Unconstrained Motion Deblurring for Dual-lens Cameras

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1 Introduction

a. Most present-day smartphones employ Unconstrained Dual-lens cameras.

Here, two cameras need *not* share the "same" configuration.

1. **Focal lengths**
   Same: Binocular or 3D vision.
   Different: Capture narrow, wide, or wider field-of-views.

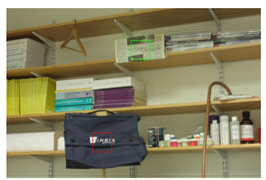
2. **Exposure times**
   Full-overlap: Super-resolution and visual odometry.
   Differently exposed: HDR and low-light imaging.

3. **Have same or different image resolutions**

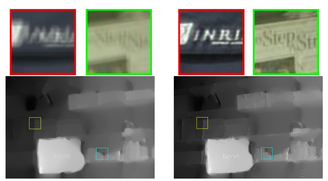
"Yet the ubiquitous phenomenon of motion blur is *unexplored* in Unconstrained Dual-lens (DL) cameras."

2 Challenges

Motion blurred image



Deblurred image



Corresponding patches and depth

1. ***No* motion blur model exists for unconstrained DL set-up.**
2. **Deblurring has to *ensure* scene-consistent disparities.**
3. **It also has to *effectively* handle more than one image.**

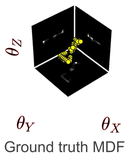
iPhone's triple-lens launch, 2019 Sept.

3 Motion blur model for Unconstrained DL Cameras

A motion blurred image is a combination of multiple warped images.

Motion blurred image

Clean image



Ground truth MDF

$$\mathbf{I}_B^n = \sum_{p \in \mathbb{P}^3} w^n(p) \cdot P^n\Big(R_p(\mathbf{X} - \mathbf{l_c}) + \mathbf{l_c} + \mathbf{l_b}\Big)\, dp,$$

$\mathbf{I}_B^n \rightarrow$ blurred image $\quad \mathbf{l_c} \rightarrow$ COR $\quad \mathbf{l_b} \rightarrow$ base-line $\quad w^n(p) \rightarrow$ MDF

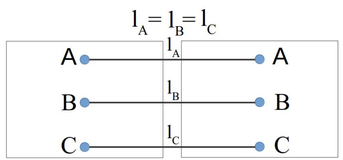
$\mathbb{P}^3 \rightarrow$ Camera pose-space $\quad P^n(\cdot) \rightarrow$ World-to-sensor projection

4 Ill-posedness in Unconstrained DL Motion Deblurring

There exist multiple valid solutions of deblurred image-pairs.

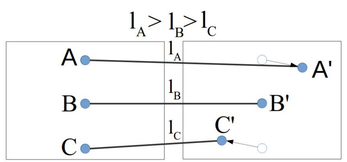
$$\mathbf{I}_B^n = \sum_p w^n(p) P^n\Big(R_p(\underbrace{\mathbf{X}}_{true} - \mathbf{l_c}) + \mathbf{l_c} + \mathbf{l_b}\Big)$$

$$= \sum_p w^n(p) P^n\Big(R_p R_n^{-1}(\underbrace{R_n(\mathbf{X} - \mathbf{l_c}) + \mathbf{l_c}}_{apparent} - \mathbf{l_c}) + \mathbf{l_c} + \mathbf{l_b}\Big), \quad \forall R_n.$$



True solution

Scene-features A, B and C are at the **same** depth.

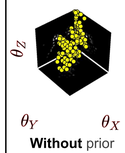


An apparent solution (inplane rotation)

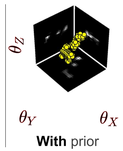
Erroneously, A, B, and C have **different** depths.

5 A New prior to address the ill-posedness

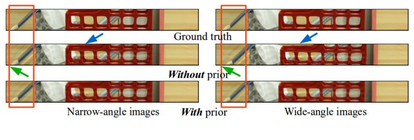
Ill-posedness is due to relative shifts among MDFs.



Without prior



With prior



$$\text{DL Cost} = \underbrace{\text{Image-pair cost}}_{\text{Convex}} + \underbrace{\text{MDF-pair cost}}_{\text{Convex, Not interdependent}} + \underbrace{\text{Prior } (\|\mathbf{w}_n - \mathbf{w}_w\|_2)}_{\text{Convex, Interdependent}}.$$

The prior increases the DL cost with relative MDF shifts.

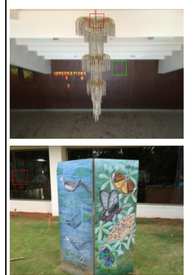
Properties of the prior

a. Convex, i.e., retains biconvexity for convergence.
b. Allows for efficient LASSO optimization.
c. Reinforces camera motion estimation.

Representative results

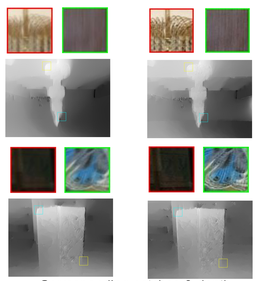
PSNR (dB)	Blur	W/o Prior W/o COR	W/o Prior W/ COR	W/ Prior W/o COR	W/ prior W/ COR
Image	22.39	25.69	26.59	27.28	28.88
Depth	28.33	23.35	**23.59**	29.12	**30.52**

Ablation study: The DL prior reduces the ill-posedness by a good margin (i.e., by 7 dB, as indicated in bold).



Real blurry images

Deblurred images



Corresponding patches & depth

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