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V-SENSE

A Pipeline for Lenslet Light Field Quality Enhancement

Pierre Matysiak, Mairead Grogan, **Mikael Le Pendu**, **Martin Alain**, Aljosa Smolic

Outline

- Motivations
- Properties of the RAW data of Plenoptic cameras
- RAW demultiplexing (i.e. low level view extraction tool)
- Post processing steps
- Results

Motivations

Capture of light fields with Plenoptic cameras

- Designed for dense light fields (views close to each other)
- Very few tools for view extraction
  - Lytro desktop software
    - → Proprietary, Not maintained
  - Matlab Light Field toolbox [1]
    - → Ghosting effects (external views)
    - → Colour inconsistency
    - → Inaccurate colour balance
    - → Loss of dynamic range
    - → noise

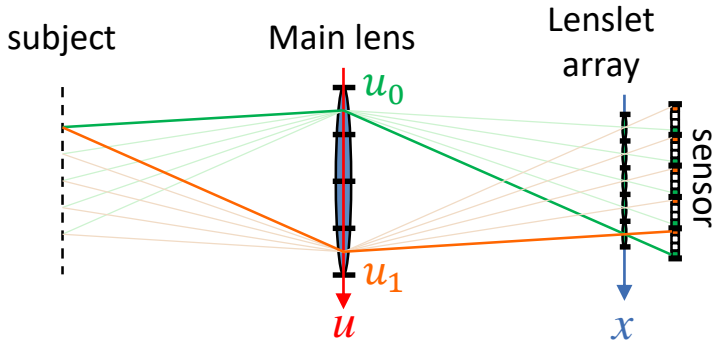
➔ Analyse these issues and propose new tools

[1] D. G. Dansereau, O. Pizarro, and S. B. Williams, **"Decoding, calibration and rectification for lenselet-based plenoptic cameras"**, in Proc. CVPR, 2013

Plenoptic cameras RAW Data

Unfocused Plenoptic camera design

- Lenslet array in front of the sensor

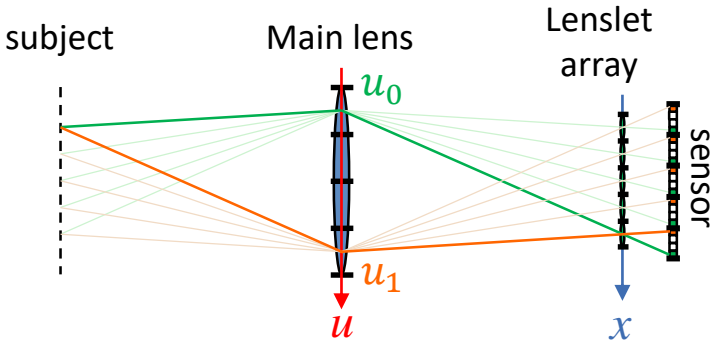


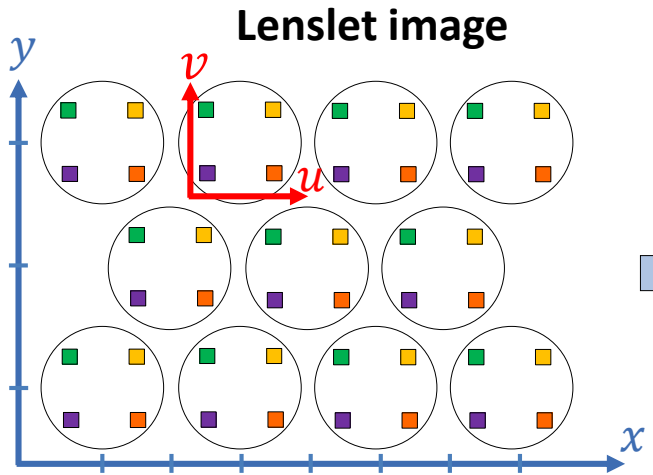
Lenslet image

Plenoptic cameras RAW Data

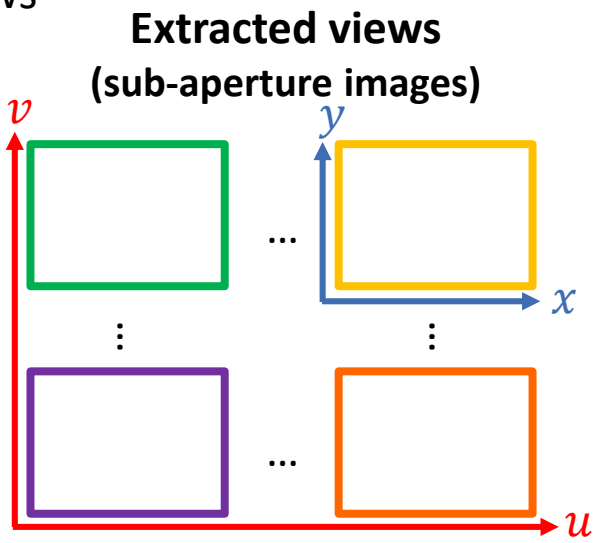
Unfocused Plenoptic camera design

- Lenslet array in front of the sensor
- Pixels behind each lenslet = angular patch
  - Demultiplexing : rearranging the pixels into views





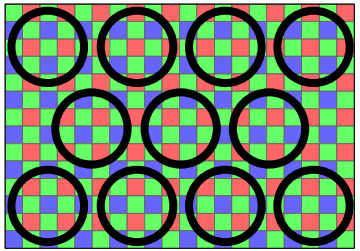
Demultiplexing



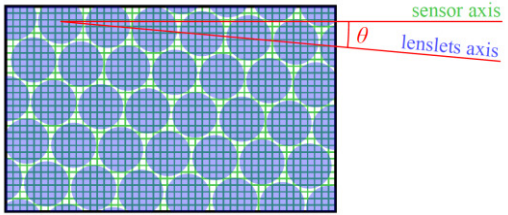
Plenoptic cameras RAW Data

Challenges for demultiplexing (1/2)

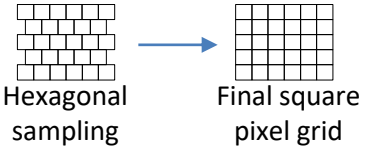
- Bayer colour filter array
  - High frequency lenslet pattern ➔ difficult demosaicing
  - Affects saturation levels of the pixels



- Imperfect alignment between lenslets and pixel grid
  - Rotation, rescaling ➔ require interpolations
    - → Made difficult by high frequency lenslet pattern



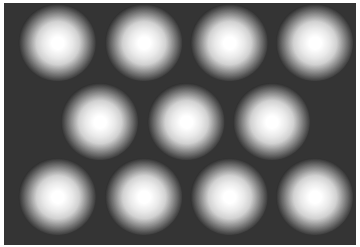
- Hexagonal lenslet grid
  - Further interpolations needed (for each SAI)



Plenoptic cameras RAW Data

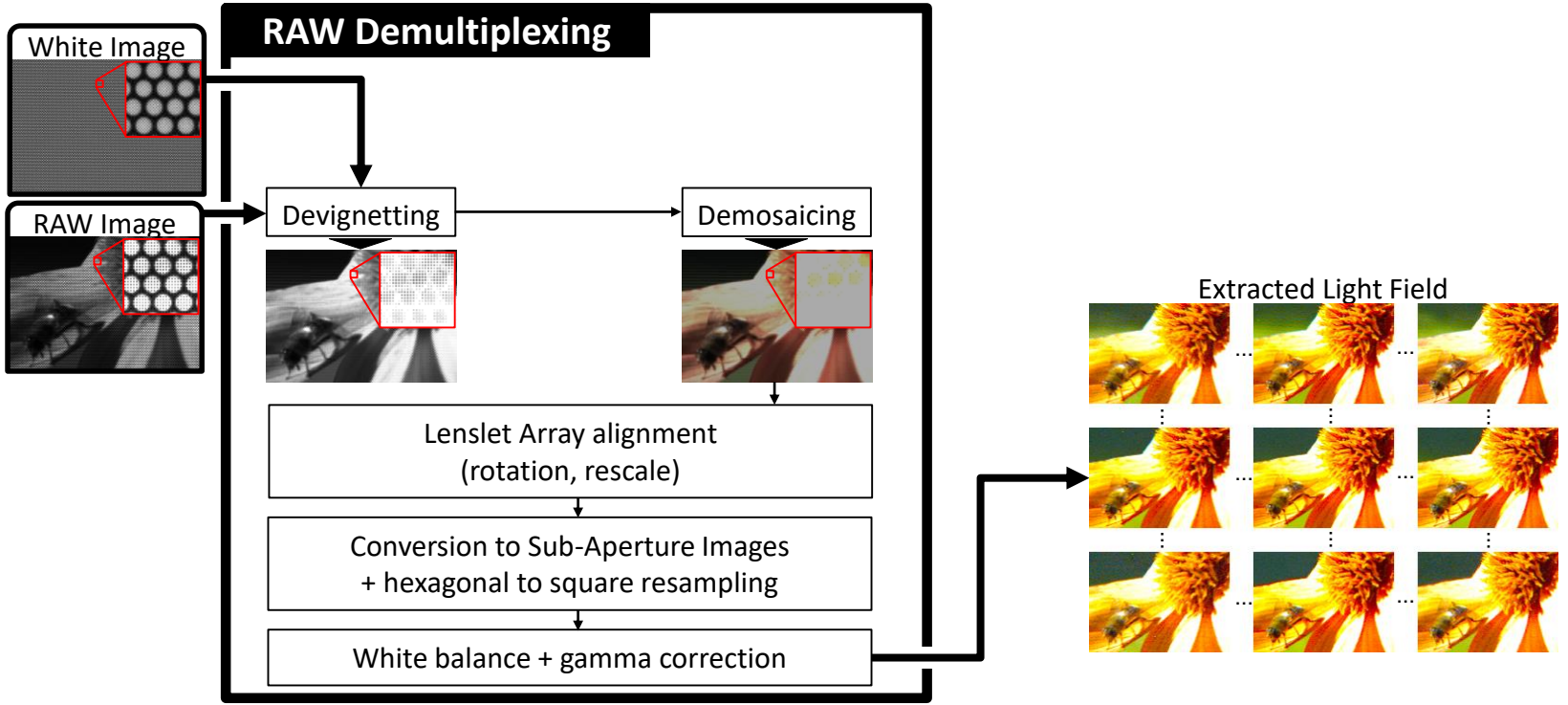
Challenges for demultiplexing (2/2)

- Lenslet vignetting
  - Inconsistent brightness between views
  - Different saturation levels of the pixels
    - → Inconsistencies between views in the highlights



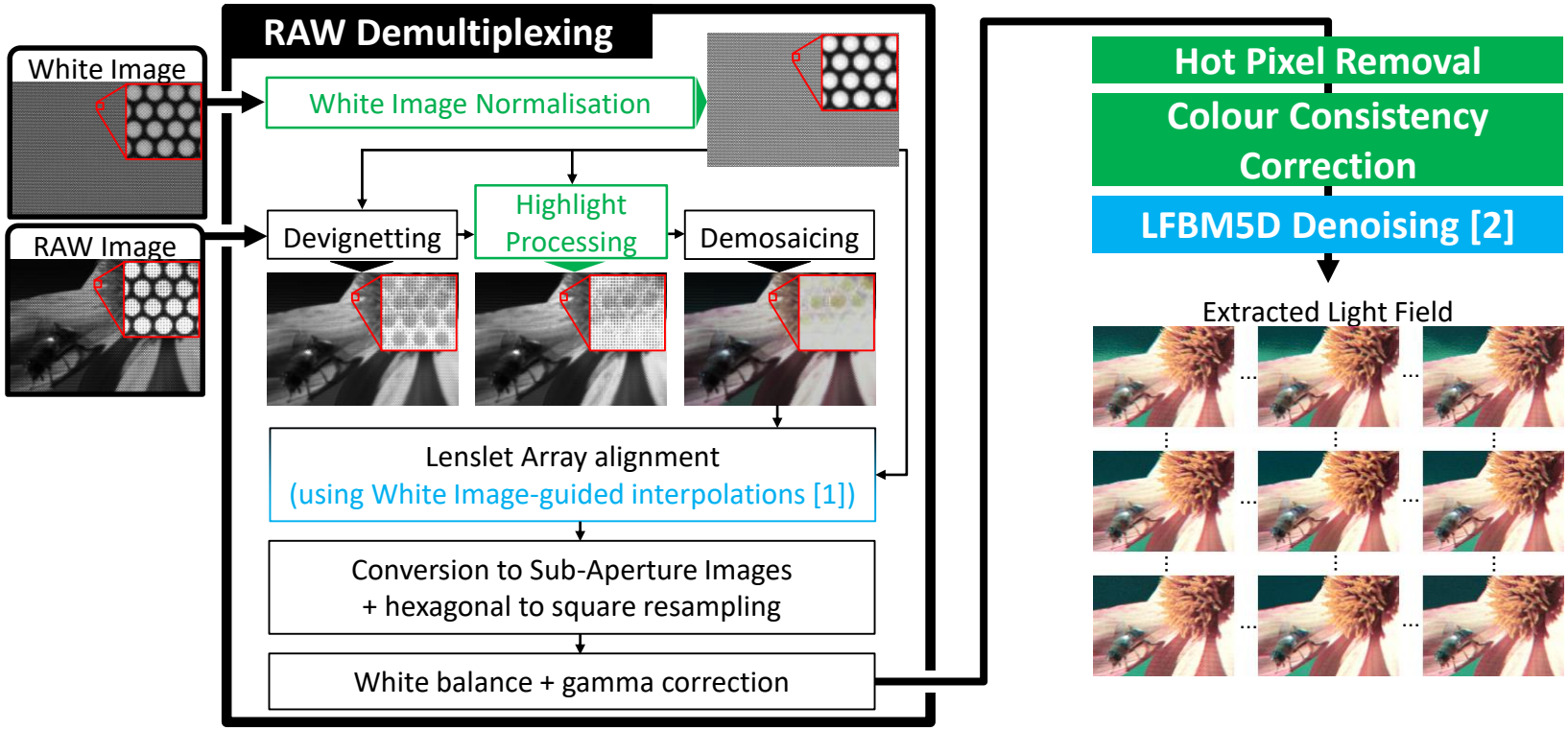
- Reduced amount of light due to lenslet array
  - More noisy data
  - Many hot pixels in practice

Existing Demultiplexing (Dansereau et. al [1])



[1] D. G. Dansereau, O. Pizarro, and S. B. Williams, **"Decoding, calibration and rectification for lenselet-based plenoptic cameras"**, in Proc. CVPR, 2013

Proposed Pipeline



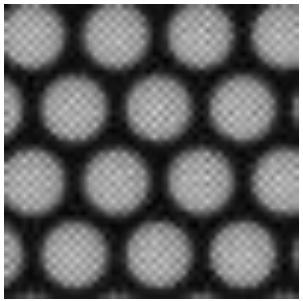
[1] P. David, M. Le Pendu, & C. Guillemot, **"White lenslet image guided demosaicing for plenoptic cameras"**, in Proc. IEEE MMSP, 2017

[2] M. Alain and A. Smolic, **"Light field denoising by sparse 5D transform domain collaborative filtering"**, in Proc. IEEE MMSP, Oct. 2017

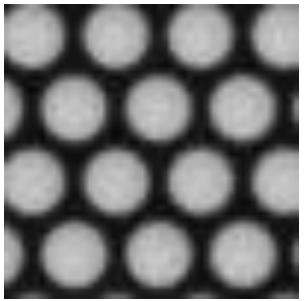
Proposed Pipeline: Demultiplexing

White image normalisation

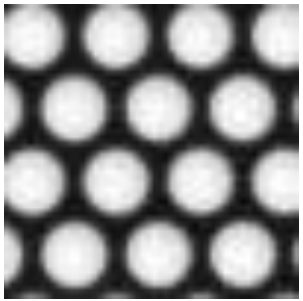
- Issues of original white image
  - Different responses of R,G and B pixels to white Light (Bayer filter array)
    - → Devignetting interferes with the white balance
  - Maximum value of the original white image lower than 1
    - → Devignetting increases the brightness



Original white image



Colour normalization



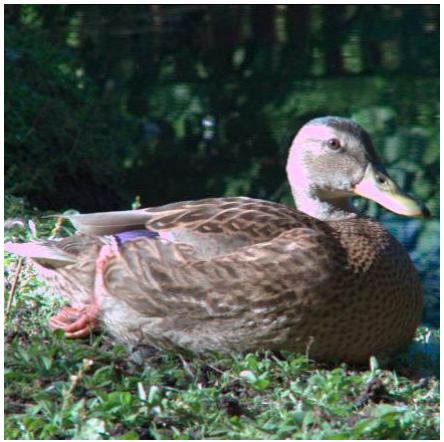
Colour normalization
+ Global normalization

Proposed Pipeline: Demultiplexing

White image normalisation

- Corrects overall brightness and colours
- But reveals wrong highlights (previously clipped)
  - Saturated : RGB $= (1,1,1)$ → after white balance : RGB $= (s_r, s_g, s_b)$ → pink highlights

Demultiplexed without white image normalisation



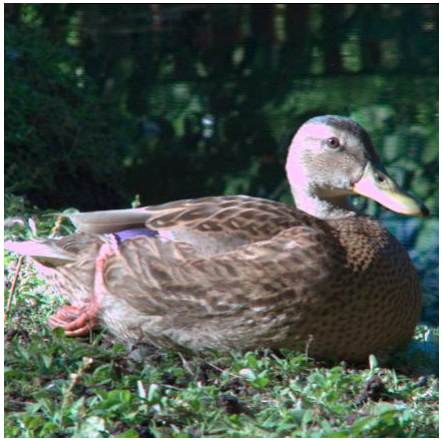
Demultiplexed with white image normalisation

Proposed Pipeline: Demultiplexing

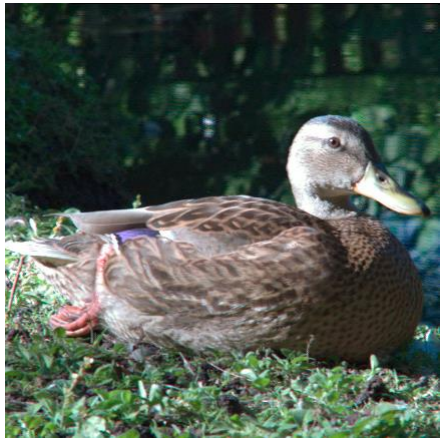
Highlight processing

- Applied before demosaicing (1 known component per pixel)
  1. Detect saturation from blocks of 4 pixels forming bayer pattern 
  2. Force the 4 pixels to have the same value after white balance is applied ➔ white highlights

no WI normalisation



WI normalisation

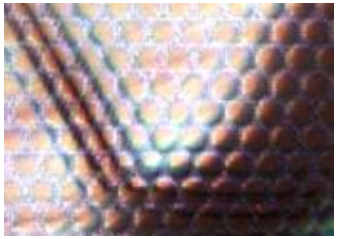


WI normalisation
+ Highlight processing

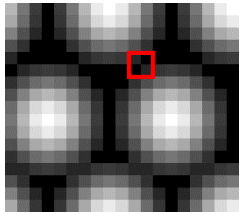
Proposed Pipeline: Demultiplexing

White Image Guided interpolations [1]

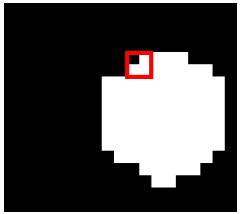
- Interpolations needed for Rotation/Rescaling of the lenslet image
  - Standard bilinear/bicubic interpolation
    - → "Bleeding" of information between lenslets (use neighbour pixels)
  - White image guided interpolation
    - → Weight contributions of neighbor pixels
    - → Exclude pixels from other lenslets



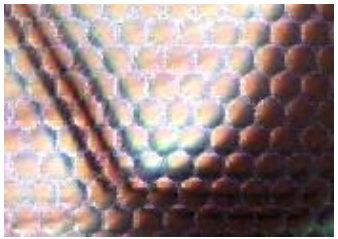
bilinear interpolation



Weights
(=White Image)



Exclusion Mask
(obtained from White Image)



WI-guided interpolation

[1] P. David, M. Le Pendu, & C. Guillemot, **"White lenslet image guided demosaicing for plenoptic cameras"**, in Proc. IEEE MMSP, 2017

Proposed Pipeline: Demultiplexing

White Image Guided interpolations [1]

- Reduces ghosting artifacts on external views
- Same principle can be applied to demosaicing

→ Better colour consistency but more colour noise

Bilinear interpolation

WI-guided interpolation

WI-guided interpolation
+WI-guided demosaicing

[1] P. David, M. Le Pendu, & C. Guillemot, **"White lenslet image guided demosaicing for plenoptic cameras"**, in Proc. IEEE MMSP, 2017

Proposed Pipeline: Demultiplexing

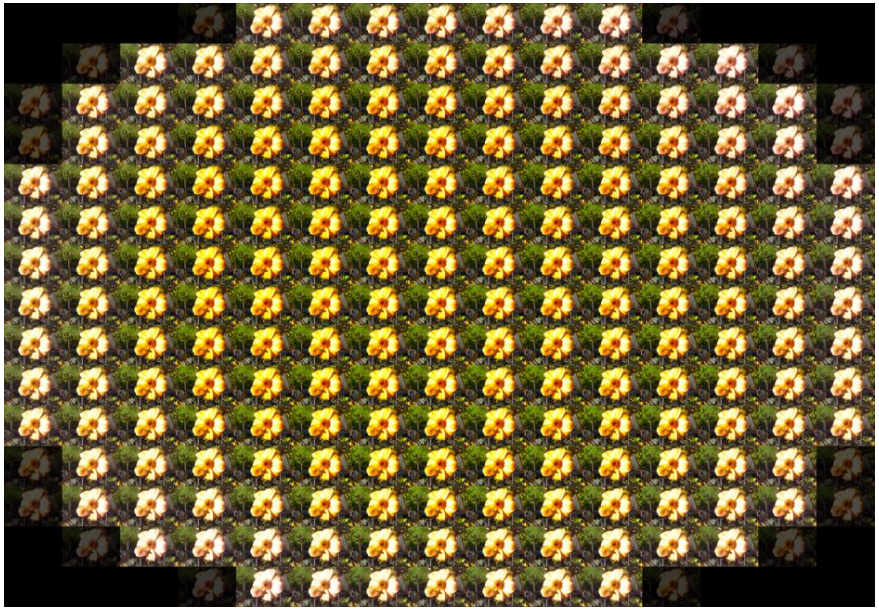
Demultiplexing Results (no post processing)

Dansereau et al. Matlab toolbox

Ours

Proposed Pipeline

Demultiplexing Results (no post processing)



Dansereau et al. Matlab toolbox

Ours

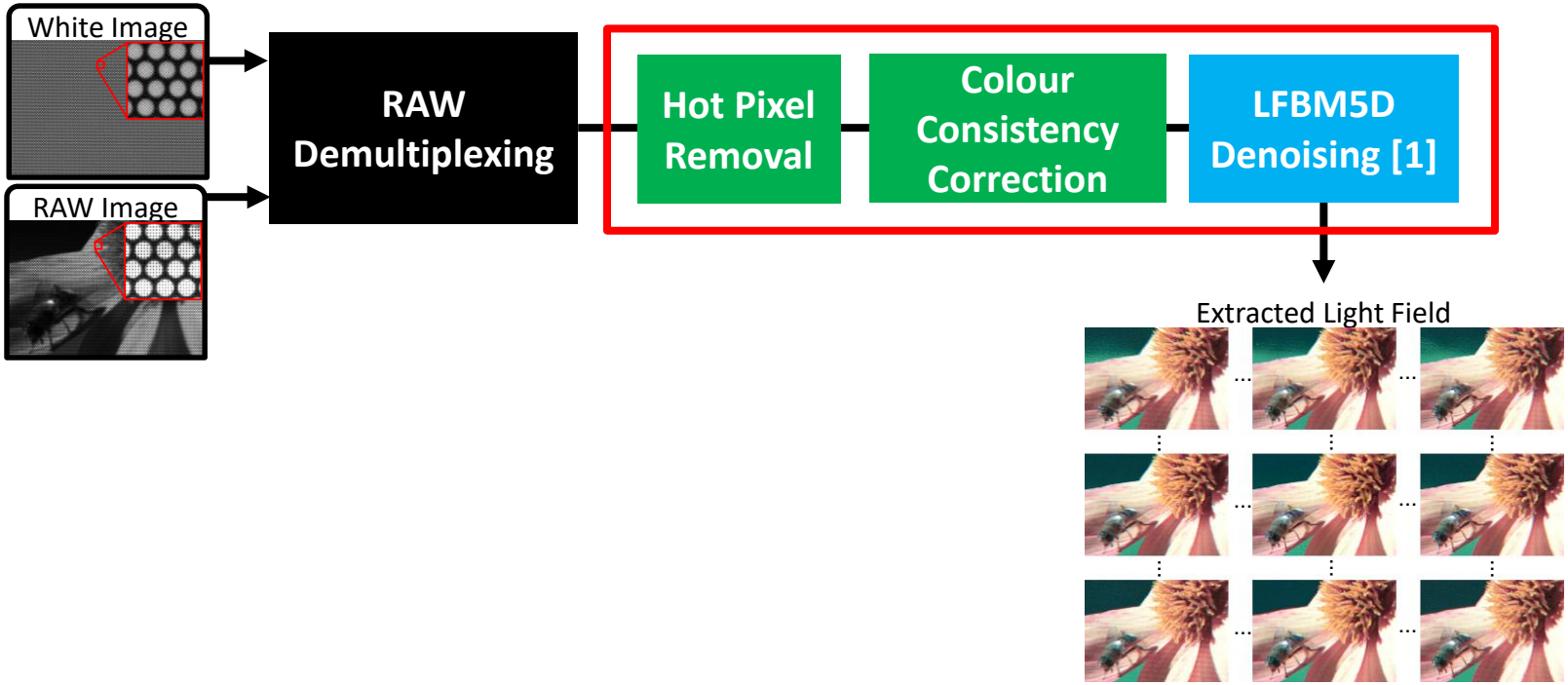
Proposed Pipeline: Demultiplexing

Demultiplexing Results (no post processing)

Central View

External View

Proposed Pipeline: Post Processing

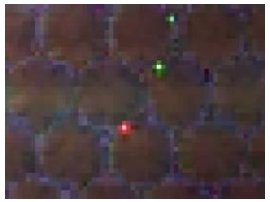


[1] M. Alain and A. Smolic, **"Light field denoising by sparse 5D transform domain collaborative filtering"**, in Proc. IEEE MMSP, Oct. 2017

Proposed Pipeline: Post Processing

Hot pixel correction

- Hot pixel effect in angular vs spatial dimensions
  - Demosaicing ➔ error spreads to angular neighbours on the lenslet image
  - Hot pixels isolated in the extracted views ➔ easier to detect in post-processing



Hot pixels in lenslet image (after demosaicing)

Hot pixels in extracted view

- Detection : CIELAB distance threshold with 7x7 neighborhood
- Correction : 3x3 median filter centered on the detected hot pixel

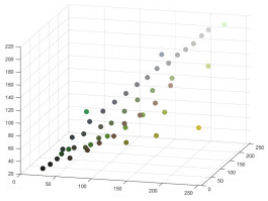
Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

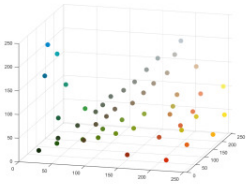
Fit GMMs

Target

Palette



p_t



p_p

Minimise $\mathcal{L}_2$

Estimate $\phi(x, \theta)$
Using
$\hat{\theta} =$
$\text{argmin}_\theta(\|p_t\|^2 - 2\langle p_t | p_p \rangle + \|p_p\|^2)$

Recolour Target

$\phi(x, \hat{\theta})$

Credit: Mairead Grogan

"L2 Divergence for Robust Colour Transfer", M. Grogan, R. Dahyot; CVIU 2019

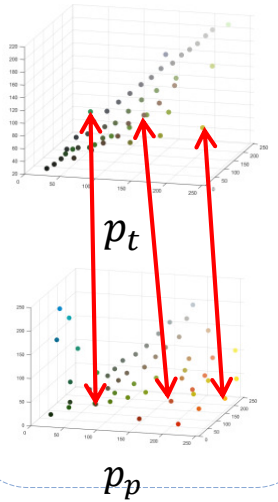
Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

Fit GMMs

Target

Palette



Minimise $\mathcal{L}_2$

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Recolour Target

$\phi(x, \hat{\theta})$

Credit: Mairead Grogan

"L2 Divergence for Robust Colour Transfer", M. Grogan, R. Dahyot; CVIU 2019

Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

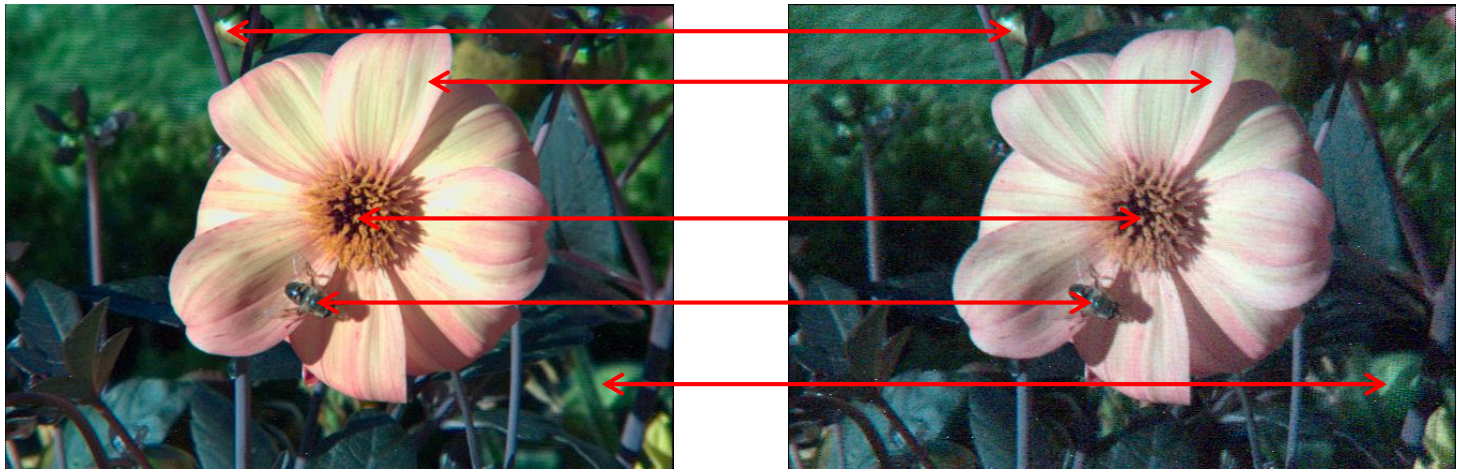
Center view - Palette

External view - Target

Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

Find correspondances between images



Center view - Palette

External view - Target

“Efficient coarse-to-fine patchmatch for large displacement optical flow”, Y. Hu, R. Song, and Y. Li; CVPR 2016

Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

Propagate colour correction from center image

Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

Propagate colour correction from center image

Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

External view - Target

Center view - Palette

External view - Result

Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

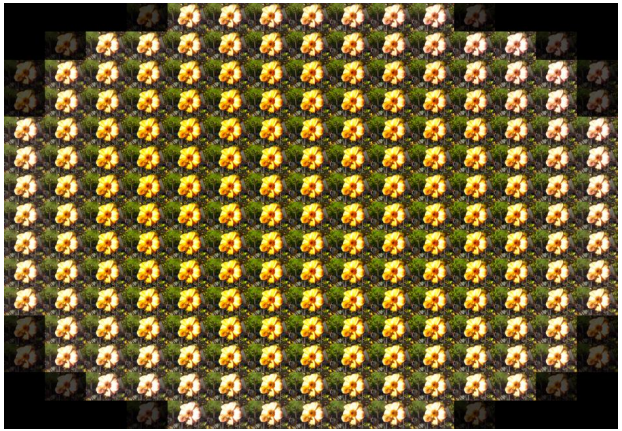
External view - Target

Center view - Palette

External view - Result

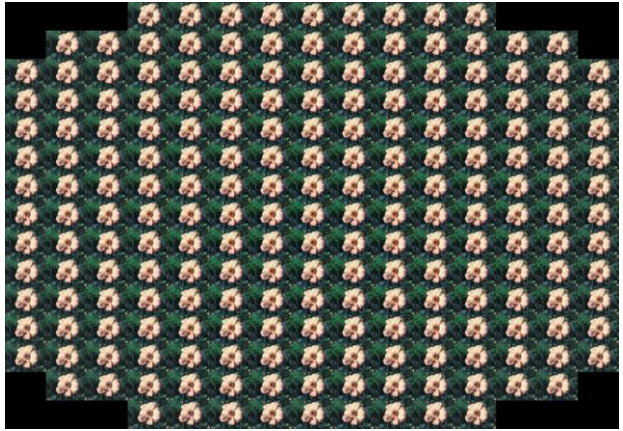
Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)



Dansereau's Matlab toolbox

Ours



Ours + recolouring

Proposed Pipeline: Post Processing

Colour Correction (based on colour transfer)

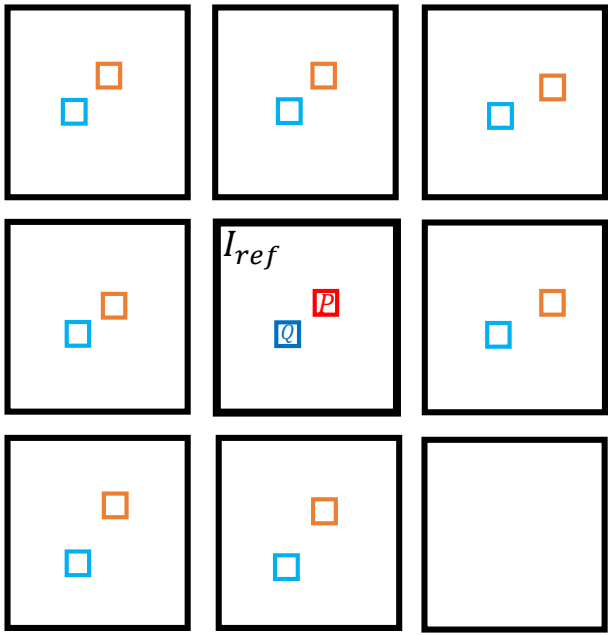
Dansereau's Matlab toolbox

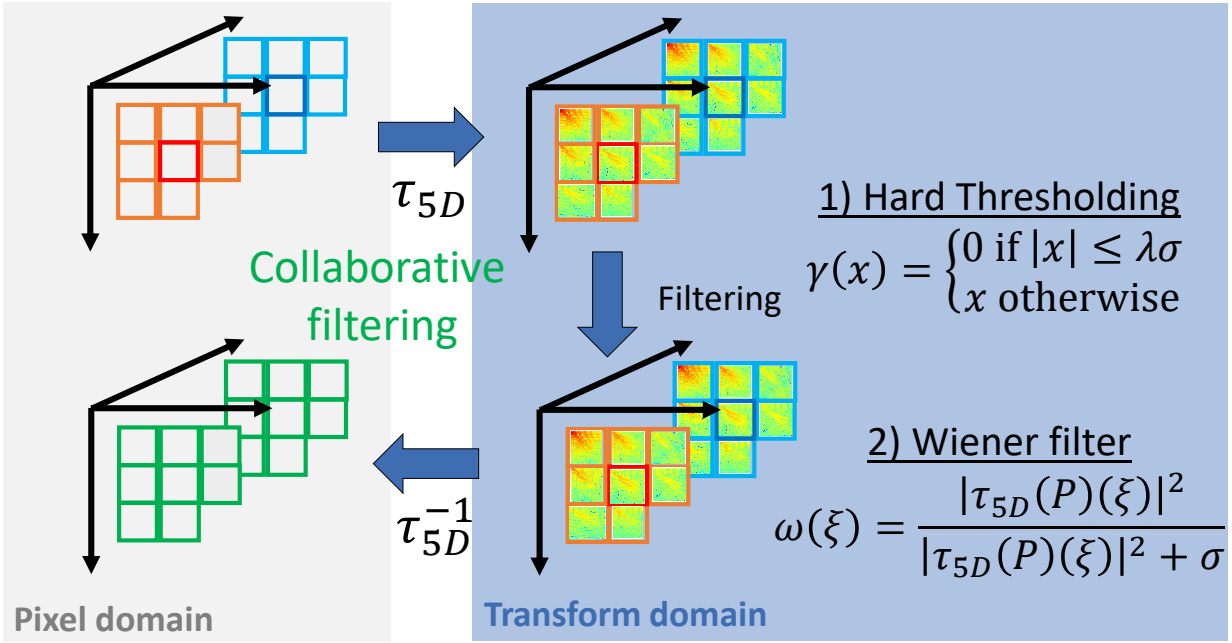
Ours

Ours + recolouring

Proposed Pipeline: Post Processing

Denoising

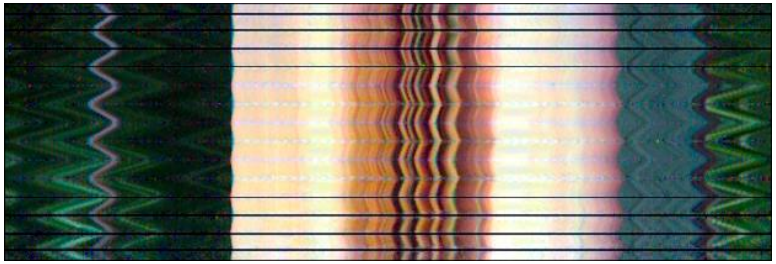




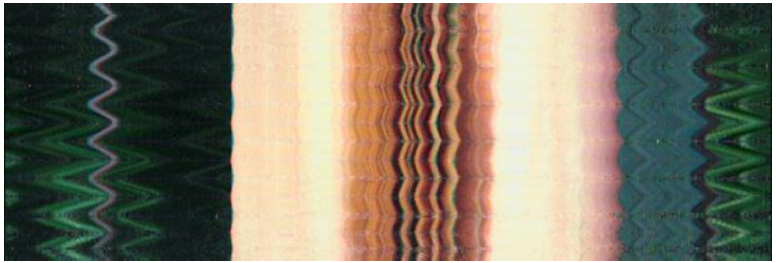
[1] M. Alain and A. Smolic, **"Light field denoising by sparse 5D transform domain collaborative filtering"**, in Proc. IEEE MMSP, Oct. 2017

Proposed Pipeline: Post Processing

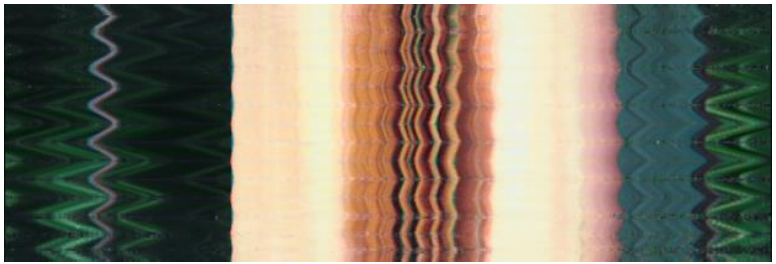
Results



Demultiplexing



Recolouring



Denoising

Proposed Pipeline: Post Processing

Results

Proposed Pipeline: Post Processing

Results

SAI extraction

Recolouring

Denoising

Proposed Pipeline: Post Processing

Results

SAI extraction

Recolouring

Denoising

Proposed Pipeline: Post Processing

Results

Demultiplexing

Recolouring

Denoising

Proposed Pipeline: Post Processing

Results

Demultiplexing

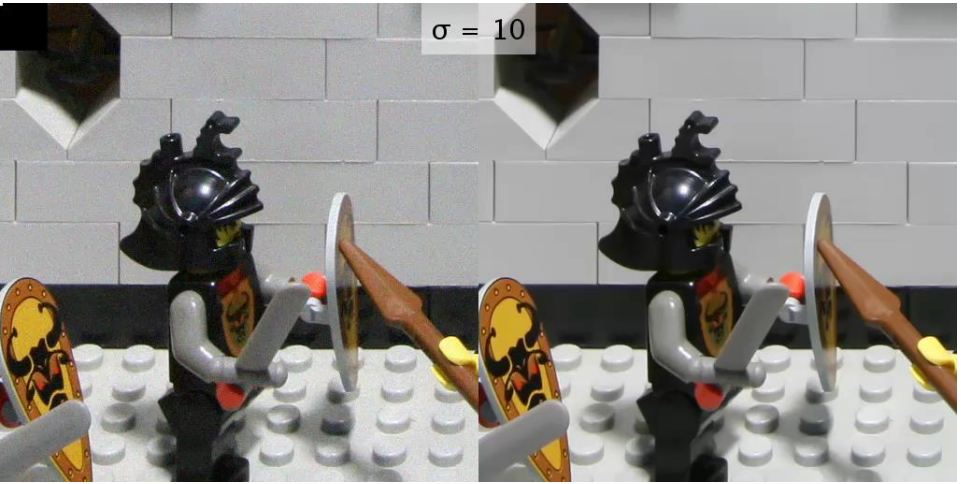
Recolouring

Denoising

Proposed Pipeline: Post Processing

Results

- Denoising example on other types of Light Fields



Proposed Pipeline: Applications

Super-resolution

Dansereau

Full pipeline

“Light Field Super-Resolution via LFBM5D Sparse Coding”, M. Alain, A. Smolic; ICIP 2018

Proposed Pipeline: Applications

Super-resolution

Dansereau

Full pipeline

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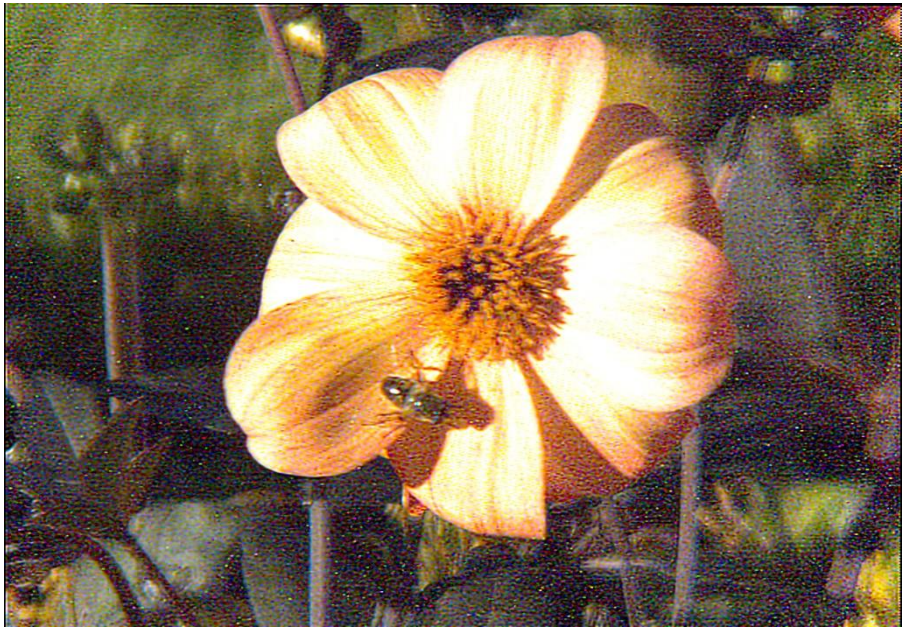
Proposed Pipeline: Applications

Super-resolution



Dansereau

Full pipeline

“Light Field Super-Resolution via LFBM5D Sparse Coding”, M. Alain, A. Smolic; ICIP 2018

Proposed Pipeline: Applications

Rendering

Dansereau

Full pipeline

Proposed Pipeline: Applications

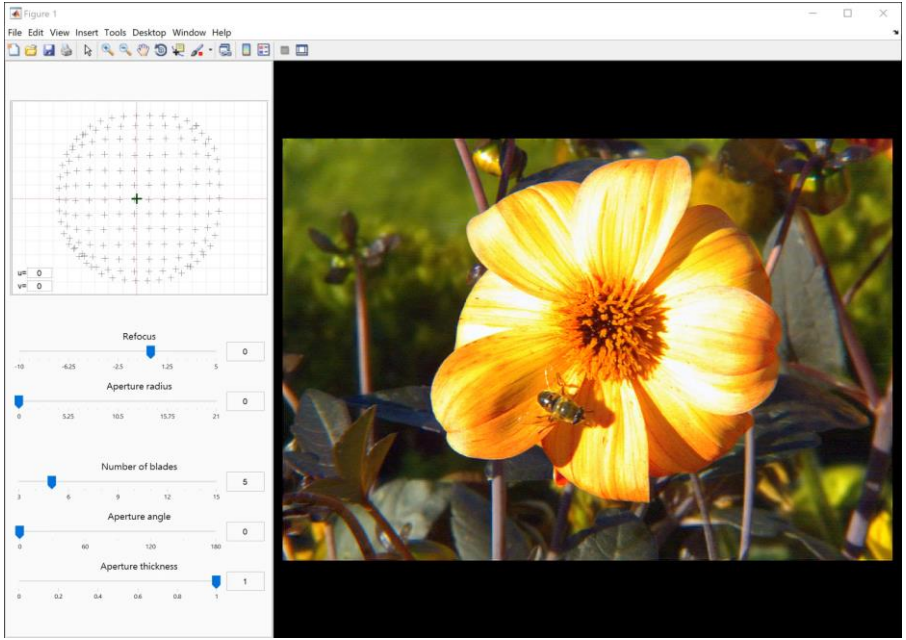
Rendering

Dansereau

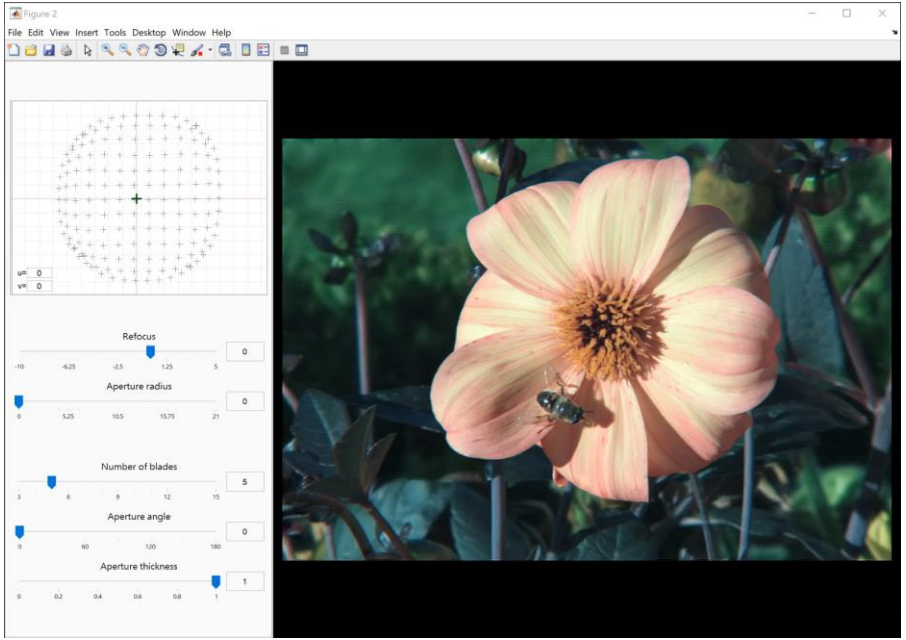
Full pipeline

Proposed Pipeline: Applications

Rendering with Fourier Disparity Layers [1]



Dansereau



Full pipeline

[1] M. Le Pendu, C. Guillemot, A. Smolic **"A Fourier Disparity Layer representation for Light Fields"** *accepted to IEEE TIP*

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The University of Dublin

V-SENSE

Many Thanks!

Resources

- https://v-sense.scss.tcd.ie/research/light-field-imaging/
- https://github.com/V-Sense