Laser Damage Image Pre-processing
Based on Total Variation

Jun Luo, Xiaowei Zhou, Xingquan Xie, and Zhigao Ni
Institute of Computer Application
China Academy of Engineering Physics, Mianyang, China
Outline

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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 $l^2$ norm fidelity, we get the TV based image reconstruction model as following:

$$\min_x \sum_{i=1}^{n^2} \|D_i x\|_2 + \frac{\mu}{2} \|Kx - f\|_2^2$$

TV regularization  $l^2$ norm fidelity

- Equivalent constrained formulation:

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

s.t. $y_i = D_i x, \quad i = 1, \ldots, n^2$
3 Damage Image Pre-processing

Applying ADMM to TV Based Model

- the augmented Lagrangian function :
  \[
  \Gamma_A(x, y, \lambda) = \sum_i (\|y_i\| - \lambda_i^T(y_i - D_i x) + \frac{\beta}{2}\|y_i - D_i x\|_2^2) \\
  + \frac{\mu}{2}\|Kx - f\|_2^2.
  \]

- Iterative scheme:
  \[
  y^{k+1} = \arg \min_y \Gamma_A(x^k, y, \lambda^k) \\
  x^{k+1} = \arg \min_x \Gamma_A(x, y^{k+1}, \lambda^k) \\
  \lambda^{k+1} = \lambda^k - \beta(y^{k+1} - Dx^{k+1}).
  \]

- Terminate condition:
  \[
  \frac{\|x^{k+1} - x^k\|}{\max\{\|x^k\|, 1\}} < \varepsilon
  \]
4 Experiments

Procedure

Original image $\rightarrow$ splitting $\rightarrow$ Interested area $\rightarrow$ pre-processing $\rightarrow$ Pre-processed image $\rightarrow$ identification $\rightarrow$ Identified defects

The comparison of accuracy

<table>
<thead>
<tr>
<th>Method</th>
<th>False Alarm Rate</th>
<th>Missing Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pre-processing</td>
<td>30%</td>
<td>15%</td>
</tr>
<tr>
<td>With pre-processing</td>
<td>8%</td>
<td>5%</td>
</tr>
</tbody>
</table>
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!