Laser Damage Image Pre-processing Based on Total Variation

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Outline

1 Background

Laser Damage

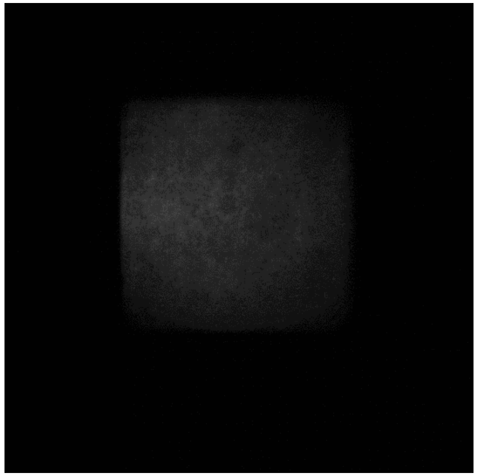
- Because of reasons such as self-focusing, laser-induced damages are likely to happen to the optics.

- Damages need to be inspected and tracked upon being initially produced, otherwise the optics would be damaged heavily and become non-repairable.

1 Background

Laser Optics Damage Inspection

- Laser-induced defects or flaws on the optics are presented in images acquired by specific charge coupled devices (CCDs).



Example image acquired by the CCD

- Laser optics damage inspection relies heavily on the image analysis to identify the damage defects or flaws.

1 Background

Related Researches

- To develop the optic illumination techniques.
- To improve the damage image analysis and defect identification technology.

Challenges of Damage Defect Identification

- The size of defects is quite tiny compared to the image.
- The grey value of different image areas is different because of the uneven distribution of illumination.
- The low-light-level property of damage images acquired makes defects blurred into the backgrounds.

2 Motivation

- Due to the challenges listed above, the accuracy of damage defect identification is not satisfying: high false alarm rates and high missing rates.

- One question: ***Can we develop algorithms to pre-process these laser damage images acquired by CCDs, and to improve the identification of defect points?***.

3 Damage Image Pre-processing

Problem Description

- Given the unknown pollutions
  image pre-processing → image restoration

- Assume that: $f = K\bar{x} + \omega$

  - $\bar{x} \in \mathbb{R}^{n^2}$: the original $n \times n$ image

  - $K \in \mathbb{R}^{n^2 \times n^2}$: the blurring operator

  - $\omega \in \mathbb{R}^{n^2}$: the additive noise

  - $f \in \mathbb{R}^{n^2}$: the observation

- Our objective: to recover $\bar{x}$ from f

3 Damage Image Pre-processing

Total Variation (TV) Based Model

- Combining TV regularization with $l2$ norm fidelity, we get the TV based image reconstruction model as following:

$$\min_{x} \underbrace{\sum_{i=1}^{n^2} \|D_i x\|_2}_{\text{TV regularization}} + \frac{\mu}{2} \underbrace{\|Kx - f\|_2^2}_{l2 \text{ norm fidelity}}$$

- Equivalent constrained formulation:

$$\min_{x,y} \sum_i \|\mathbf{y}_i\| + \frac{\mu}{2} \|Kx - f\|_2^2$$

$$\text{s.t. } \mathbf{y}_i = D_i x, \quad i = 1, \dots, n^2$$

3 Damage Image Pre-processing

Applying ADMM to TV Based Model

- the augmented Lagrangian function :

$$\Gamma_{\mathrm{A}}(x, y, \lambda) = \sum_i \left(\|\mathbf{y}_i\| - \lambda_i^{\mathrm{T}}(\mathbf{y}_i - D_i x) + \frac{\beta}{2}\|\mathbf{y}_i - D_i x\|_2^2\right) + \frac{\mu}{2}\|Kx - f\|_2^2 .$$

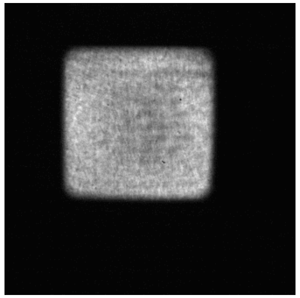
- Iterative scheme:
  - $y^{k+1} = \arg\min_y \Gamma_{\mathrm{A}}(x^k, y, \lambda^k)$.
  - $x^{k+1} = \arg\min_x \Gamma_{\mathrm{A}}(x, y^{k+1}, \lambda^k)$.
  - $\lambda^{k+1} = \lambda^k - \beta(y^{k+1} - Dx^{k+1})$.

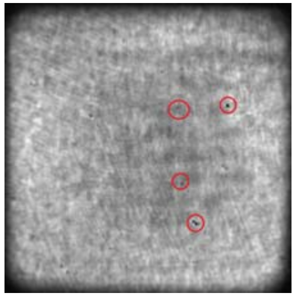
- Terminate condition: $$\frac{\|x^{k+1} - x^k\|}{\max\{\|x^k\|, 1\}} < \varepsilon$$

4 Experiments

Procedure

Original image → spliting → Interested area → pre-processing → Pre-processed image → identification → Identified defects





The comparison of accuracy

Method	False Alarm Rate	Missing Rate
No pre-processing	30%	15%
With pre-processing	8 %	5%

5 Conclusion

- Concluding remarks
  - Optics damage inspection directly with original images shows a high false alarm rate and a high missing rate
  - Pre-processing images through reconstructing them, by utilizing the total variation (TV) based model and an alternating direction method of multipliers (ADMM) algorithm
  - Preliminary experiments demonstrate the potential of pre-processing method: both the false alarm rate and the missing rate are reduced
- Future research
  - The optimal regularization parameter of this method varies when dealing with different images.
  - The scheme of the optimal regularization parameter selecting.

Thanks

for your attention!