Analysis of the Confluence of Three Patterns Using the Centering and Pointing System (CAPS) Images for the Advanced Radiographic Capability (ARC) at the National Ignition Facility

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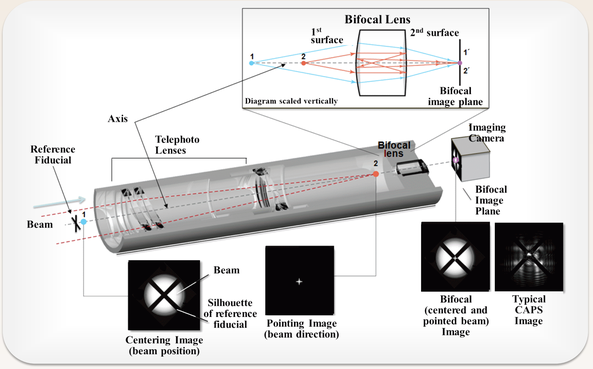
ABSTRACT

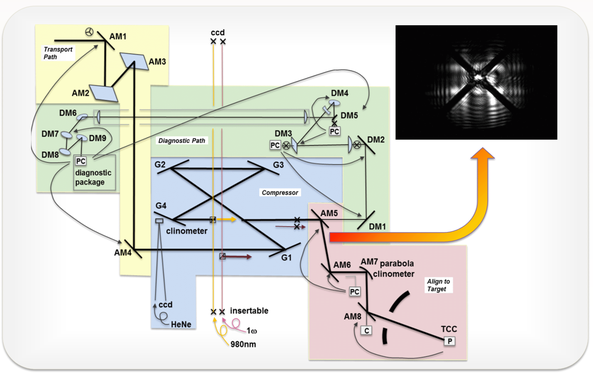
The Advance Radiographic Capability (ARC) at the National Ignition Facility (NIF) is a laser system that employs up to four petawatt (PW) lasers to produce a sequence of short pulses that generate X-rays which backlight high-density internal confinement fusion (ICF) targets. Employing up to eight backlighters, ARC can produce an X-ray "motion picture" to diagnose the compression and ignition of a cryogenic deuterium-tritium target with tens-of-picosecond temporal resolution during the critical phases of an ICF shot. Multi-frame, hard-X-ray radiography of imploding NIF capsules is a capability which is critical to the success of NIF's missions. The function of the Centering and Pointing System (CAPS) in ARC is to provide superimposed near-field and far-field images on a common optical path. CAPS images contain the confluence of pointing, centering, and reference patterns. The patterns may have uneven illumination, particularly when the laser is misaligned. In addition, because several patterns appear in the CAPS image simultaneously, features of one pattern can sometimes mask features of another pattern. Image analysis algorithms have been developed to determine the centering and pointing position of ARC from these images. In the poster we present the image analysis algorithms used to detect and identify the centers of these patterns.

ADVANCED RADIOGRAPHIC CAPABILITY (ARC) CENTERING AND POINTING SYSTEM (CAPS)

Precise alignment of a laser beam involves adjusting the beam's position within the component apertures through which it passes (centering) , as well as sending the beam in the correct direction toward the target (pointing). CAPS is monolithic, formed in a single piece with no moving parts. CAPS consists of a single, mechanically simple, optic tube that contains a bifocal imaging lens to view both pointing and centering points simultaneously. CAPS provides a single image containing a confluence of centering , pointing, and reference features required to align the beam.



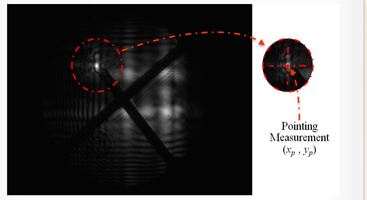
Beam paths and main optics for the ARC compressor vessel, path to the diagnostic package, and path to the NIF Target Chamber Center (TCC) are shown below. Mirrors labeled AM1-AM4 direct laser pulses from a NIF beamline into the ARC compressor vessel. The compressor vessel (blue), contains gratings labeled G1-G4 and other optics used to assess the alignment of the gratings. The gratings compress the pulse into its final shape before propagation to the NIF TCC. The compressed pulse leaves the compressor vessel at AM5 and is split along two paths. A small fraction of the pulse's energy is directed towards a diagnostic package using mirrors DM1-DM9 (green). The remainder of the pulse is directed towards the NIF TCC using AM5-AM8 (red) where CAPS is located.



THREE PATTERNS IN CAPS IMAGES

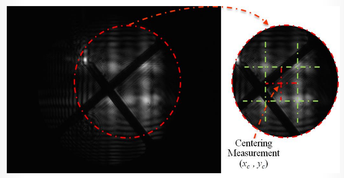
Using a single optic tube has several advantages, including size, simplicity, and mechanical stability. This system, however, produces complex images which contain critical alignment features. The CAPS images contain a confluence of three features or patterns, each providing in turn the reference, pointing, and centering location of the beam.

POINTING PATTERN



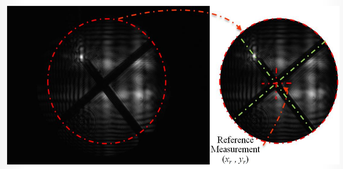
Pointing is measured using an estimate of the pixel location (x_p, y_p) of the center of the bright spot in the CAPS image.

CENTERING PATTERN



Centering is measured using an estimate of the pixel location (x_c, y_c) of the center of the diffraction pattern (patch) in the CAPS image.

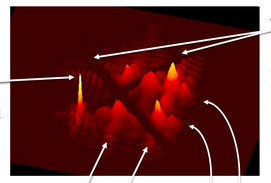
REFERENCE PATTERN



Reference is measured using an estimate of the pixel location (x_r, y_r) of the center of the intersection of the two diagonal, dark bands or lines in the CAPS image.

CAPS IMAGE SURFACE PLOT

The pointing beam pattern appears as a bright, tall peak



The reference is the dark cross 'trough' pattern

The centering beam diffraction pattern appears as four 'ridges'

CAPS IMAGE PROCESSING ALGORITHMS

Locating multiple patterns in CAPS images contain some systematic knowledge of size and feature locations. An effective method to take advantage of this is to process the image in stages. We begin by processing the least difficult pattern and then knowledge obtained from the first stage is stored and utilized in the later stages. Processing for CAPS begins with locating the center of the pointing beam in the first stage and continues by locating the center of the reference fiducial pattern in the second stage and finishes by locating the center of the centering beam to complete the image processing.

POINTING BEAM IMAGE PROCESSING

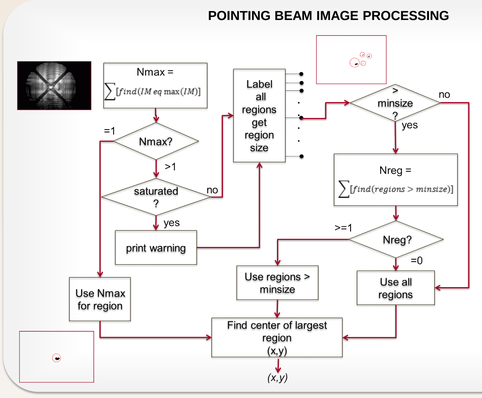


Image containing *m* rows and *n* columns is represented by matrix *A*

$$A = (a_{ij})_{m \times n}$$

Distance is calculated for all pixels to the center (*x,y*) found previously

$$d_{ij} = \sqrt{(i-x)^2 + (j-y)^2}$$

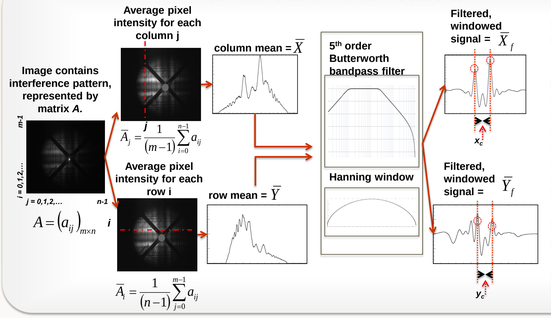
Intensity threshold I_{th} from the intensity value a_{xy} at the brightest pixel (*x,y*) in a selected region based on its size and intensity.

$$I_{th} = \frac{\sqrt{2}}{2} \times a_{xy}$$

Pixels where d_{ij} exceed nominal beam radius r_{nom} and a_{ij} is greater than I_{th} are used to calculate a weighted centroid for (x_p,y_p)

$$\begin{bmatrix} x_p \\ y_p \end{bmatrix} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} \begin{bmatrix} x_i \\ y_j \end{bmatrix}}{\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij}}$$

CENTERING BEAM IMAGE PROCESSING



The centering beam pattern is a complex pattern that is the result of light that has been significantly diffracted before it is recorded at the camera. A filtered projection of the mean of the rows and columns in the image is used to isolate and emphasize the bright streaks in the horizontal and vertical direction. The mean location of the resulting peaks provides an estimate of the center position of the centering beam (x_c,y_c).

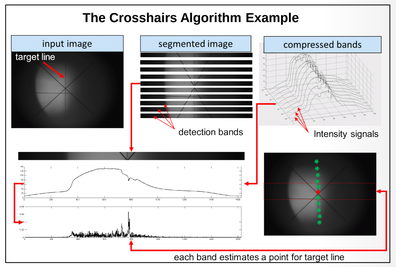
REFERENCE CROSSHAIRS IMAGE PROCESSING

The Crosshairs Algorithm is used to locate the center of the reference pattern which appears as two diagonal dark bands in the image. This algorithm is commonly used in NIF for line and edge estimation where automatic alignment requires precise location of line objects.

CROSSHAIRS ALGORITHM

- **Orient image to a uniquely angled target line**
- **Segment image into detection bands**
- **Transform bands into set of intensity vectors**
- **Estimate location of target line edges in each vector**
- **Perform series of tests to remove outliers from the resulting set of points**
- **Perform linear fit to remaining points**

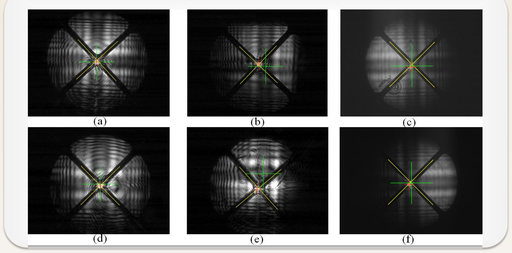
The Crosshairs Algorithm Example



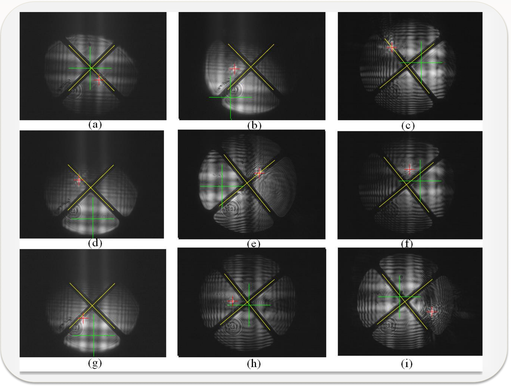
CAPS line fit is performed using the Hough Transform. Rotated and processed CAPS image on the left produces a set of edge detections used to create binary input (center). The resulting accumulator space yields high certainty of an accurate line fit to the data as seen in the high sharp spike (right)

RESULTS AND ANALYSIS

The images directly below illustrate several examples of images with aligned, or nearly aligned, beams in the CAPS system. The images seen in (a), (b), (d), and (e) are some of the most recent images produced by the ARC, CAPS system. (June 2014). The center of the pointing beam is denoted by the red x. The center of the centering beam is denoted by the green +. The center of the reference crosshairs is denoted by the yellow x. Current results meet the requirements for the ARC alignment.



CAPS pointing and/or centering beams are intentionally mis-aligned during testing. For example in (b) below, the centering pattern is partially clipped by the tube aperture. An increase in clipping beyond this example would prevent measurement of the centering pattern. (ARC alignment is unlikely to experience this condition, however, during normal operation.) A second issue occurs in the centering diffraction pattern which consists of mottled, white streaks and four bright spots near its center. As the beam moves out of alignment, one or more of these spots can be mistaken for the pointing beam. This can be seen in (g), where the pointing beam is nearly coincident with the upper left spot in the centering pattern. An additional, automated processing step is performed to mitigate this condition. The distance from the initial pointing beam location to the center of the four bright spots is measured. If they coincide, the pointing beam is re-located using an image with the four centering spots masked.



SUMMARY

1. **A new Advanced Radiographic Capability (ARC) was recently commissioned at the National Ignition Facility (NIF).**
2. **A new Pointing And Centering System (CAPS) was invented to simultaneously provide near and far-field images on a common optical path.**
3. **Automated image processing algorithms were developed to process the confluence of three patters in CAPS output images.**
4. **Image features were processed in stages such that knowledge from earlier stages was stored and utilized in later stages.**
5. **Beginning March 2014, ARC began providing CAPS images and the image processing produced good results for pointing, centering, and reference locations.**

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NIF