Particle Detection on Low Contrast Image of Large Aperture Optics

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Quick Overview

Introduction

Particulate contamination deposition

1. initiates damage on both bare and coated optical surfaces.
2. decrease of cleanliness level of optics surface.
3. reduces the load capacity of optical systems.

Online particle detection problem

1. challenging problems due to the particle's microsize and optic's large aperture.
2. ease of contaminated by people and external contamination source.

Introduction

Figure, Research field & Application

a	b
c	d

(a) Inspecting and sustaining the cleanliness level of optics
(b) Inspecting the particulate contamination on large optics.
(c) Inspecting the grass contained neodymium.
(d) Inspecting the crystal with size of $\Phi 380mm$.

Method

Particle Coarse Detection Algorithm

Three steps

- A gradient-based edge detection filter is constructed and used as the saliency criterion.
- Find particle's edge.
- Generate the whole particle region.

gradient-based edge detection filter

$$\mathbf{I}'_s = \frac{1}{Z_s} \sum_{t \in \Omega} g(|\nabla \mathbf{I}_t|; \sigma_s) \mathbf{I}_s \qquad (1)$$

$g(x; \sigma)$: Gaussian function, variance σ^2.
Z_s is the normalization term $Z_s = \sum_{t \in \Omega} g(|\nabla \mathbf{I}_t|; \sigma_s)$.

Method

Particle Coarse Detection Algorithm(cont.)

Edge criteria & Particle Region

Edge criteria:

$$\mathbf{I}_s - \mathbf{I}'_s \geq \varepsilon_1$$

$$\begin{aligned} \mathbf{R}_p = \{s | \mathbf{I}_s \geq \mathbf{I}_e \\ \&\& \ (\exists \ t \ \text{ s.t. } \mathbf{I}_t \geq \mathbf{I}_e \ \&\& \ t \in U_4(s))\} \end{aligned} \tag{2}$$

Particle Region

$$\begin{aligned} & \textit{if} \quad t_1 \in \mathbf{R}_p^1 \ \&\& \ t_2 \in \mathbf{R}_p^2 \ \&\& \\ & \qquad t_1, t_2 \in U(s) \\ & \textit{then} \quad s \in \mathbf{R}_p \end{aligned} \tag{3}$$

Method

Image Alignment

Pose Match

$$\mathbf{m}_1 = \lambda_1^{-1}\mathbf{A}[\mathbf{R}_1, \mathbf{t}_1]\mathbf{M}$$
$$\mathbf{m}_2 = \lambda_2^{-1}\mathbf{A}[\mathbf{R}_2, \mathbf{t}_2]\mathbf{M} \quad (4)$$

$$\mathbf{m}_i = \begin{bmatrix} u_i & v_i & 1 \end{bmatrix}^T$$
$$\mathbf{M} = \begin{bmatrix} X & Y & 1 \end{bmatrix}^T \quad (5)$$

$$\mathbf{m}_2 = \mathbf{H}\mathbf{m}_1 \quad (6)$$

$$\mathbf{H} = \lambda^{-1}\lambda_2\mathbf{A}[\mathbf{R}_1, \mathbf{t}_1][\mathbf{R}_2, \mathbf{t}_2]^{-1}\mathbf{A}^{-1} \quad (7)$$

$$\mathbf{H} = \begin{bmatrix} c_{00} & c_{01} & c_{02} \\ c_{10} & c_{11} & c_{12} \\ c_{20} & c_{21} & c_{22} \end{bmatrix} \quad (8)$$

Solve Homgraph

substitute (**??**) into Intrinsic parameter matrix, we can get

$$u_2 = \frac{c_{00}u_1 + c_{01}v_1 + c_{02}}{c_{20}u_1 + c_{21}v_1 + c_{22}} \quad (9)$$

$$v_2 = \frac{c_{10}u_1 + c_{11}v_1 + c_{12}}{c_{20}u_1 + c_{21}v_1 + c_{22}} \quad (10)$$

$$\begin{cases} c'_{00}u_1 + c'_{01}v_1 + c'_{02} + c'_{20}u_1u_2 + c'_{21}v_1u_2 = u_2 \\ c'_{10}u_1 + c'_{11}v_1 + c'_{12} + c'_{20}u_1v_2 + c'_{21}v_1v_2 = v_2 \end{cases} \quad (11)$$

where $c'_{ij} = c_{ij}/c_{22}$ $(i, j \in 1, 2\&\&i, i \neq 2)$. For n given known points, $\mathbf{H}$ can be determined (**??**).

Method

Image Alignment(cont.)

To find the matched point pairs, we use Binary Robust Invariant Scalable Keypoints (BRISK) to detect the keypoints and find the matched point pairs.

- Detects keypoints in octave layers & layers in-between of the image pyramid.
- Apply Features from Accelerated Segment Test (FAST) detector.
- A non-maxima suppression method is performed to find the extreme point.
- Compute the main direction to have rotate variant.
- Compute Hamming distance and Match.

Method

Particle Fine Extraction

Assumption

1. Two particles are concentric or have big degree of overlap.
    1. Average intensity around the area changes greatly. This means that a new particle exists in the inspected image.
    2. Average intensity around the area does not change greatly. It means that no new particle exists.
2. If two particle regions are non-concentric and have small degree of overlap, a new particle condition exists.

Method

Particle Fine Extraction(cont.)

Mean intensity variance

The mean value inside the curves is $M_p = \frac{1}{N}\sum_{p\in\Gamma}\mathbf{I}(p)$, where N is the pixel number of set Γ, Γ is the set containing all the pixels inside of $\mathbf{B}$. M_{pp} and M_{pr} are the mean intensity of particle candidates in the inspected image and the reference image, if $M_{pp} - M_{pr} \geq \lambda_2$, then mean intensity changes greatly.

Concentric

Let $\mathbf{P}_i$ be particle candidate set in inspected image and $\mathbf{P}_r$ particle candidate set in reference image, and $D_{ir} = |C_i - C_r|$ where C_i and C_r are the centroids of $\mathbf{P}_i$ and $\mathbf{P}_r$. If $D_{ir} \leq \lambda_1$, the candidates are concentric.

Method

Particle Fine Extraction(cont.)

Overlap definition

N_o is pixel number of $\Gamma_i \cap \Gamma_r$, N_u is pixel number of $\Gamma_i \cup \Gamma_r$. The degree of overlap $D_o = \frac{N_o}{N_u}$. If the degree of overlap of two candidates $D_o \geq \lambda_3$, two particle candidates are overlap.

Two cases of overlap

1. the contours of two candidates are intersected.
2. one contour fully inside the other contour.

Method

Particle Classification

Feature of Dust and Defects

- Digs in defects are point-like in shape as dust particles.
- particles are usually smooth and round, usually regular in shape.
- shapes of dust vary greatly.

Feature used for Classification

- histogram of gradient.
- texture. constructed by Gray Level Co-occurrence Matrix (GLCM) from image: Contrast, Correlation, Energy.
- Morphological characters. represented by invariant moment.

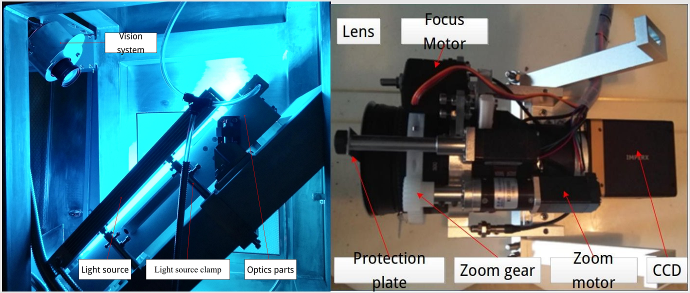
Experiment

The Inspection System

1. Experiment system is with a 2.66 GHz processor and 8 GB of memory.
2. Light source. wavelength at 525nm long with blue light.
3. Used 30 optics images without particle as the reference image and 5 optics images with various sizes of particles.
4. Used another 8 optics images. for the performance evaluation.
5. The size of the image is 6600×4400 pixels.

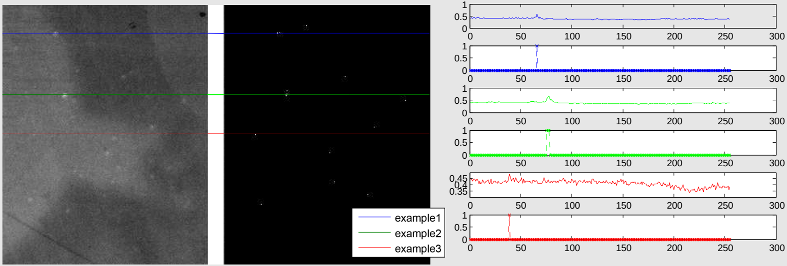
Experiment

Inspected Object and Vision System



a | b
Real inspection system.
(a) The whole inspection system and the inspected optics.
(b)The vision system composition.

Particle Coarse detection

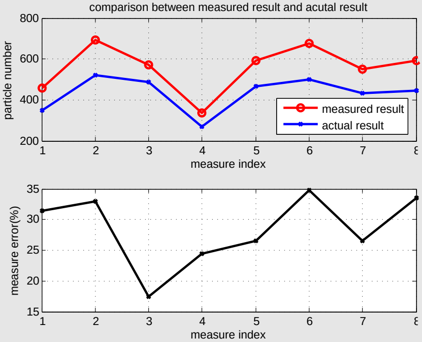


a | b | c

Particle candidate detection result.
(a)Magnified part of original optics image.
(b)The extracted particle candidates. Three rows of images in (a) and (b) are labeled with horizontal line.
(c)Their gray value is shown in (c).

Experiment

Particle Fine Extraction



parameters

Gradient Filter variance	σ_s	5
Edge threshold	ε_1	0.03
ε-neighborhood	ε_2	5
Filter window	Ω	5×5

Particle generation

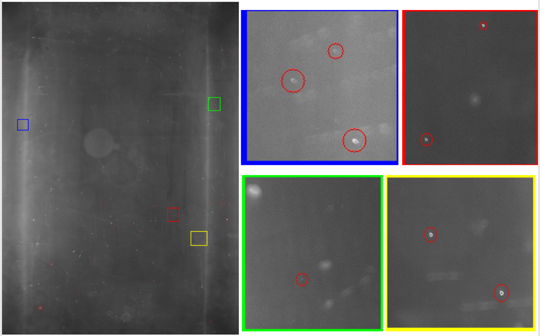
$$\xi = N(\lambda_4/\delta_i, \sigma_1^2) \tag{12}$$

parameters

particle size distribution mean	λ_4	100
particle size distribution variance	σ_1^2	50
minimum distance	λ_1	5
minimum lightness variance	λ_2	50
minimum degree of overlap	λ_3	0.1

Experiment

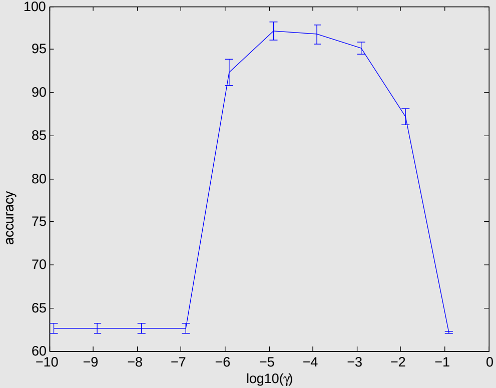
Particle determination(cont.)



The comparison between the actual particle number and the measured result of the real optics image. It gave the particle number with the error less than 35%.

Experiment

Particle classification



The result of SVM classifier parameter optimization. When $C = 0.1$ and $\gamma = 10^{-5}$, the classifier had best performance, then on the test dataset the error was 5%.

Conclusion

1. The inspected image with actual particle has low contrast.
2. Particle detection algorithm preformed only on the inspected image cannot realize accurately identifying.
3. A particle coarse detection method was proposed to detect all possible particles, then the reference image was utilized to fine extract the actual particles.
4. It demonstrated a good ability of detecting particles on low contract image of large aperture optics which is implemented by several steps on the inspected image.

Thank you