Image Processing Alignment Algorithms for the Optical Thomson Scattering Laser at the National Ignition Facility
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Motivation for Building a Plasma Diagnostic Using Thomson-Scattering (TS)

- Fusion is one of the grand challenges
- TS enables measurement of both ion and electron temperatures
- Thomson-scattering laser-pulses can be timed to probe the plasma at key points during the plasma evolution
- Short wavelength laser (5w) avoids self-emission background from the experiment
Loop 1: Alignment of the pointing beam in the OTSL

Desired detection spot is within the head of the dragonfly which is generally the brightest.
Centroiding Algorithm

Threshold for each image = \((\text{maxValue} - \text{meanValue}) \times \text{th} + \text{meanValue}\); where \(\text{th}=0.66\)

Cross-section B353A

Region selection (largest connected area at T% intensity level)

Weighted Centroid

66% threshold
50% threshold (for comparison only)
Position with nominal threshold of 0.3 shows the detection spot is off the required position. Threshold was raised to 0.75 to mitigate (right).
Data taken repeatedly at the same position reveals two significant outliers.

*Instability*
Analysis of the two unstable images point to smearing as the cause

Normal images

Smeared images

What causes the smearing as shown below?

- Sudden movement of the beam
- Long exposure time
- Other camera problems

Smeared image: brightest spot moves to the tail (19 pixels)
Motivation for testing to determine potential improvement using matched filtering

- An intensity insensitive approach
- Approach based on tracking shape
Appling a single, image-based template overcomes effect of smearing

Normal Image

Horizontal smear

Vertical smear

Image 64

Image 59 (using centroiding resulted in a 19 pixel displacement)

Image 240

Image 229 (using centroiding resulted in a 21 pixel displacement from mean position)

Image 91
Centroid indicates large movement, but matched filter results in 99% aligned images within 0.3 pixels

Testing with 100 Image sets

99% within 7-pixel radius vs 0.3-pixel radius for matched filtering
Observation

- Matched filter with certain templates reports 89% locations within 0.3 pixels
Loop 2: An OTS_ISP_TTI_PL beam with two diffraction rings

ISP = ISP laser
TTI = transport
Telescope Input (gimbal)
PL = pointing loop
Template defined

Left fraction

R_{est \_le ft} \quad \text{Left fraction} = 0.35

delta

gamma
Segmentation, correlation, peak selection, distance check, output positions

Pre-processing → Segmentation → Matched filter

Peak selection → Post-processing → position
Optimization...

left_frac=0.35
Gamma=12
R_est_left=78
Delta1=50

100 image sets

Historic Image Set (recent)
Parameters for the template after optimization

left_frac=0.35  
Gamma=12 
R_est_left=78 
Delta1=50

right_frac=0.45  
Gamma=12 
R_est_right=82 
Delta2=48
When image is rotated, a certainty detector is needed
Detector produces high score when valid detection and negative when false

- Design a reliability detector: stored pattern bipolar binary (+1,-1)
- Input pattern (-1,0,+1)

- Inner product (0 1 -1 -1) . (1 1 -1 -1) = 3, correct detection gives 80+ value and incorrect a -50 or less
New Requirement: Diffraction ring moves and has variable missing fraction
Effect of ring movement

- Optimization difficulty increases
- Begin optimizing with one set (aligned)
- Apply other sets for minimum divergence
- Missing fraction varies
- If one spot is sparse, we must know the other spot is correct before estimating the unknown spot
Template Redefined

Left fraction

Left fraction = 0.35

New template

R_{est \_le ft}

gamma

delta
Template redesigned: from simulated diffraction shape also from the top set of 500-image set

Top template radius = 77 width = 48
missing fraction = 0.3 gamma = 12

Bottom template radius = 73 width = 45
missing fraction = 0.6 gamma = 12
Two additional blocks: Reliability detector and missing fraction estimator

Pre-processing → Segmentation → Matched filter

Output positions → Post-processing

Reliability detector → New positions

Missing fraction estimator
New template and missing fraction calculator provides better detection of the rings

Phase I design

Phase II design
Summary

• An OTS laser pointing loop compared a weighted centroid and matched filtering for a pointing beam
• Template based Algorithm for diffraction ring detection
  • Optimization for parameter selection
  • Reliability detector
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