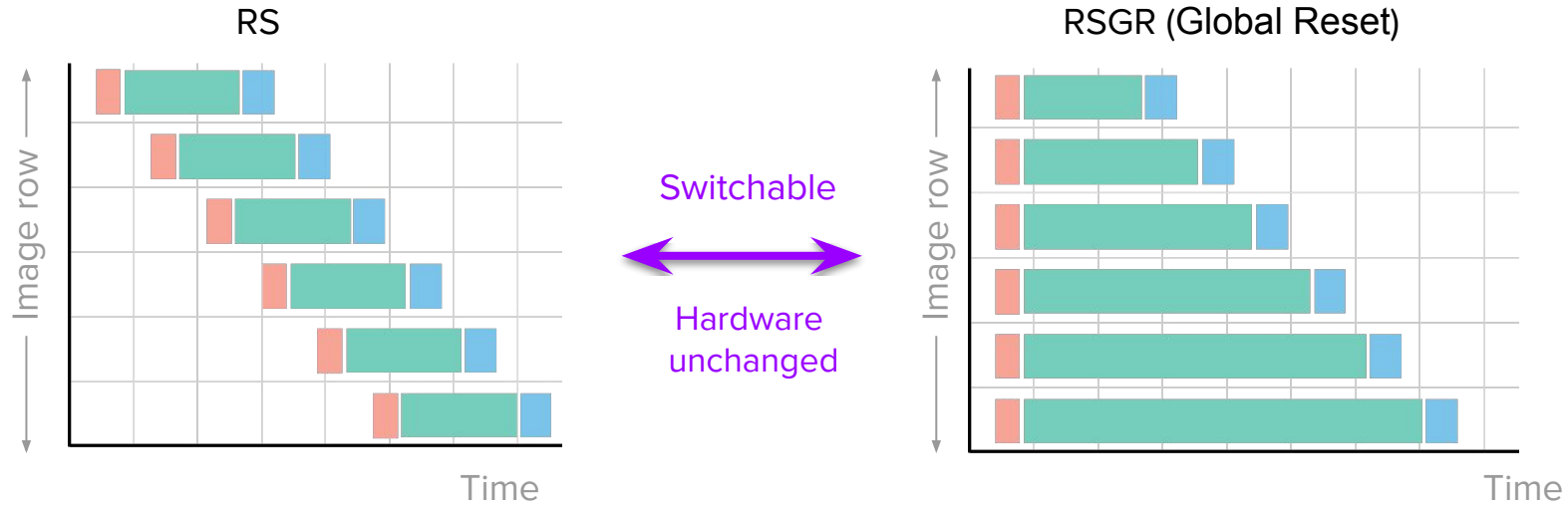
Ignored **hardware** feature of rolling shutter — **RSGR**





[+]**Other name:** Global Reset Release (GRR)

Ignored **hardware** feature of rolling shutter — **RSGR**



[+]**Other name:** Global Reset Release (GRR)

FLIR's Blackfly S product line, 63S4M/C, 120S4M/C, 200S6M/C

Hardware solution for using **RSGR**

- Using an external mechanical shutter
- Ambient light suppression

Limitations

- Additional hardware + precise control

https://www.e-consystems.com/blog/camera/products/what-is-global-reset-release-how-does-it-work-in-e-con-cameras/
https://www.baumer.com/ve/en/service-support/technical-information-industrial-cameras/rolling-shutter-global-shutter-two-principles-of-exposure-/a/rolling-shutter-global-shutter

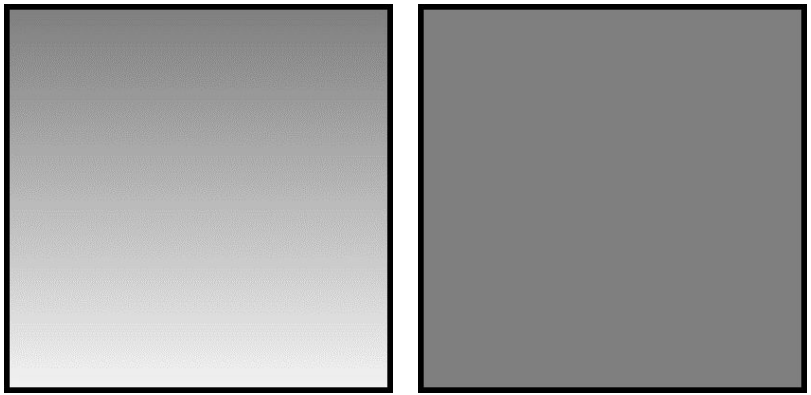
Intrinsic distortion of RSGR

Static scene:

- Brightness variation

Dynamic scene:

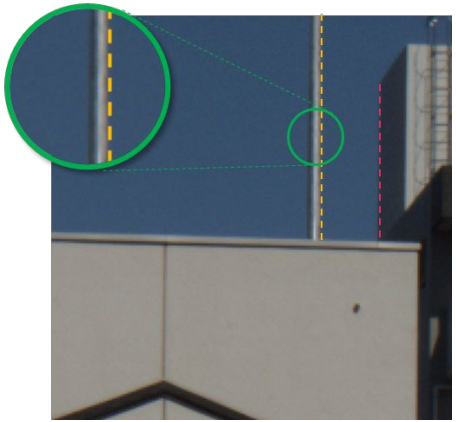
- Brightness variation
- Spatial-varying motion blur



RSGR

Ground truth

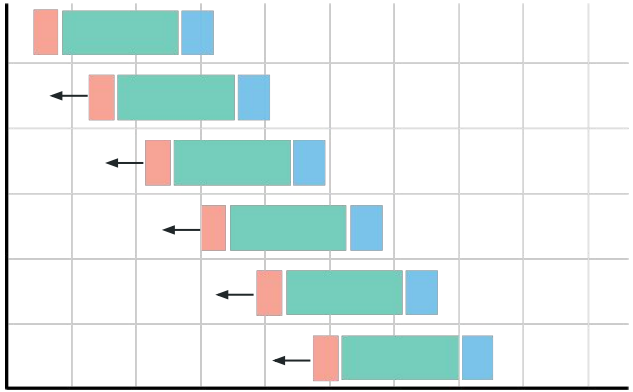
RSGR



Ground truth

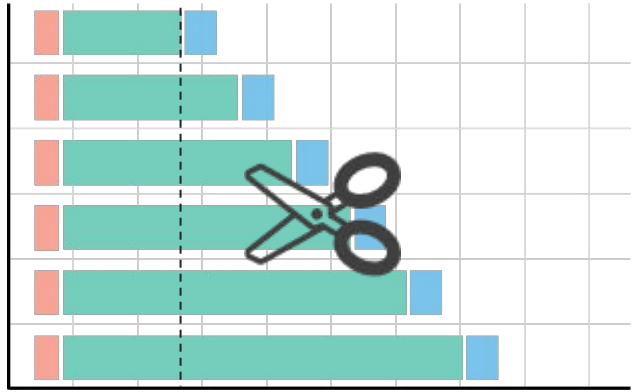
Our idea: **hardware** feature + **learning**-based algorithm

Geometric distortion correction



Conventional RS

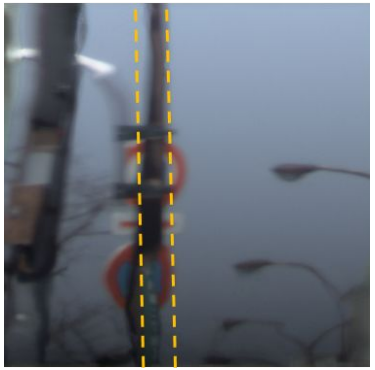
Deblur-like



RSGR

Can we use **prior** knowledge from **relevant** tasks? **NO**

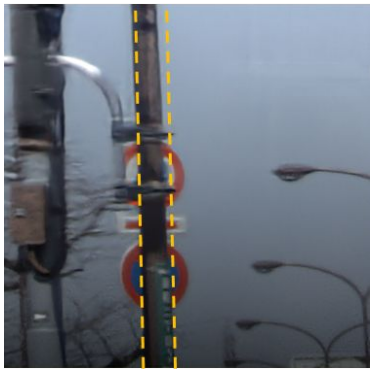
Input



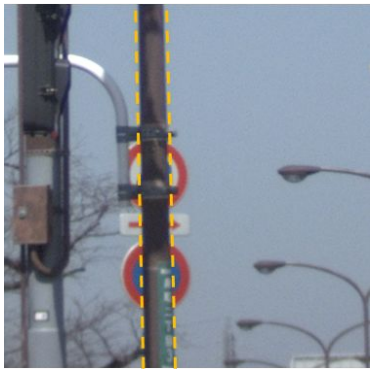
RS correction

RS correction+motion deblur

Out-of-focus deblur



GS motion deblur

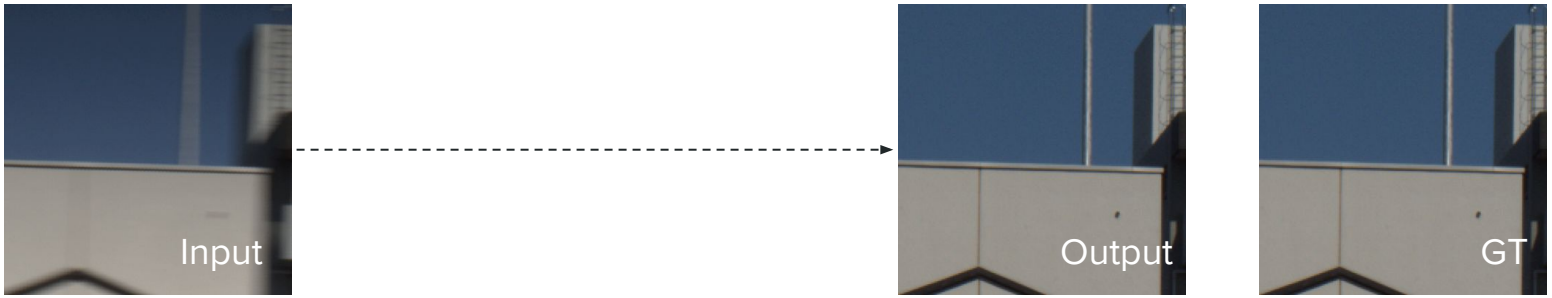


Ground truth

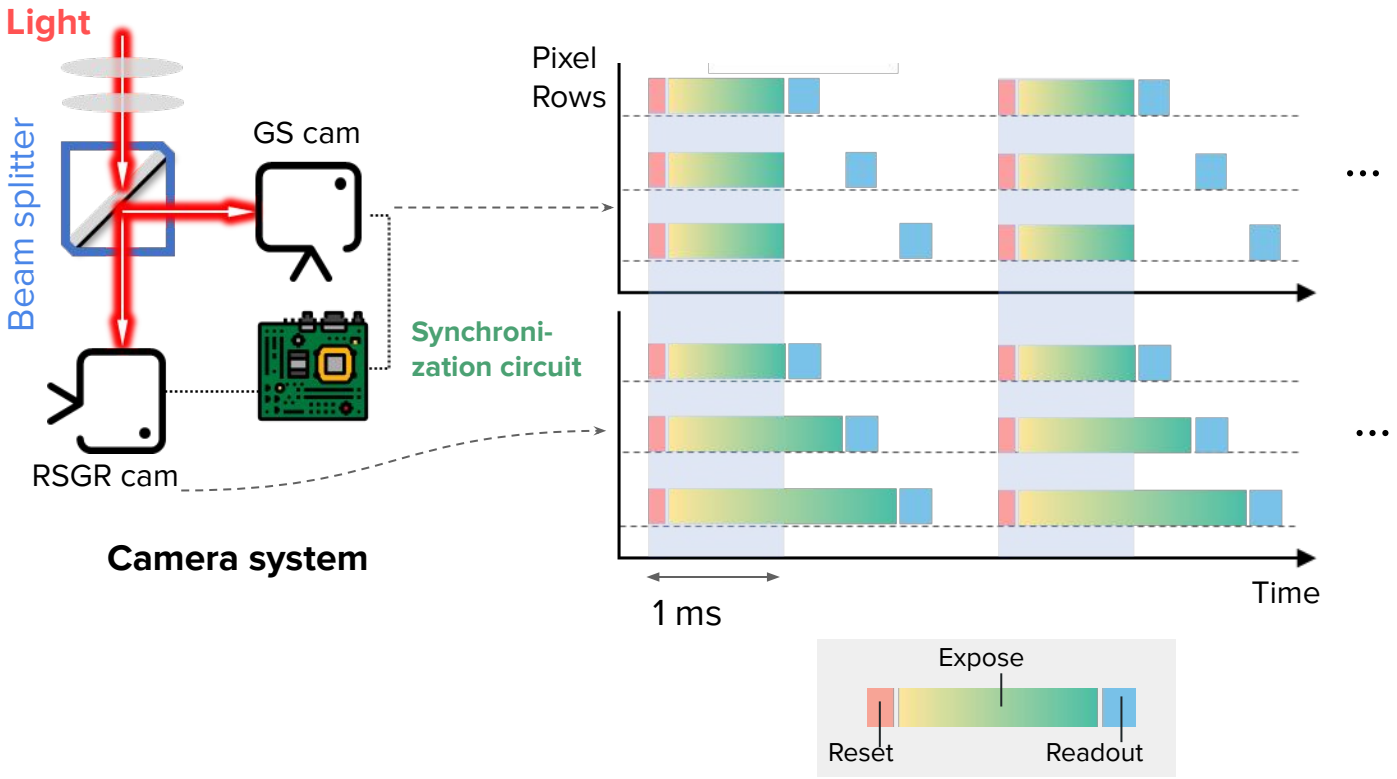
Develop a solution

Develop a solution (1/3) — Capture **paired data**

Step 1: Dataset



Develop a solution (1/3) — Capture **paired data**



Develop a solution (1/3) — Capture **paired data**

↦ Hardware prototype

Relay lens
Focal length: 85 mm

GS camera
FLIR
GS3-U3-23S6C
Sensor: Sony IMX178
30 FPS, 640X640

Object lens
Focal length: 12 mm

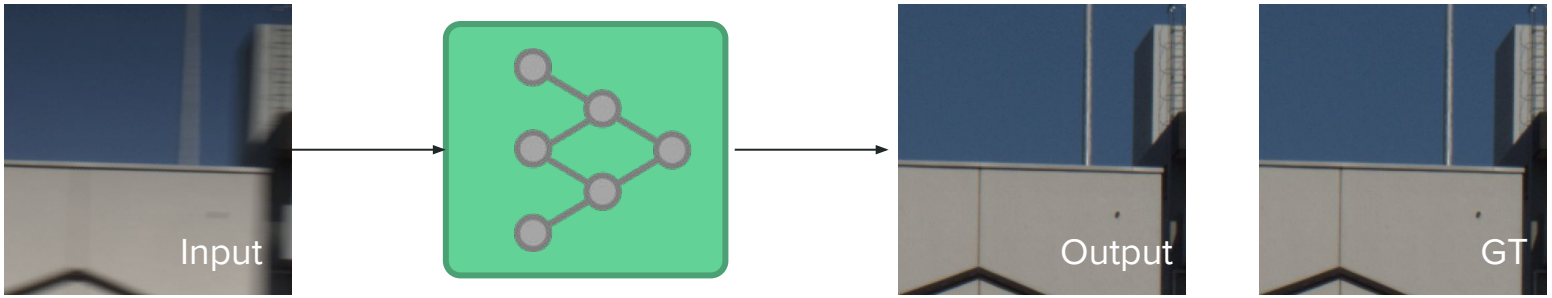
Beam splitter
THORLABS
CCM1-BS013/M

RSGR camera
FLIR
BFS-U3-63S4C
Snesor: Sony IMX174
30 FPS, 640X640

Scene	in-the-wild
Frames	300 / Seq
Train	27 Seq
Test	55 Seq

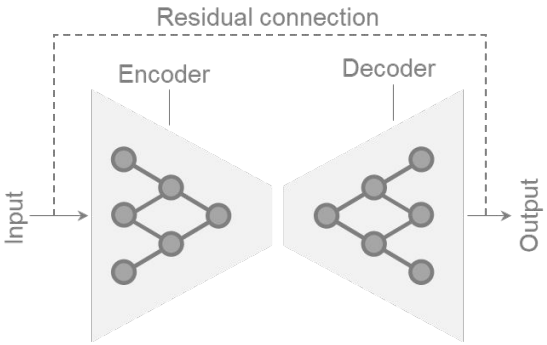
Develop a solution (2/3) — Architecture designs

Step 1: Dataset

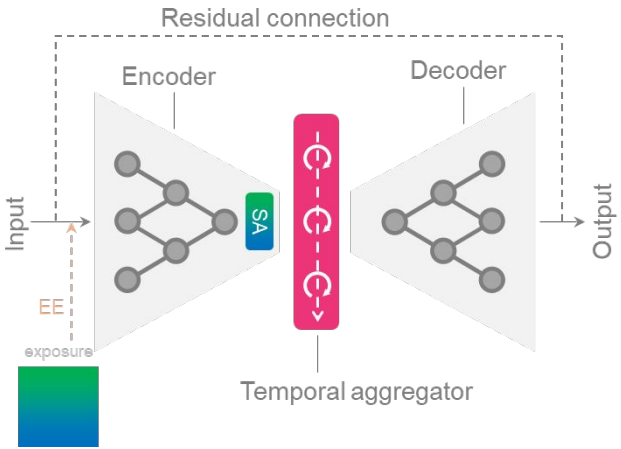


Step 2: Architecture

Develop a solution (2/3) — Architecture designs



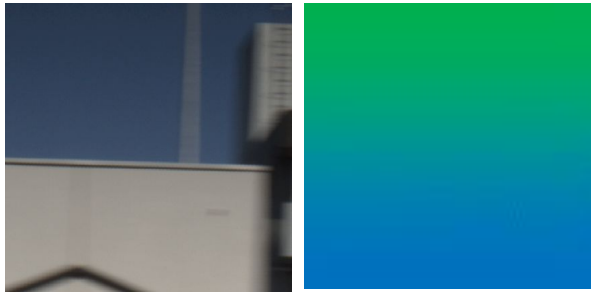
Deblur
architecture



Our customized
architecture

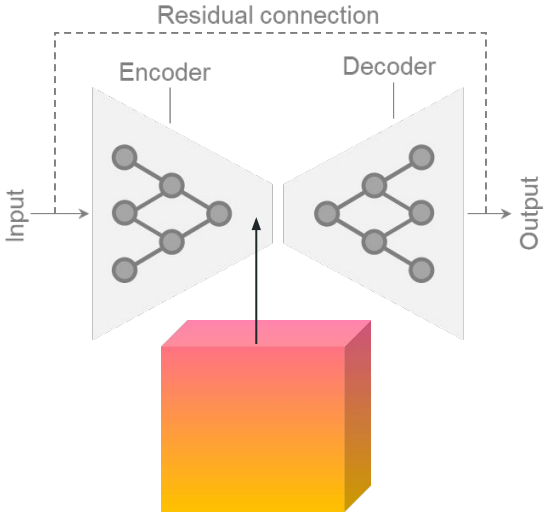
Develop a solution (2/3) — Architecture designs

- Correct spatial-varying distortion



Input

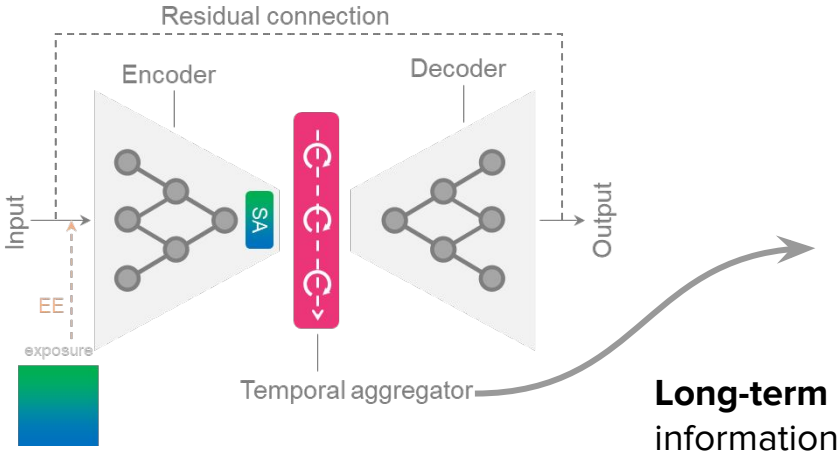
Exposure time encoding



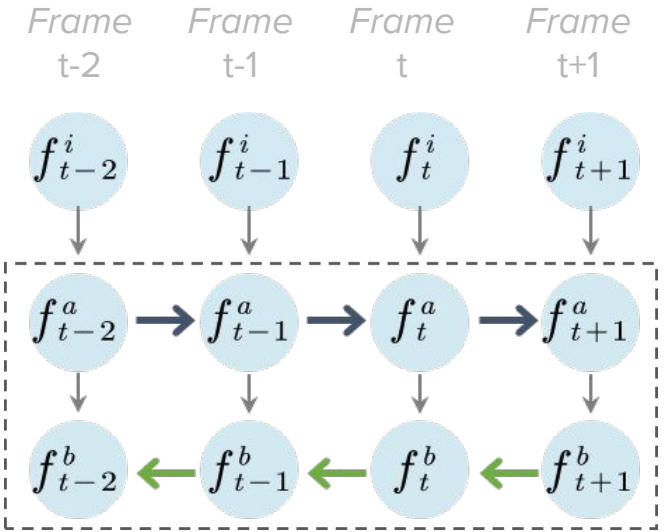
Spatial Attention

Develop a solution (2/3) — Architecture designs

- Leverage temporal information

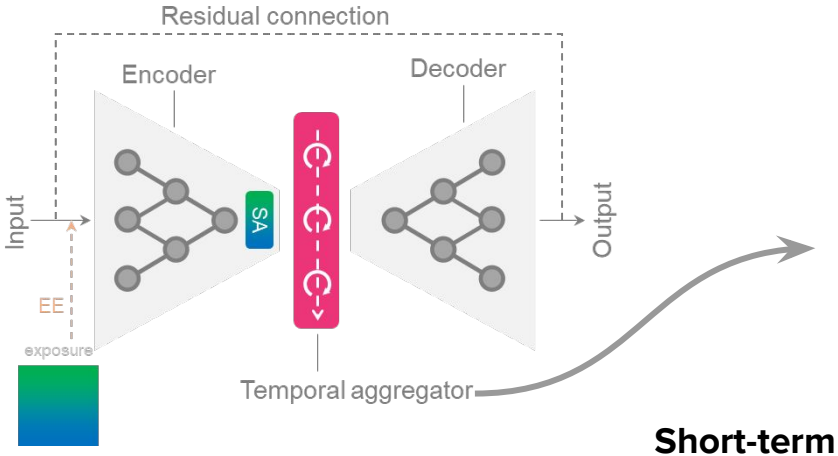


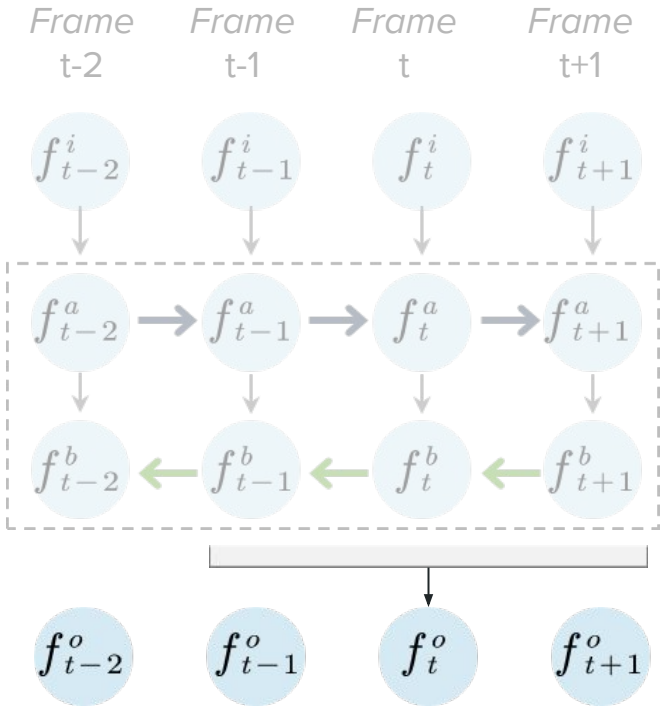
Long-term information



Develop a solution (2/3) — Architecture designs

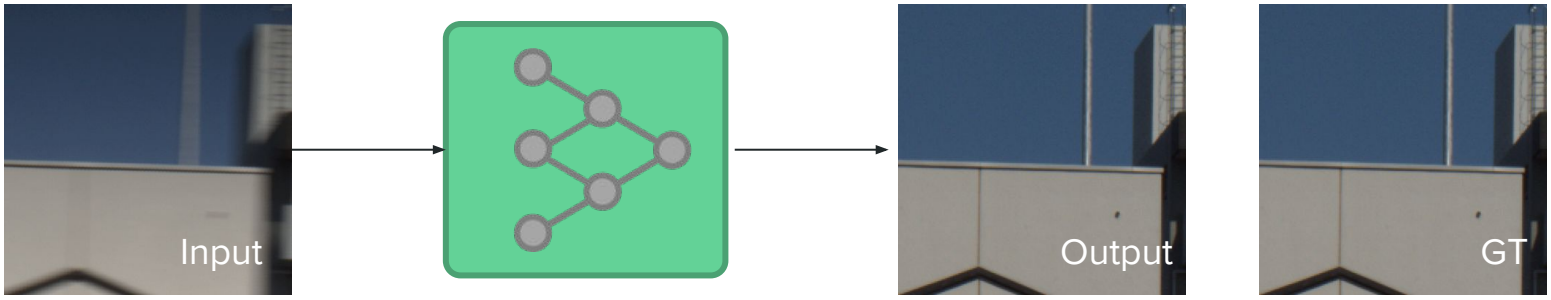
↦ Leverage temporal information



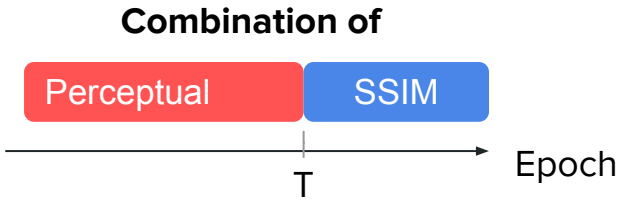


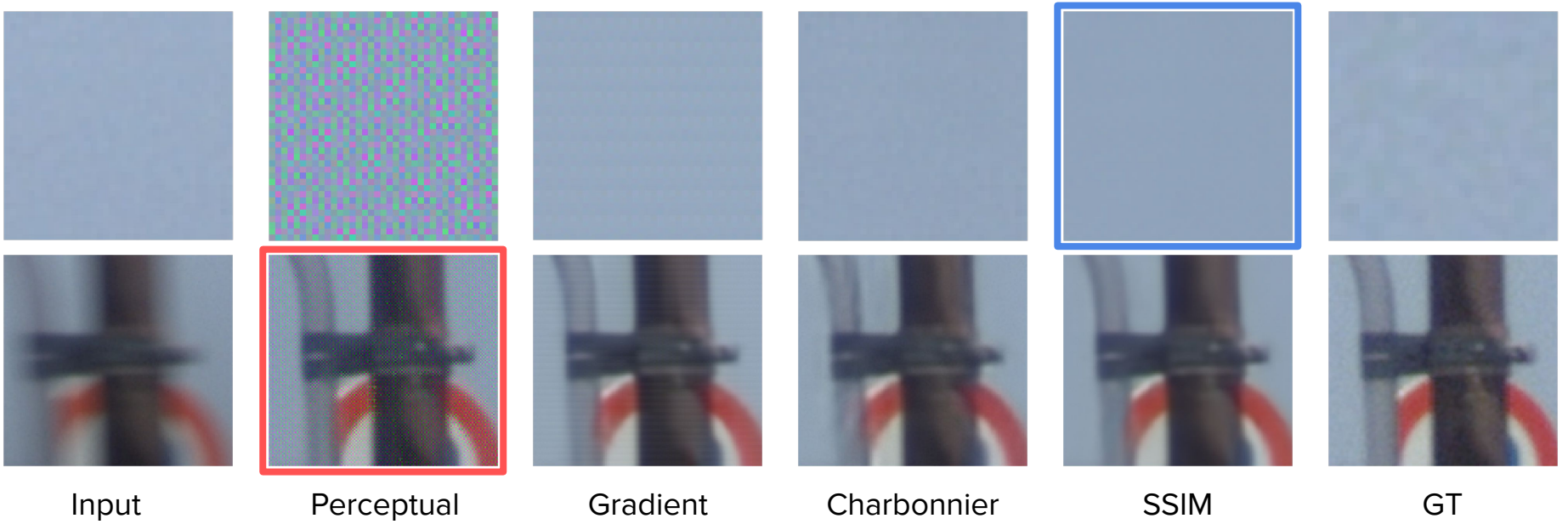
Short-term information

Develop a solution (3/3) — Loss function



Loss function





Results — **camera** motion

Input

Our result

GT

Results — **camera** motion

Input

Our result

GT

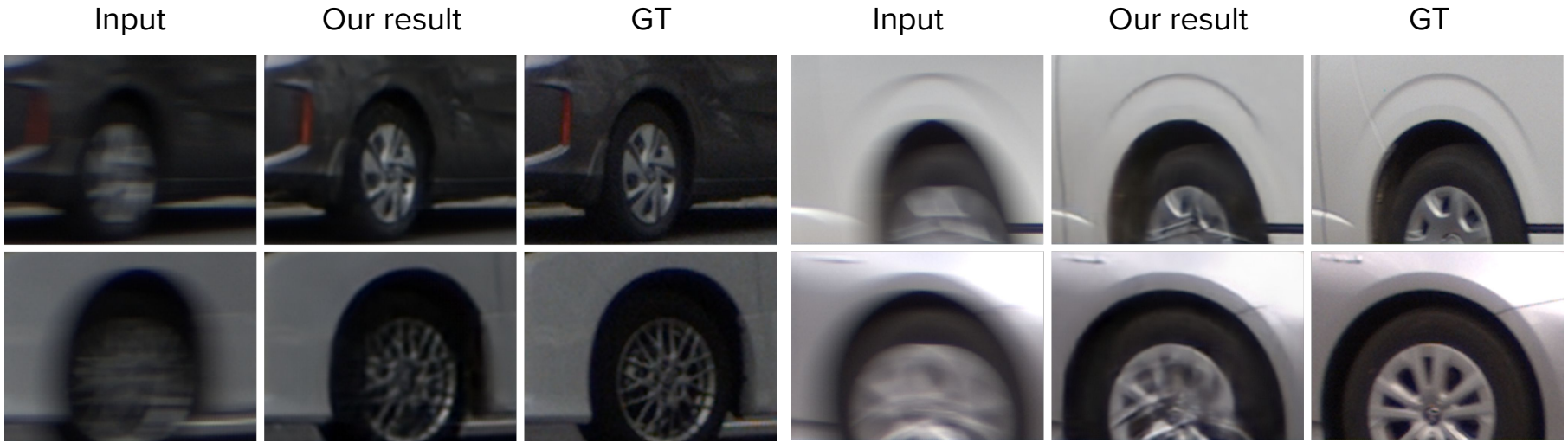
Results — **camera** motion

Input

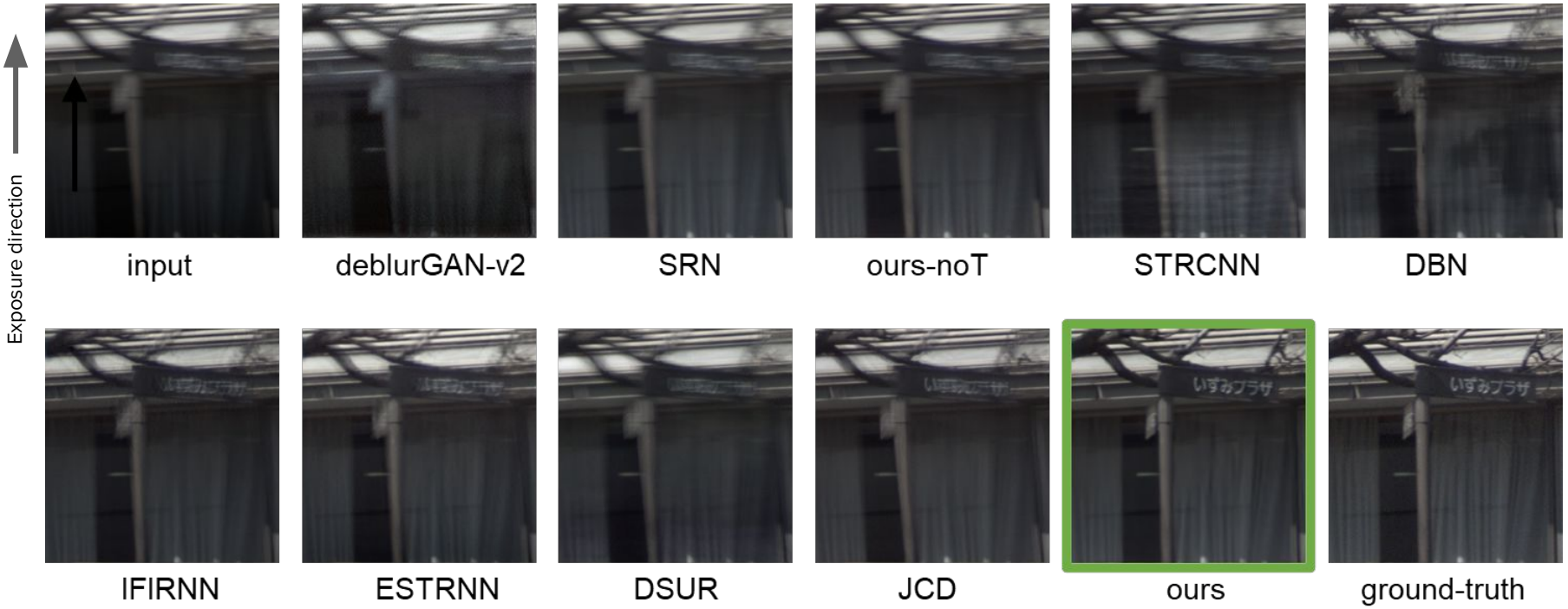
Our result

GT

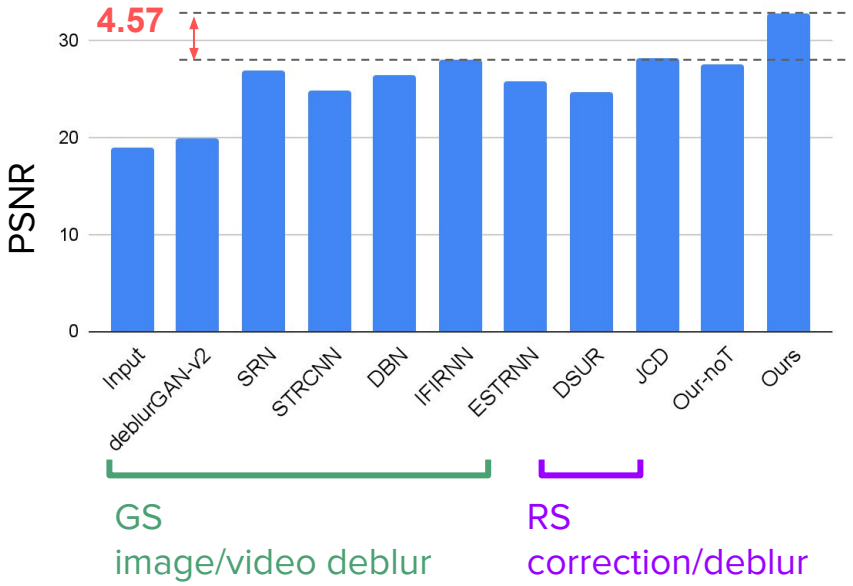
Results — camera + **scene** motion

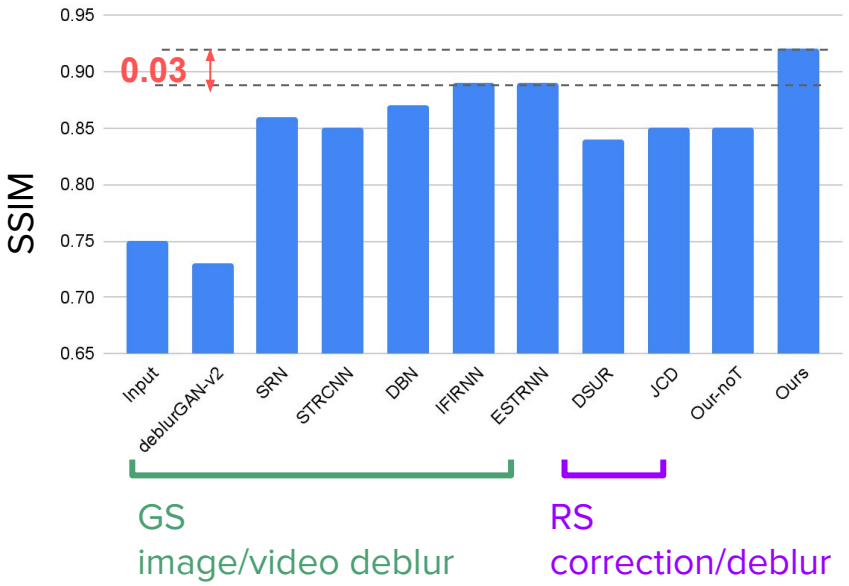


Results — qualitative comparisons

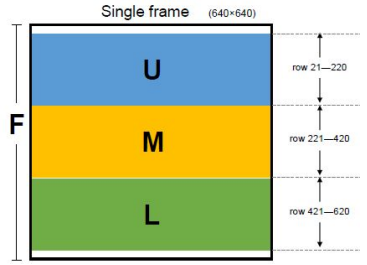


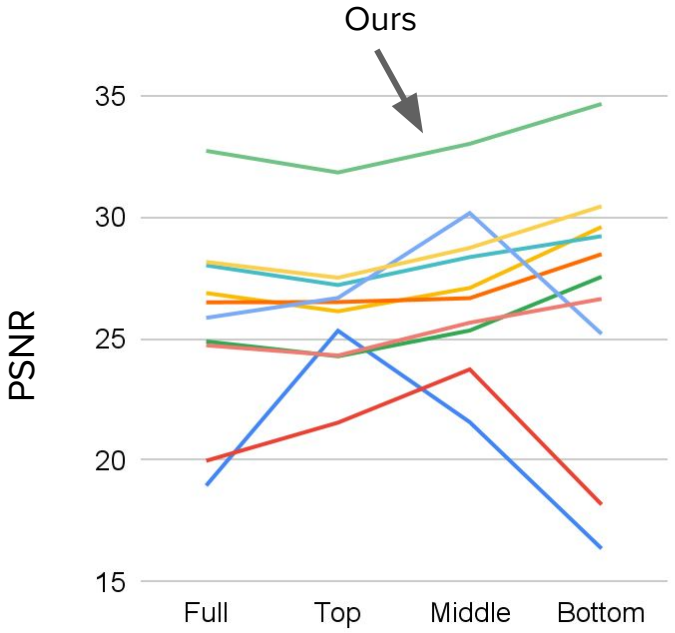
Results — quantitative comparisons

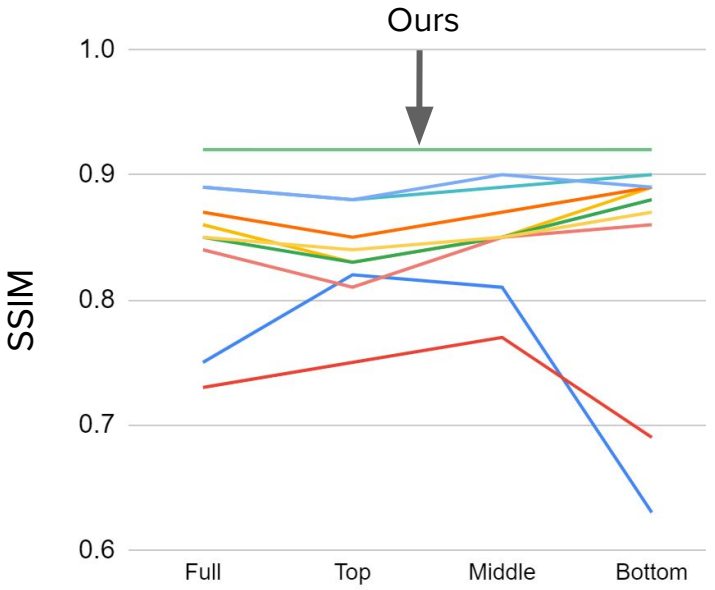




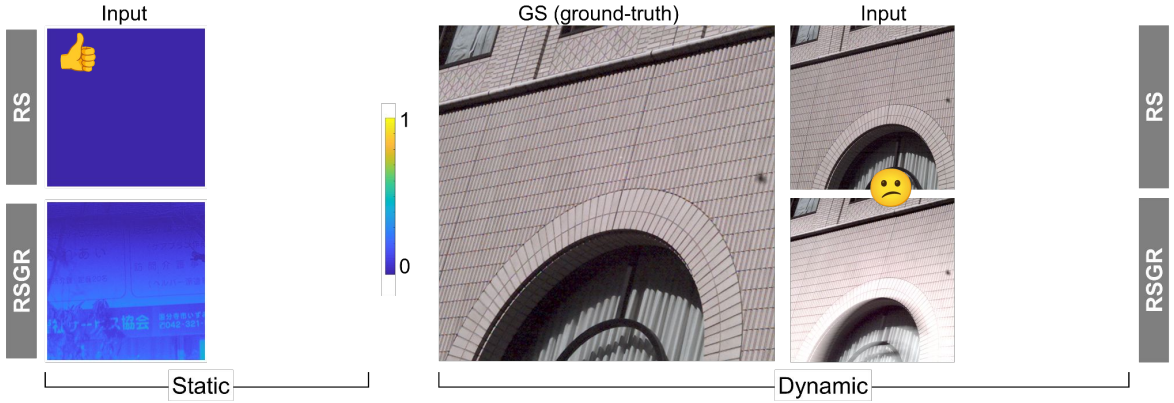
Results — quantitative comparisons



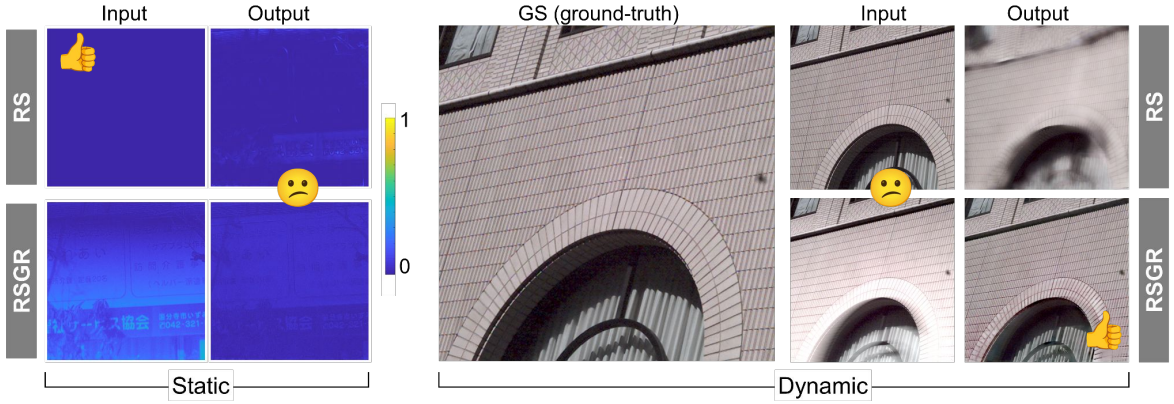




Discussion: RS *vs.* RSGR

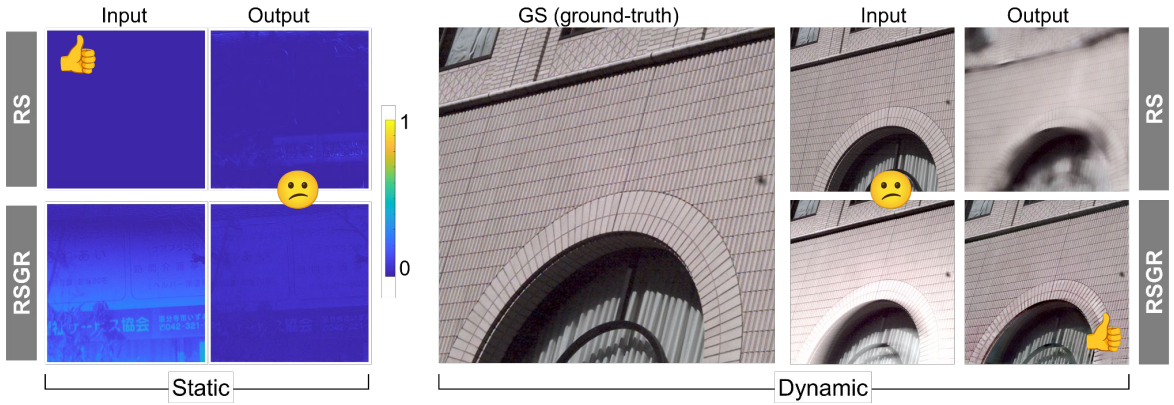


Discussion: RS *vs.* RSGR



Zhuang+, Rolling-shutter-aware differential sfm and image rectification, ICCV'17.
DSUR: Liu+, Deep shutter unrolling network, CVPR'20.
JCD: Zhong+, Towards rolling shutter correction and deblurring in dynamic scenes, CVPR'21

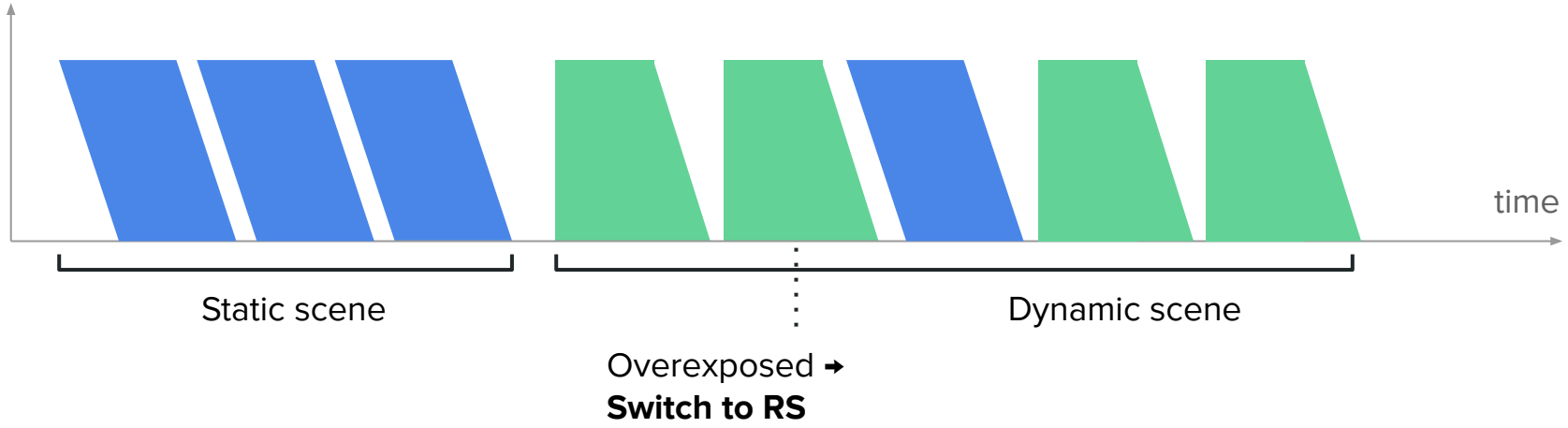
Discussion: RS *vs.* RSGR



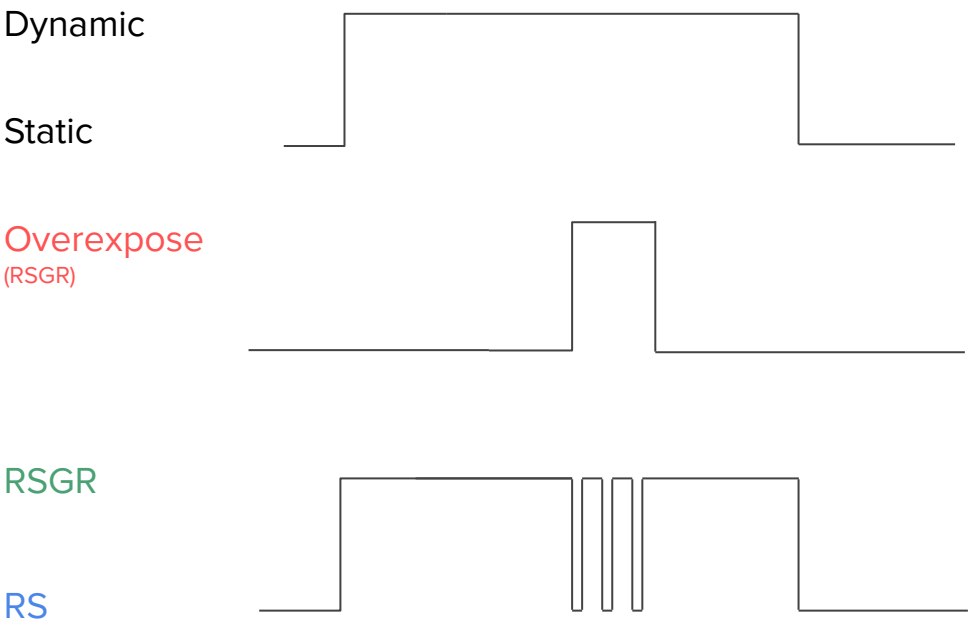
	Method	Time/frame
RS correction	Zhuang+	400.00 sec
	DSUR	0.43 sec
	JCD	0.83 sec
👍	Ours	0.04 sec

Zhuang+, Rolling-shutter-aware differential sfm and image rectification, ICCV'17.
DSUR: Liu+, Deep shutter unrolling network, CVPR'20.
JCD: Zhong+, Towards rolling shutter correction and deblurring in dynamic scenes, CVPR'21

Future direction: ~~RS *vs.* RSGR~~ ⇒ RS + RSGR



Future direction: ~~RS *vs.* RSGR~~ ⇒ RS + RSGR



Future direction: task-specific shutter modes for learning

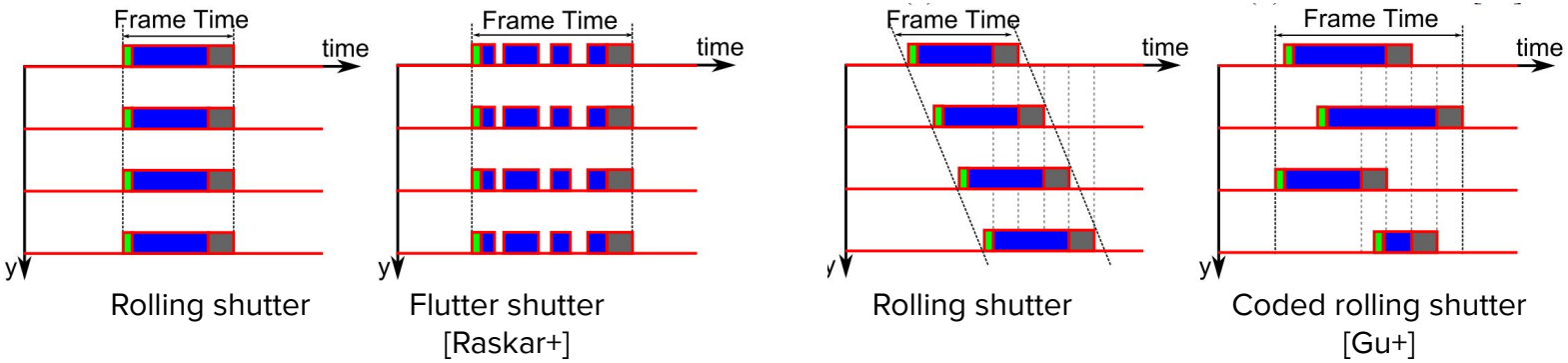


Figure borrowed from [Gu+]

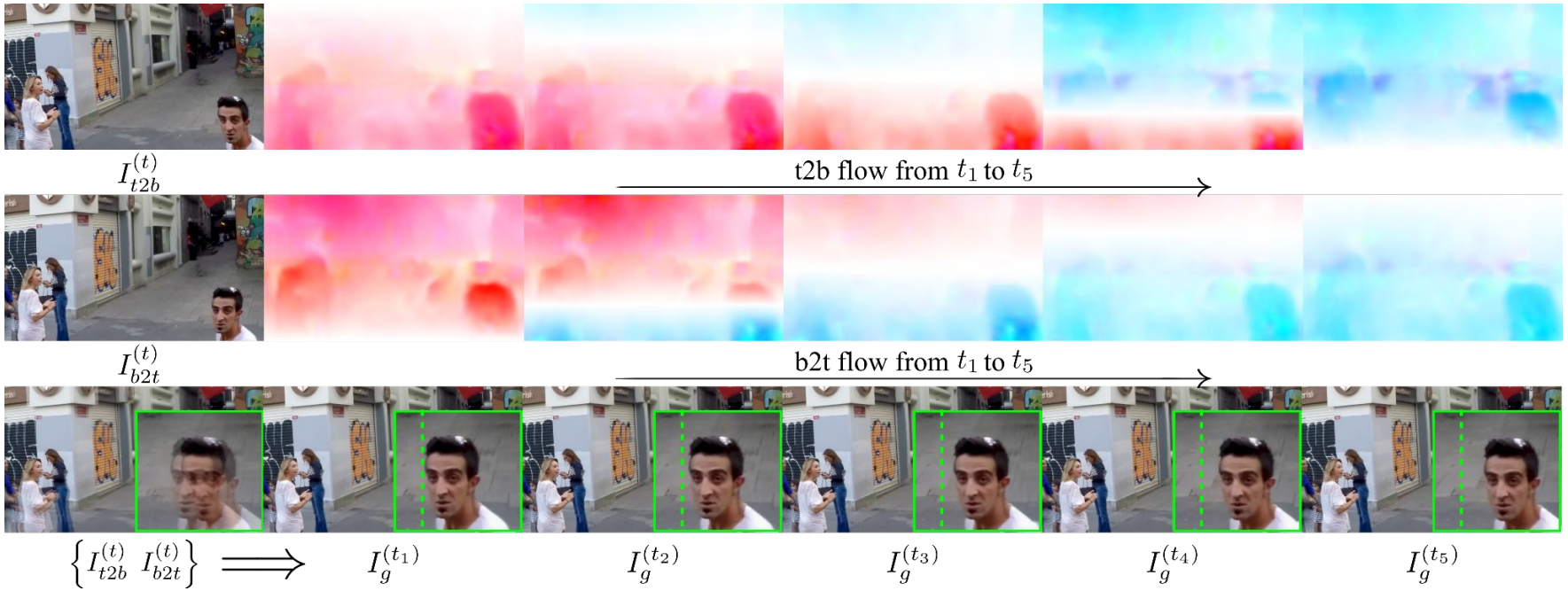
Raskar+, Coded Exposure Photography: Motion Deblurring using Fluttered Shutter, SIGGRAPH'06
Gu+, Coded Rolling Shutter Photography: Flexible Space-Time Sampling, ICCP'10

Feature II:
Dual Reversed Rolling Shutter

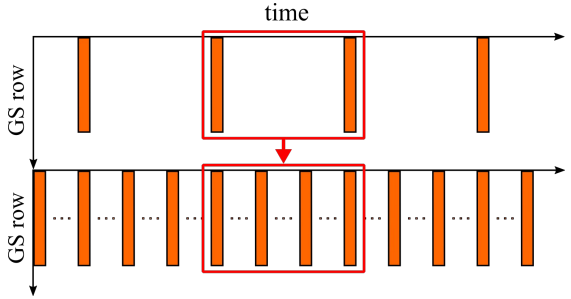
Zhihang Zhong, UTokyo

https://zzh-tech.github.io/

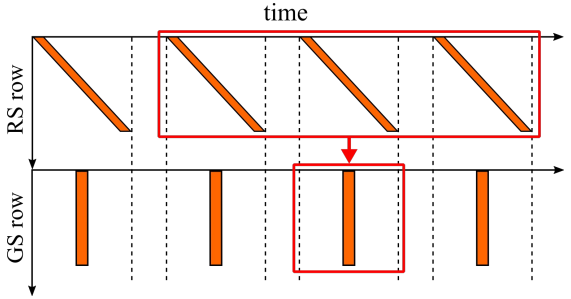
Bringing RS images alive with dual reversed distortion



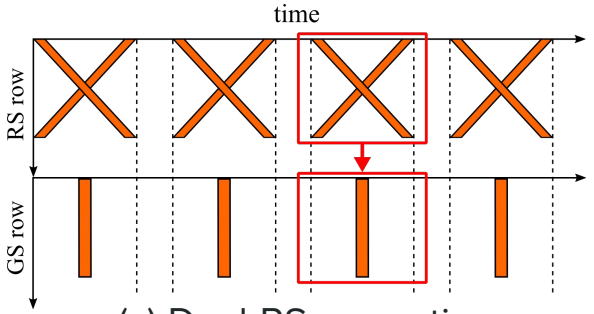
Relevant task settings



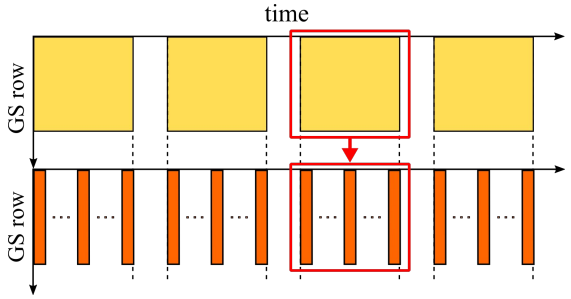
(a) Video frame interpolation



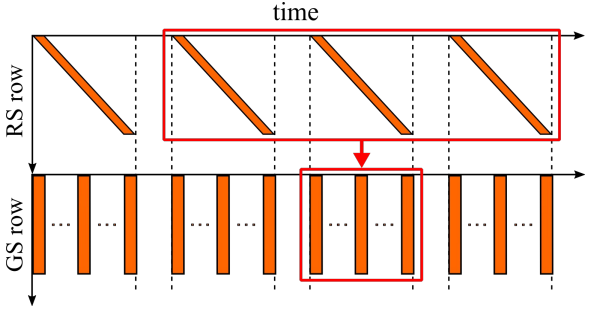
(b) RS correction



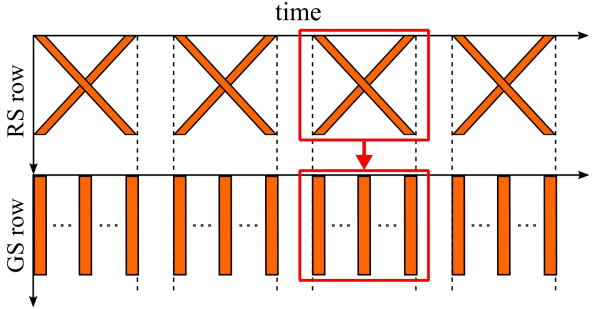
(c) Dual-RS correction



(d) Blur interpolation

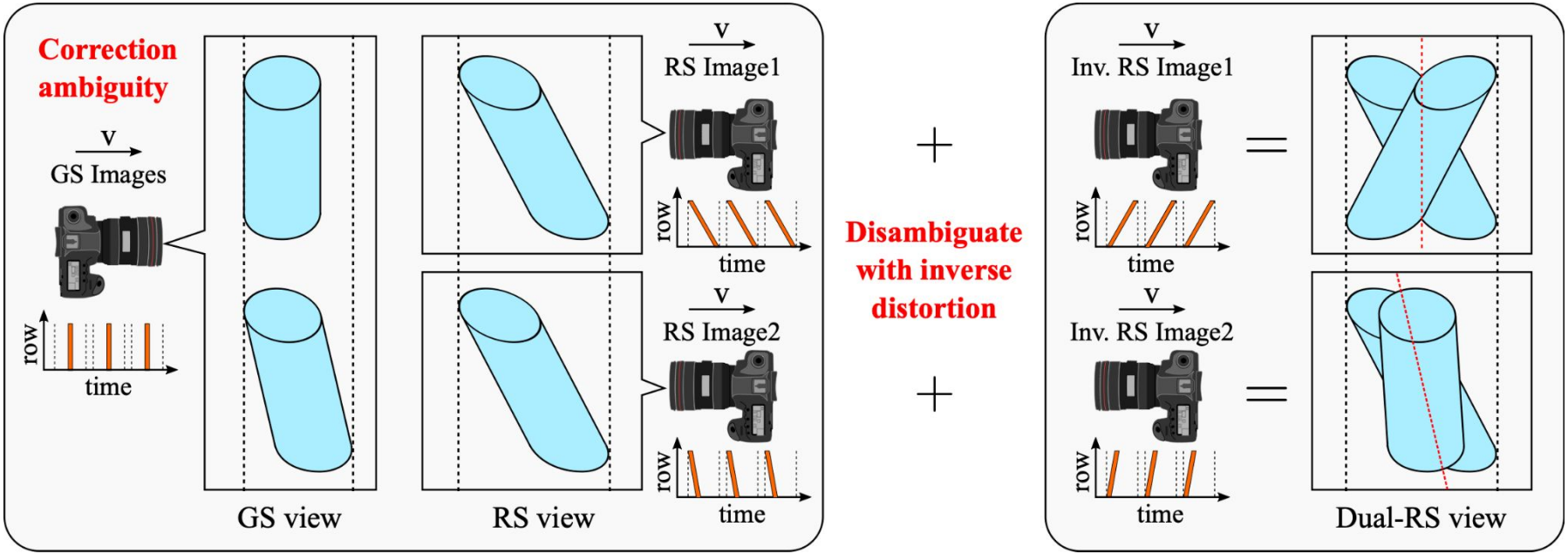


(e) RS interpolation

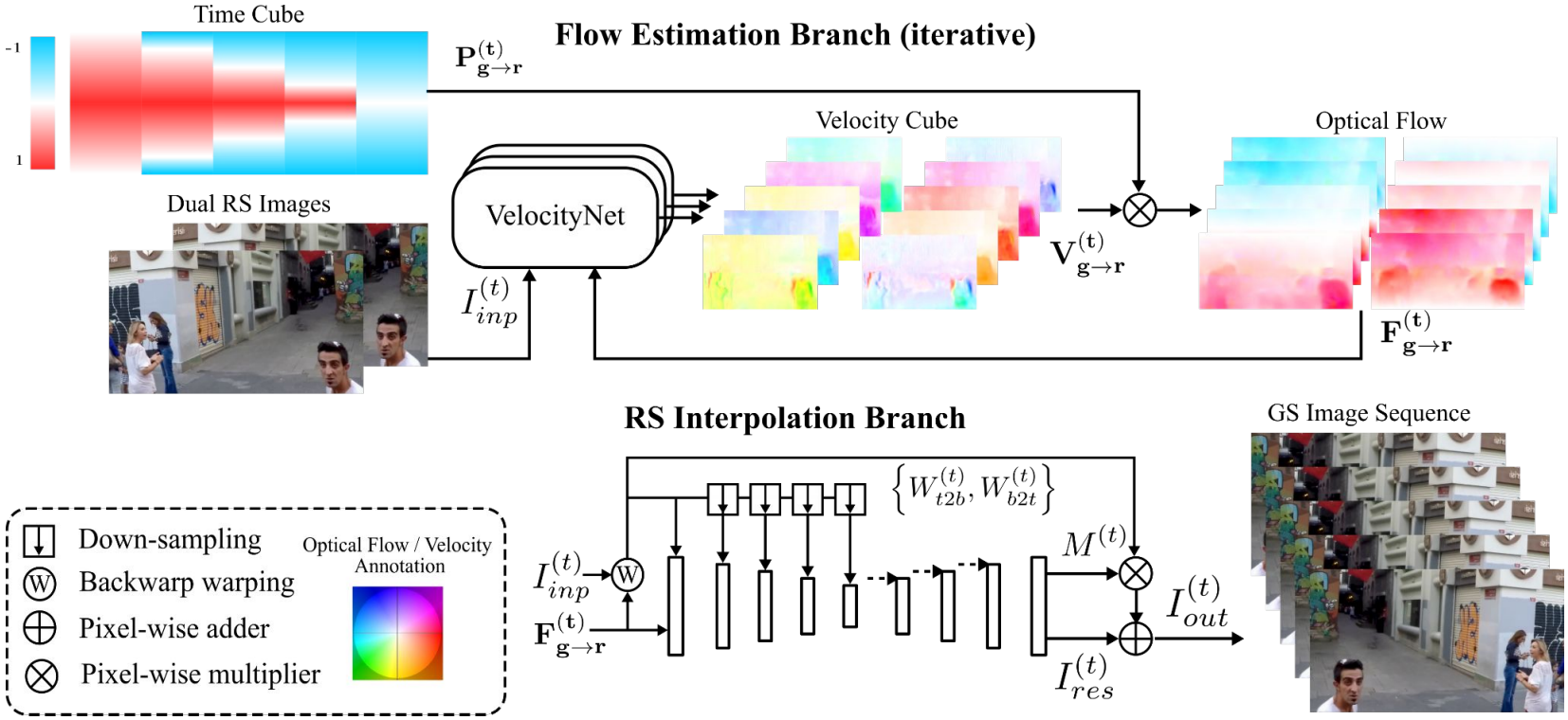


(f) Dual-RS interpolation

Why dual reversed distortion?



Neural network architecture (IFED)



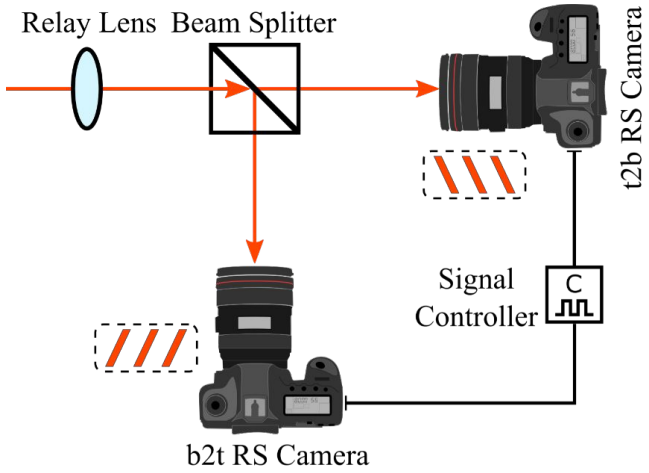
Dataset

Synthetic dataset
(RS-GOPRO)

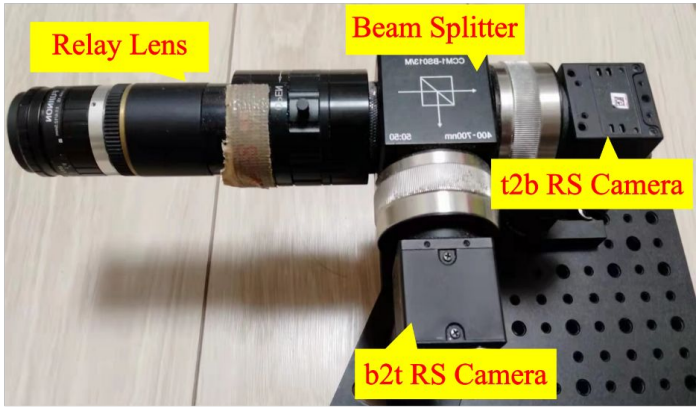
	train	validation	test
sequences	50	13	13
RS images	3554 (×2)	945 (×2)	966 (×2)
GS images	31986	8505	8694
resolution		960×540	
row exposure		1.0 ms	
row readout		87 μs	

Dataset

Real-world test set



(a)



(b)

Bringing Rolling Shutter Distorted Images Alive with Dual Reversed Distortion

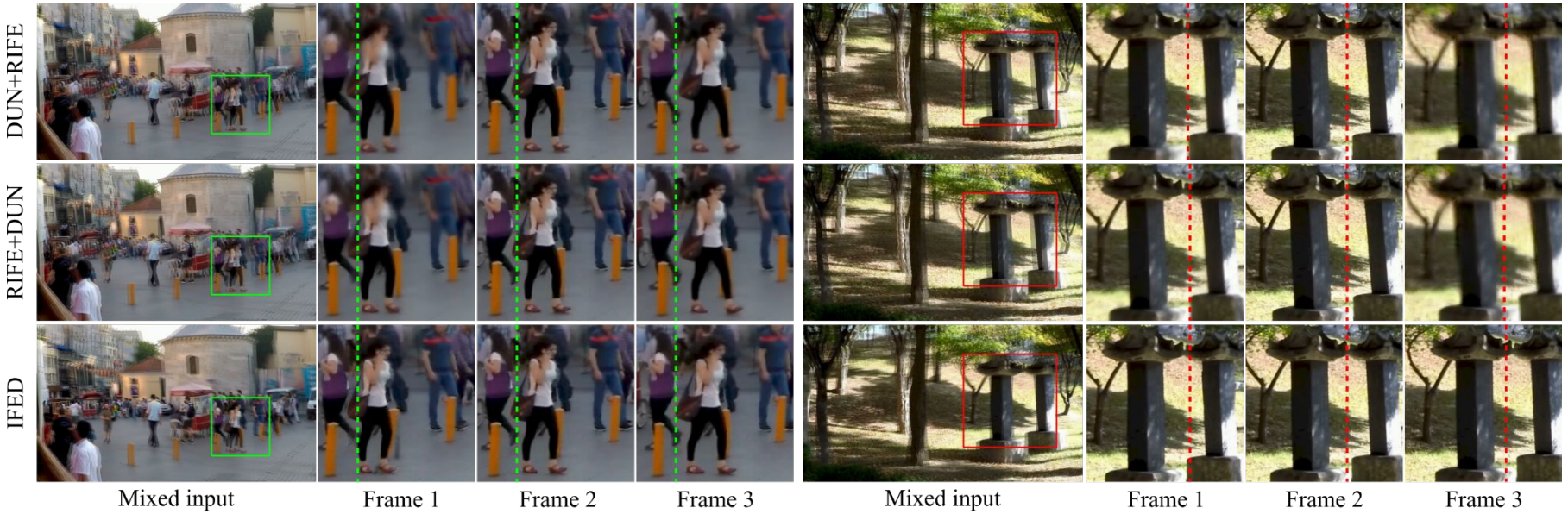
Zhihang Zhong, Mingdeng Cao, Xiao Sun, Zhirong Wu, Zhongyi Zhou, Yinqiang Zheng, Stephen Lin and Imari Sato

Experiments – compared to cascaded solution

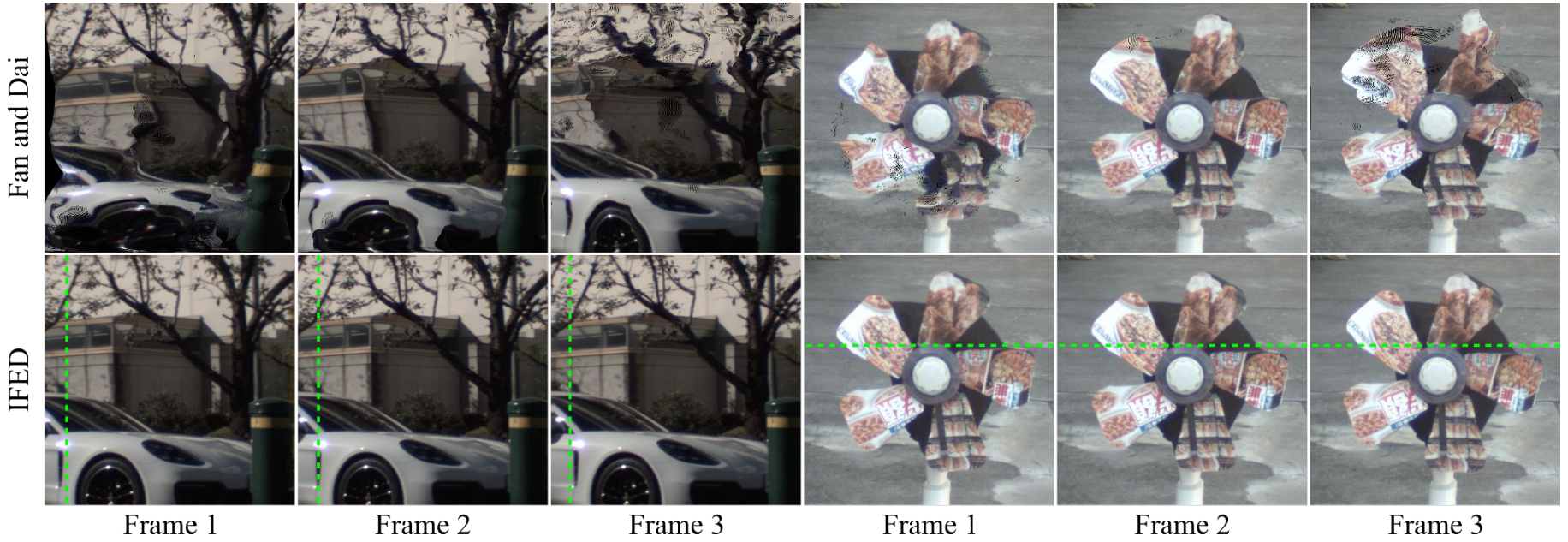
Quantitative results on RS-GOPRO. f# denotes # of frames extracted from the input RS images.

	PSNR ↑	SSIM ↑	LPIPS ↓
DUN (f1)	26.37	0.836	0.058
DUN + RIFE (f3)	25.38	0.788	0.159
DUN + RIFE (f5)	25.45	0.798	0.111
DUN + RIFE (f9)	25.31	0.795	0.102
RIFE + DUN (f3)	23.05	0.719	0.124
RIFE + DUN (f5)	22.28	0.692	0.118
RIFE + DUN (f9)	21.88	0.677	0.113
IFED (f1)	32.07	0.934	0.028
IFED (f3)	28.48	0.872	0.058
IFED (f5)	29.79	0.897	0.049
IFED (f9)	30.34	0.910	0.046

Experiments – compared to cascaded solution



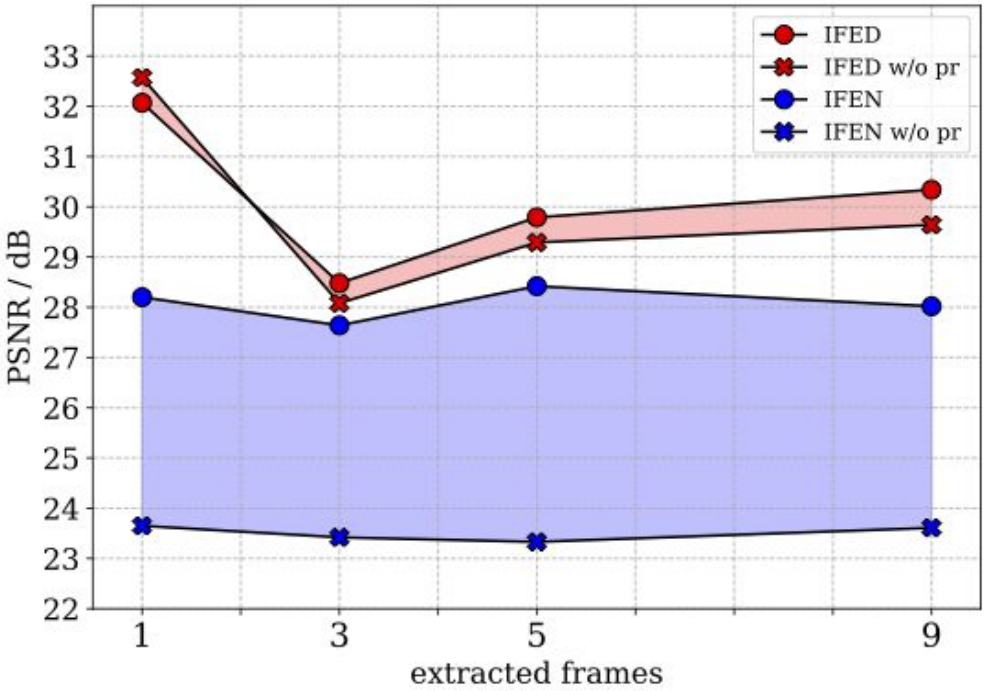
Experiments – compared to single RS temporal solution



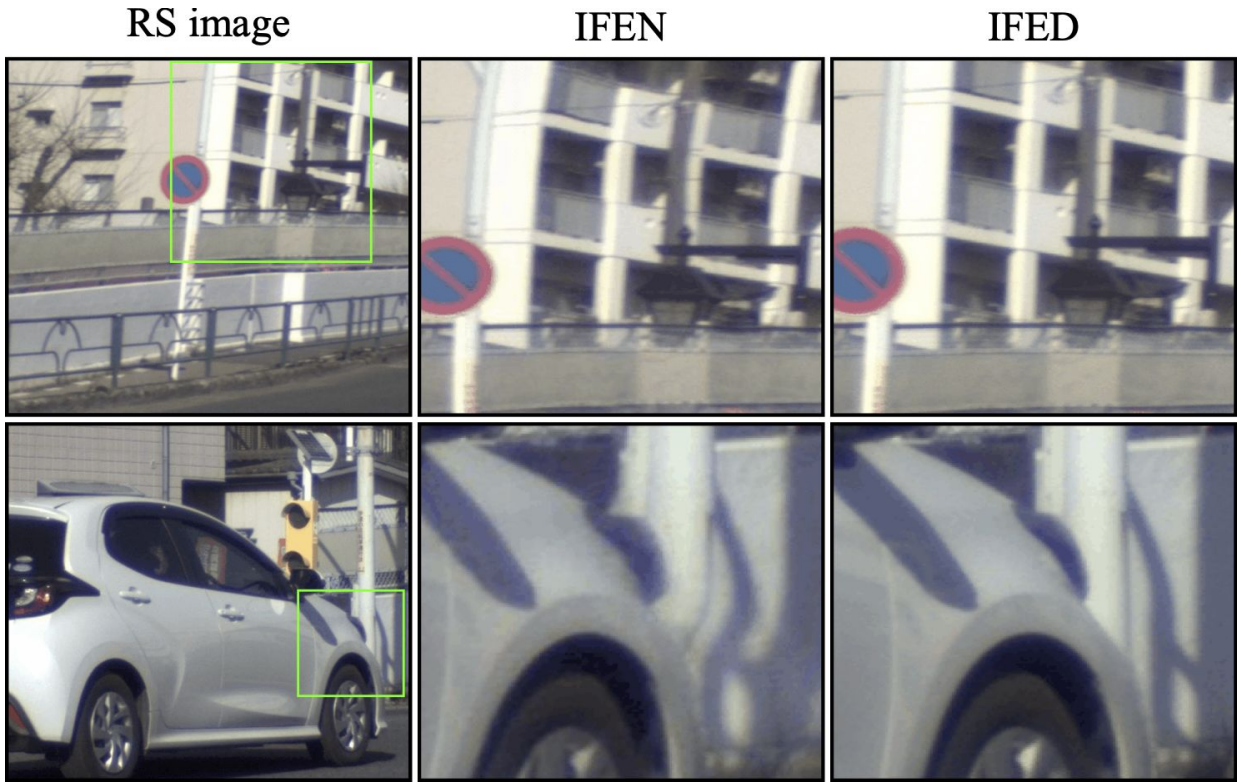
Experiments – robustness to different readout settings

Ablation studies

IFED: dual reversed RS solution
IFEN: single RS temporal solution

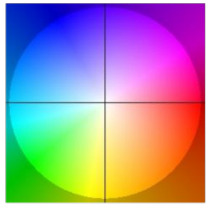


Ablation studies – dual RS



Ablation studies – time cube prior

Optical Flow Annotation

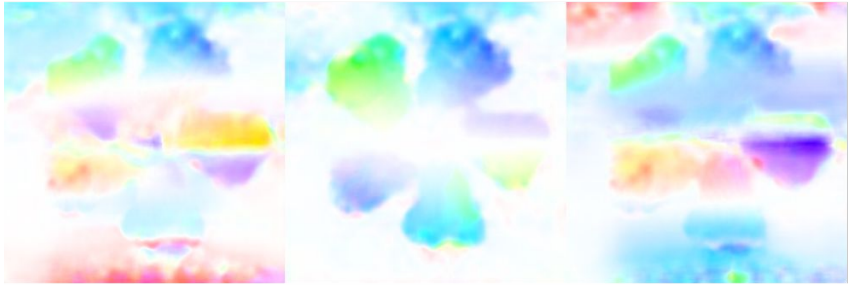


t2b

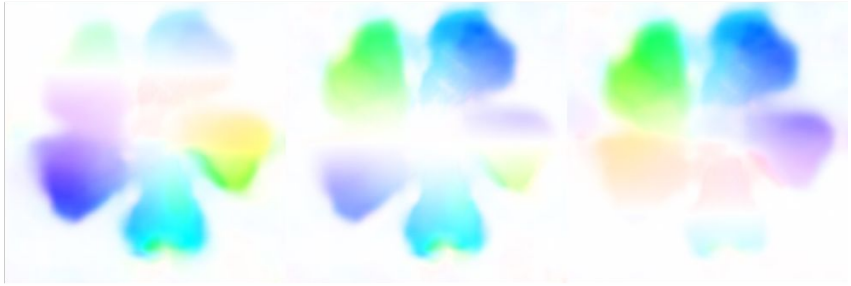
b2t

Dual Inputs

Velocity Field Sequence (t2b)

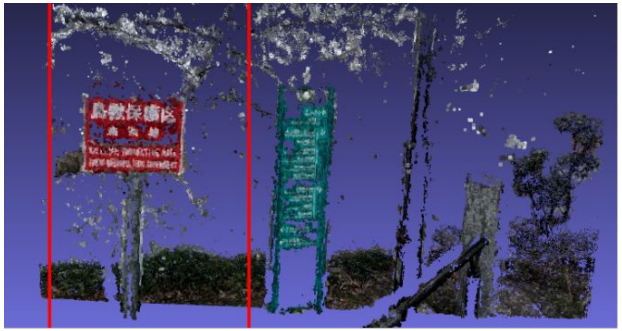


Optical Flow Sequence w/o RS Time Cube (t2b)

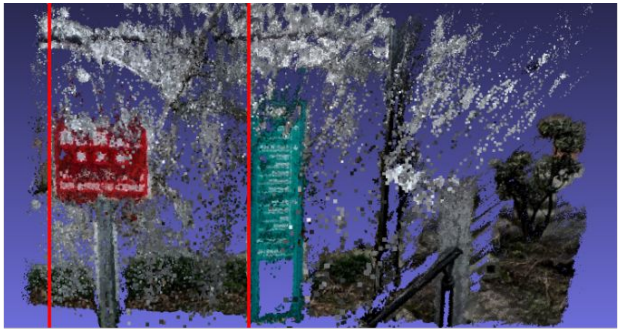


Optical Flow Sequence w/ RS Time Cube (t2b)

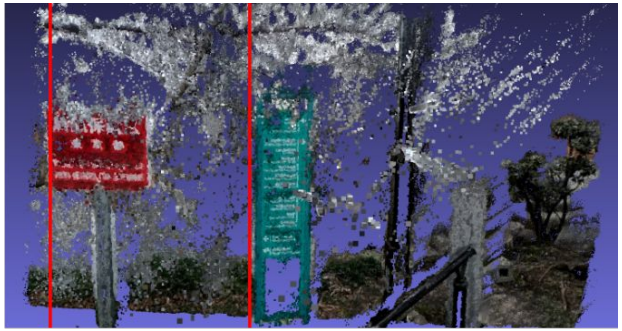
Discussion – benefits for other task



(a) Reconstructed 3D with RS

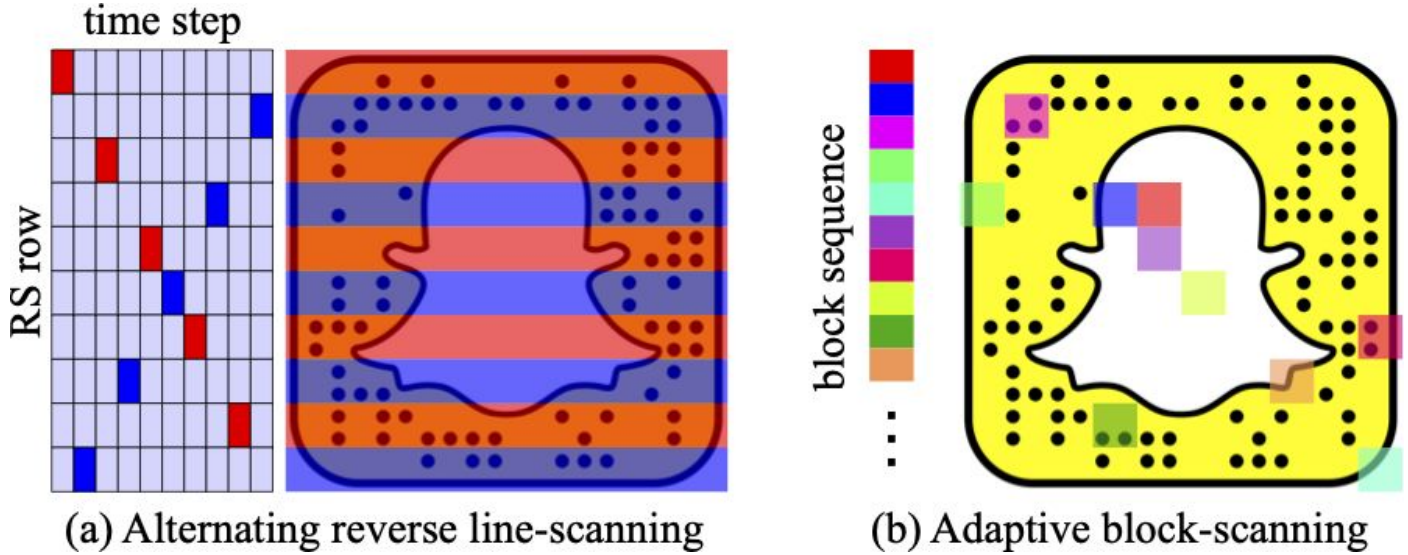


(b) Reconstructed 3D with ours



(c) Reconstructed 3D with GS

Discussion – programmable rolling shutter scanning mode



CVPR 2023 Tutorial on
Rolling Shutter Camera

New trends with combination of hardware features and deep learning

Q & A