ICIP2021
Anchorage, Alaska

Multi-illumination Fusion with Crack Enhancement using Cycle-Consistent Losses

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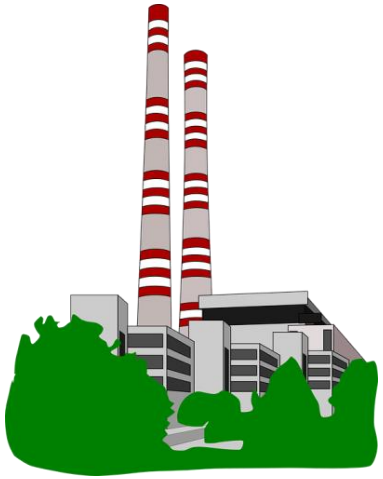
Introduction

- Periodic inspection and maintenance of industrial components



Industrial components

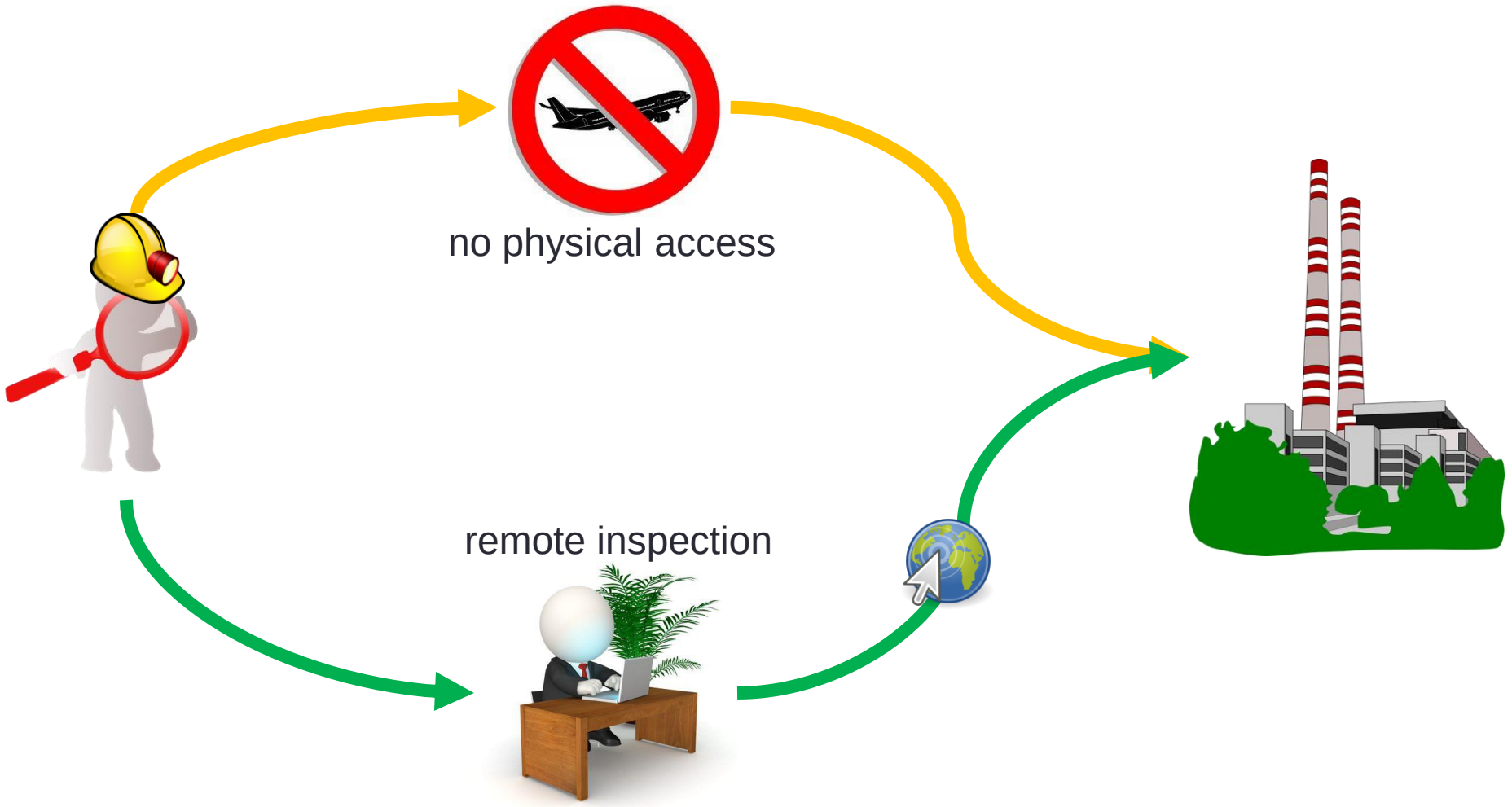
Inspection

Expert

Accept / Replace

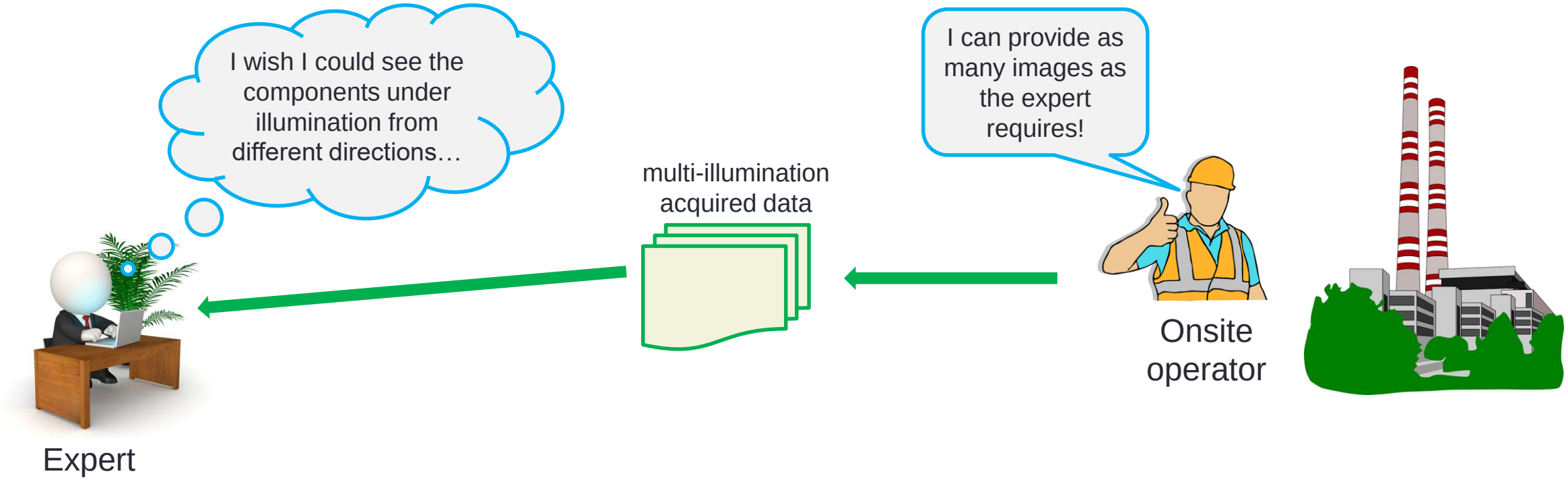
Introduction

- In person visual inspection may not be possible

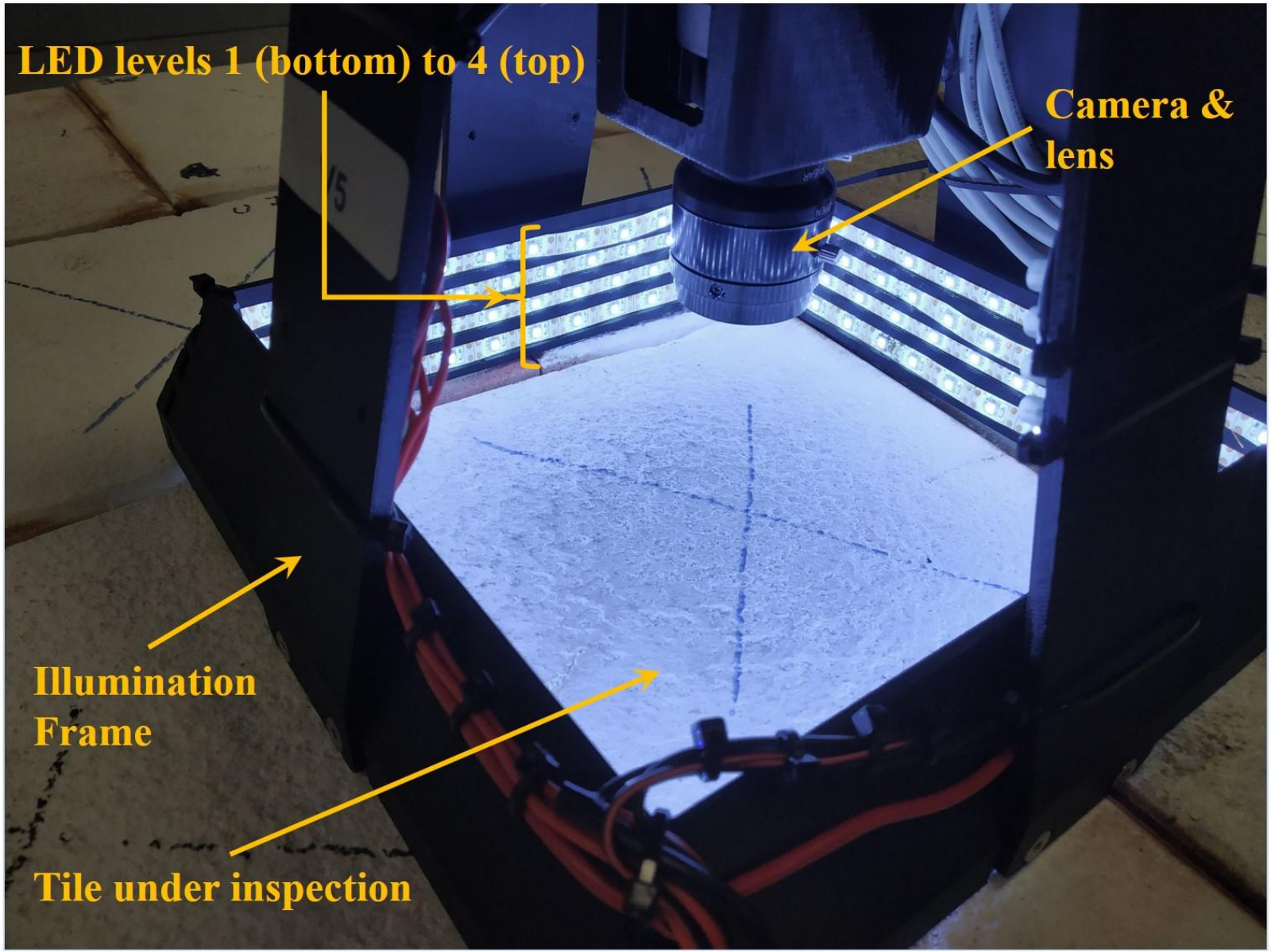


Introduction

- Need for several images from different viewpoints/lighting conditions



Expert

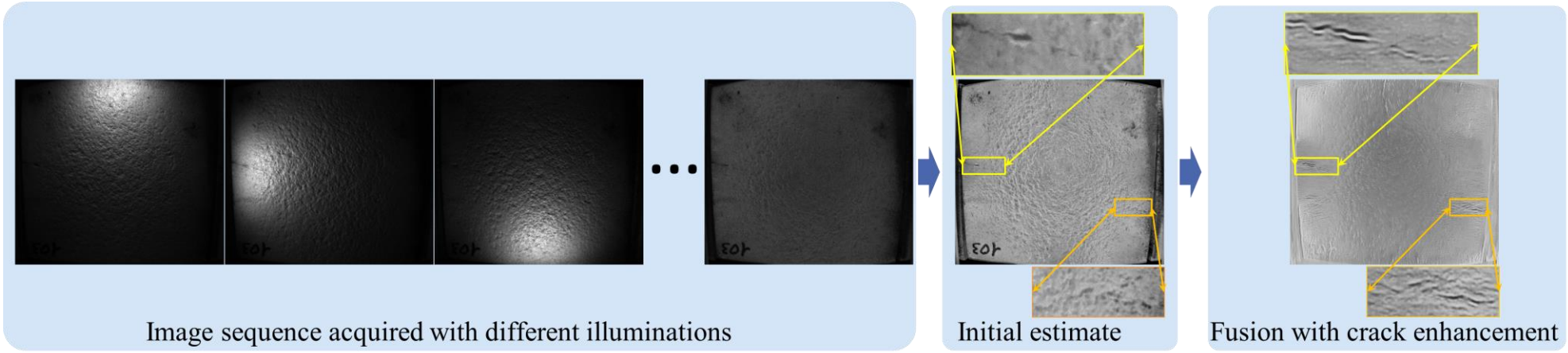


Padalkar et al., "A Versatile Crack Inspection Portable System based on Classifier Ensemble and Controlled Illumination," ICPR2020

Paper Highlights

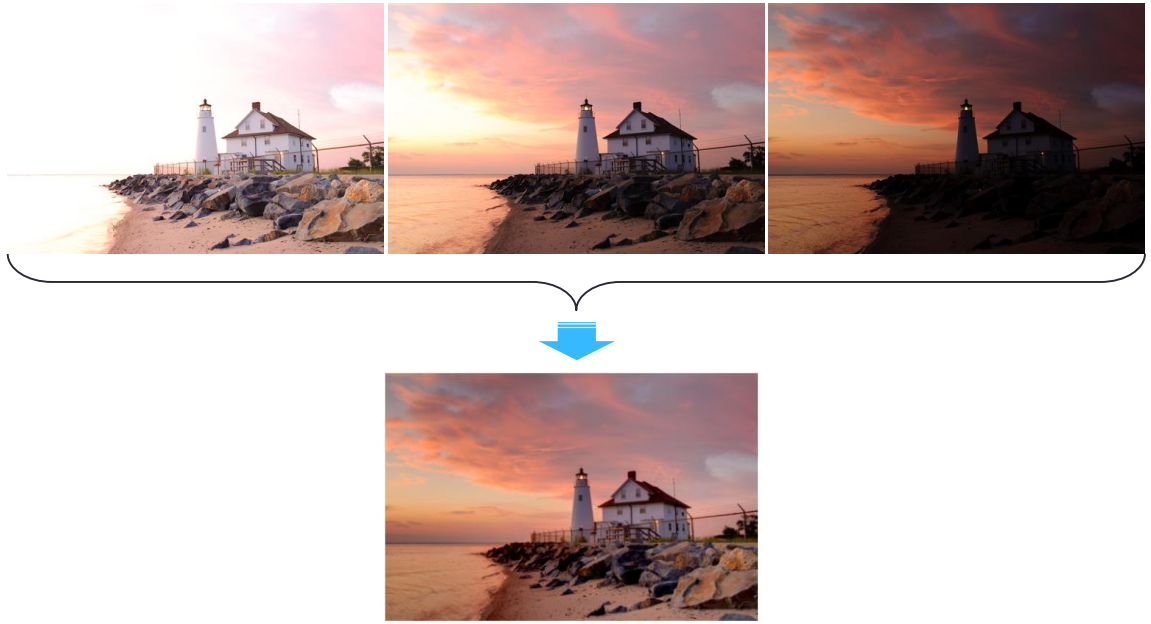
- A method to combine and enhance cracks from a multi-illumination sequence
  - Cracks can have better visibility under certain illumination conditions
  - Object illuminated from different directions
  - Provides a single representative image

- Fusion based on cycle-consistent losses
  - Transformation from multi-illumination to fused and back needs to be consistent
  - Constrained by loss networks that generate binary crack representations



Related Work

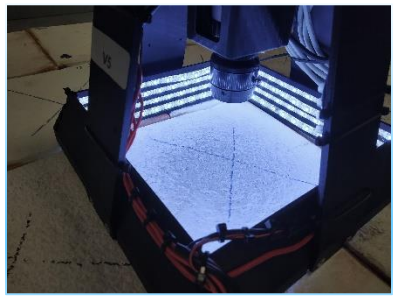
- Multi-Exposure Fusion (MEF)
  - Fusion of images acquired by varying exposure time
  - Change across pixels in the different images is consistent



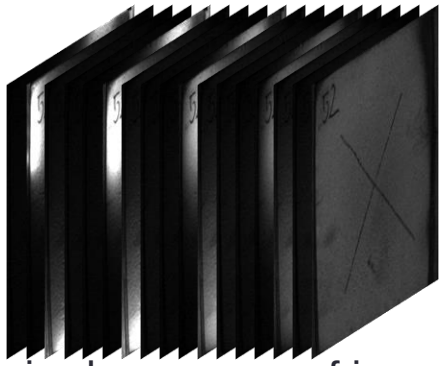
- Our problem
  - Varying illumination directions can easily create noticeable shadows on cracks, as opposed to varying exposure time
  - Fusion of images acquired by varying illumination directions
  - Pixels are well exposed only in few images but underexposed in most

Notable MEF techniques:
- Mertens et al. PG'07
- Prabhakar et al., ICCV'17
- Ma et al., TIP'15, TCI'18
- Kou et al., ICME'17
- Jianrui et al., TIP'18
- Wang et al., TCSVT'20

Data Acquisition and Preparation



Customized acquisition setup



Acquired sequence of images (Domain *A)*

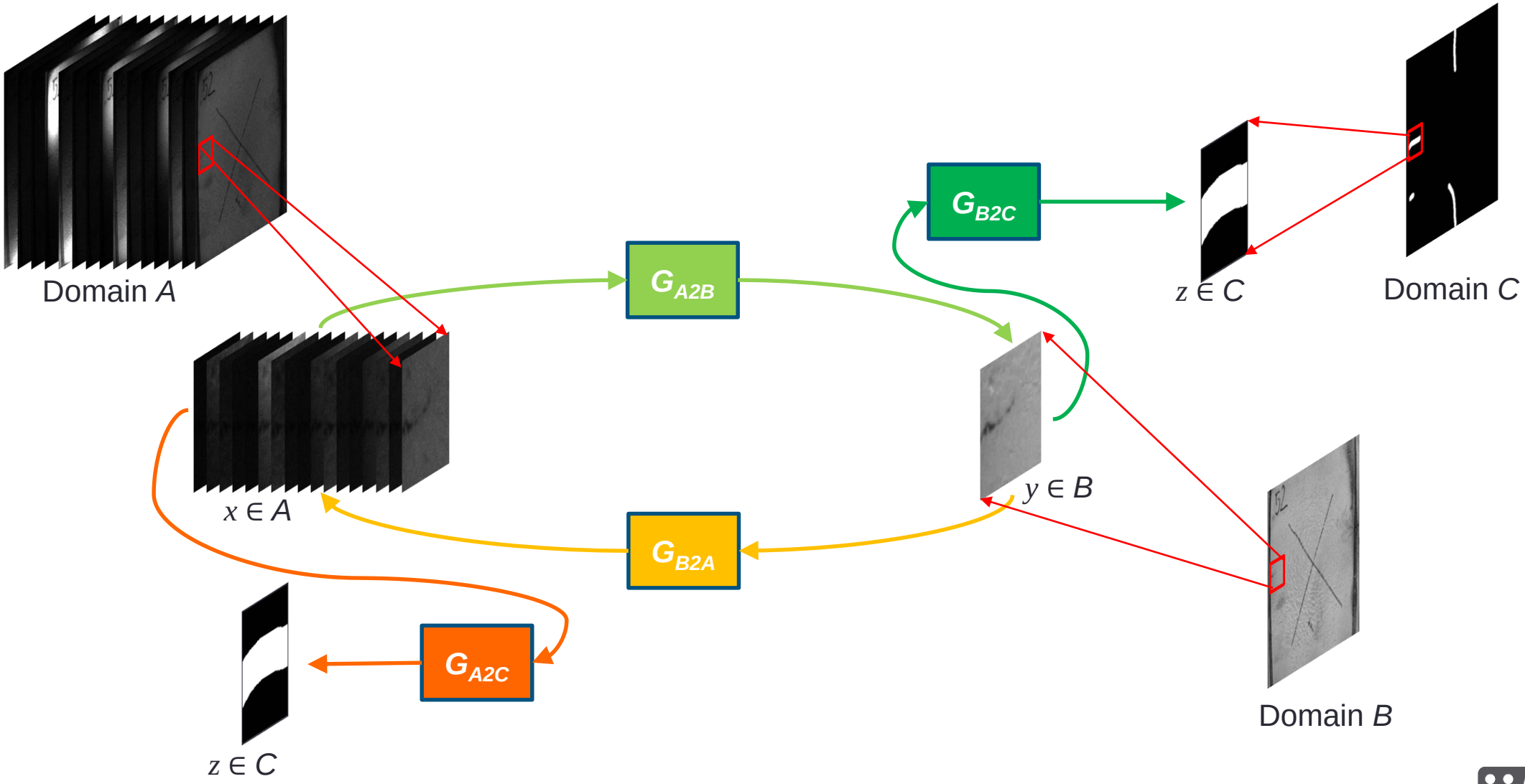
Experts' annotations

Binary crack annotations (Domain *C)*

Modified exposure fusion

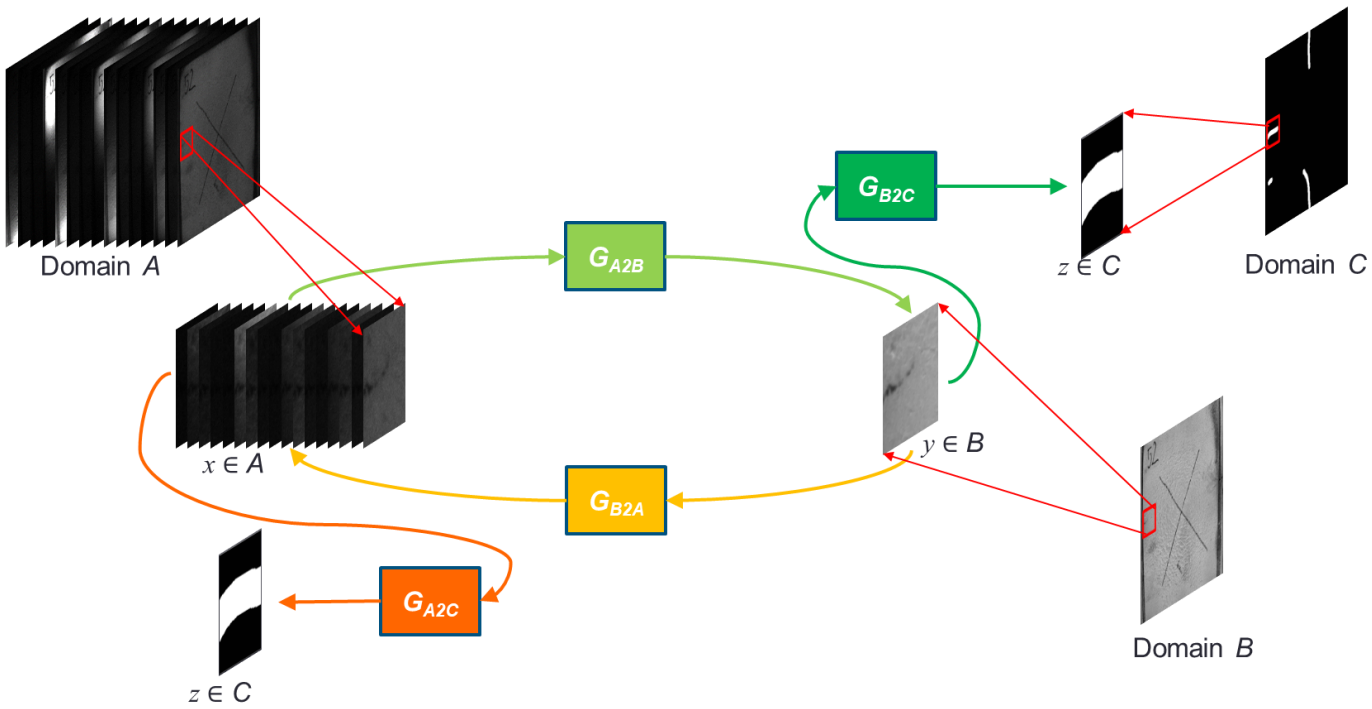
Initial estimate (Domain *B)*

Training

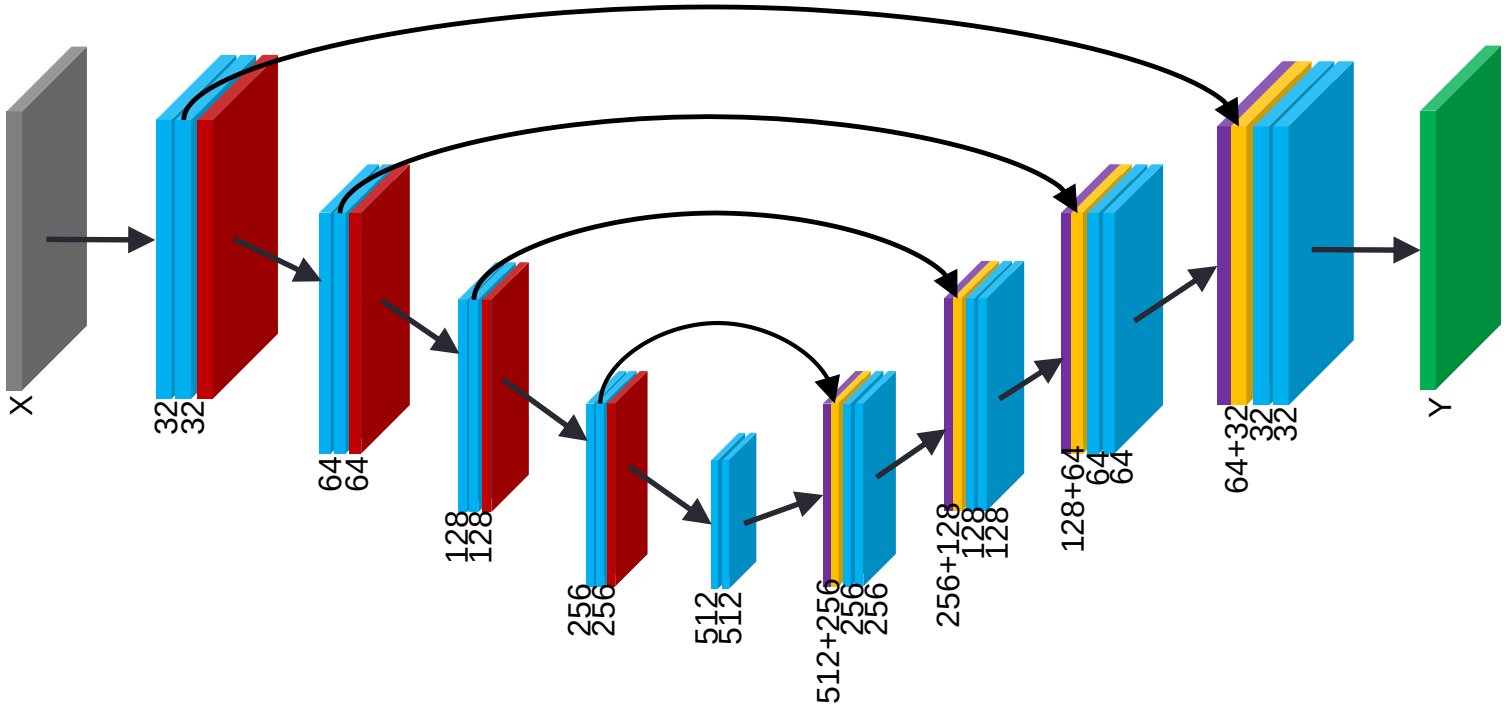

Domain A
G_{A2B}
G_{B2C}
$z \in C$
Domain C
$x \in A$
$y \in B$
G_{B2A}
G_{A2C}
$z \in C$
Domain B

Training

1. Train G_{B2A}
2. Train G_{A2C}
3. Train G_{A2B}
4. Train G_{B2C}



Model architecture



Input with X channels

Convolution (3x3, stride 1, same padding) + ReLU

Maxpooling (2x2, stride 1)

Upsample (2x2, stride 1)

Concatenated with Skip-connection

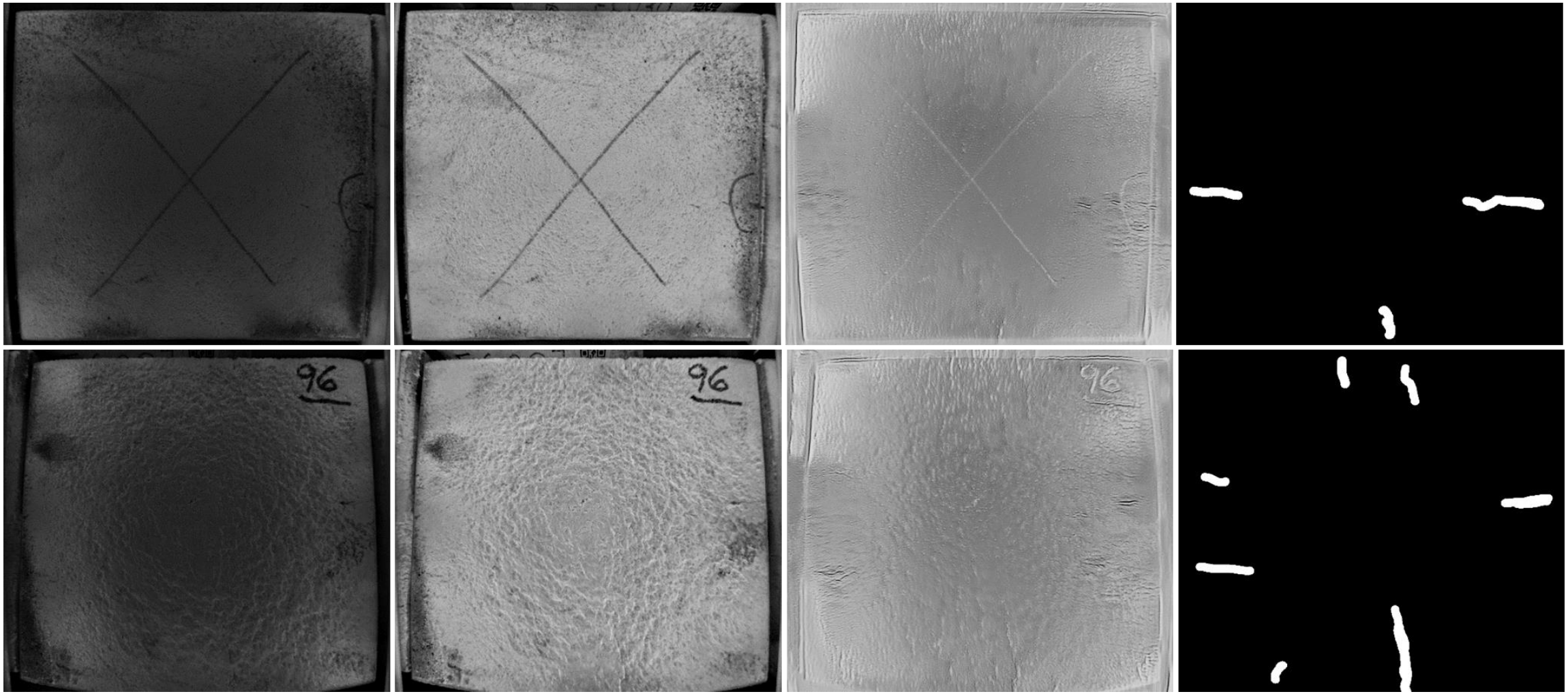
Convolution (3x3, stride 1, same padding) + Sigmoid [Output with Y channels]

Model	X	Y
G_{A2B}	N	1
G_{B2A}	1	N
G_{A2C}	N	1
G_{B2C}	1	1

Experiment details

- Real-world industrial data of 88 ceramic tiles
- Every tile imaged with 65 different illuminations
- Image size: 1944 x 2592
- Patch size used for training: 128 x 128
- Trained from scratch for 2 epochs
  - NVIDIA RTX-2080 GPU
  - Batch size: 8
  - Adam optimizer
  - Learning rate:
    - 0.0001 for image generators
    - 0.00001 for crack generators

Results



Fusion with a MEF method

Initial estimate

Proposed fusion with crack enhancement (G_{A2B})

Ground truth crack annotations

Evaluation

- Edge strength
  - For $\Omega \in I$ to be easily noticeable, its edge strength should be higher than the global edge strength
  - Edge strength measured in term of Laplacian of Gaussian (LoG)

$$ES = \frac{mean(|L_p|)}{mean(|L_q|)},$$

$p \in \Omega,\ q \in I,\ L = LoG(I),$

L_p is value of L at pixel $p \in \Omega$,

L_q is value of L at pixel $q \in I$.

Image #	Exposure Fusion	Initial Estimate	Proposed (G_{A2B})
1	1.2369	1.2354	**2.6695**
2	1.0719	1.1380	**3.1600**
3	1.036	1.1272	**1.9077**
4	1.0825	1.1279	**1.7663**
5	1.0844	1.1723	**2.4617**
6	1.1637	1.0021	**2.3807**
7	0.9425	0.9081	**1.9220**
8	1.0956	0.9017	**2.4140**
9	1.0581	1.2385	**2.6135**

Performance comparison using *ES*. The higher, the better.

Conclusions

- Proposed a method to combine and enhance crack details into a single representative
  - Several images acquired using different illuminations
- Trained generators using cycle-consistent losses
  - Cracks enhanced using crack generators as loss networks
  - Improved noticeability of cracks, helping visual inspection
- Addressed enhancement of pixels that are underexposed in most of the images of the acquired sequence
  - Proposed method better suited than MEF for fusion of multi-illumination images