Advanced Radiographic Capability (ARC)
ISP Alignment Mask Fiducial Pattern Design and Image Processing

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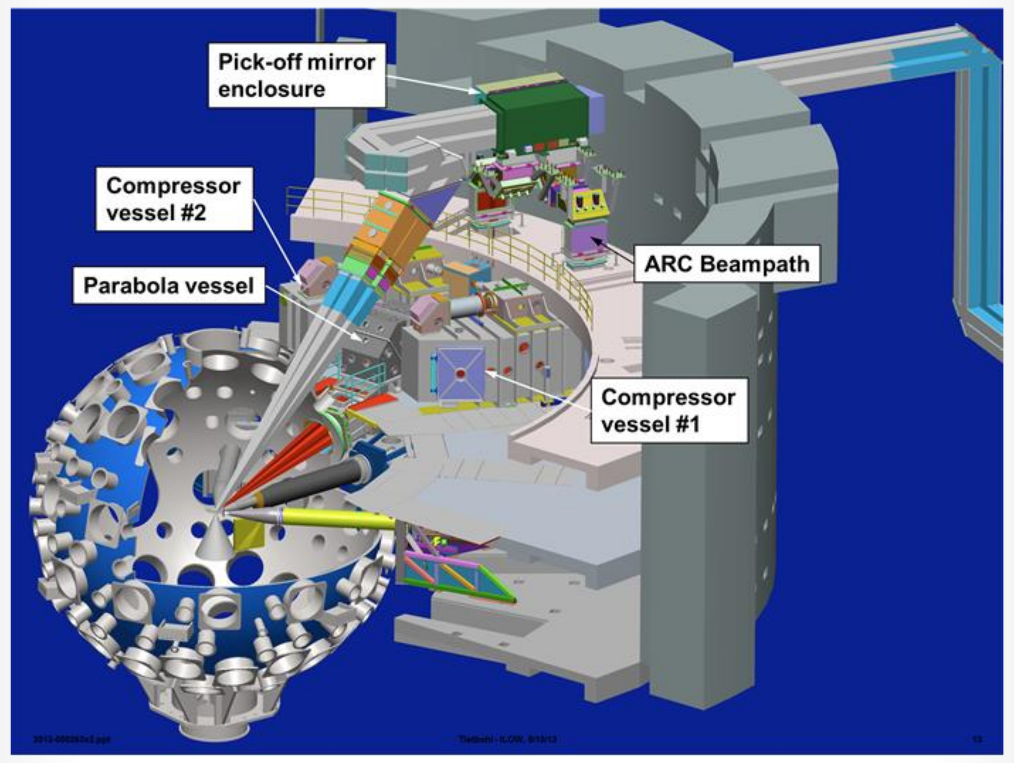
ABSTRACT

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 inertial confinement fusion (ICF) targets. ARC is designed to produce multiple, sequential X-ray images by using up to eight backlighters. The images will be used to examine 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 ARC laser is integrated into one quad of the 48 NIF laser quads and uses many of the same alignment and diagnostic systems. This quad of beams can either be used in normal NIF operation or for ARC. When the quad reaches the Target Bay, the beams may follow the NIF path or a separate ARC path via a motorized pick-off mirror. As in the NIF system, ARC requires an optical alignment mask that can be inserted and removed as needed for precise positioning of the beam. Due to ARC's split beam design, inserting the nominal NIF main laser alignment mask in ARC produced partial blockage of the mask pattern. Requirements for a new mask design were needed, which did not interfere with the existing NIF mask capabilities. We describe the ARC mask requirements, the resulting mask design pattern, and the image analysis algorithms used to detect and identify the beam and reference centers required for ARC alignment.

ADVANCED RADIOGRAPHIC CAPABILITY (ARC)

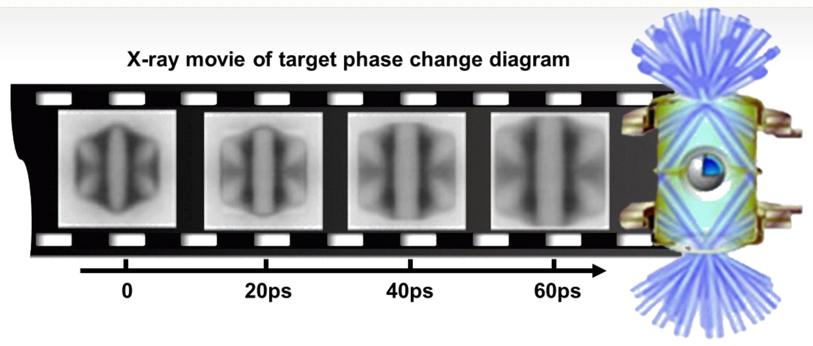
ARC is a petawatt-class laser with peak power exceeding a quadrillion (10^{15}) watts. ARC is designed to produce brighter, more penetrating, higher-energy x rays well beyond what can be obtained using conventional radiographic techniques. ARC is the world's highest-energy short-pulse laser, capable of creating picosecond-duration laser pulses to produce energetic x rays in the range of 50,000 to 100,000 electron volts for backlighting NIF experiments.



Amplified beams from the NIF laser enter ARC where they are compressed in the target bay and focused to Target Chamber Center. The ARC beamlines can ultimately provide up to eight backlighters for ignition evaluation.

ARC currently uses two of NIF's 192 beamlines and propagates two short-pulse beams for each NIF aperture resulting in a split-beam configuration. Staggering the arrival of the ARC beamlets onto backlighter targets will produce an x-ray "movie" to diagnose the fuel compression and ignition phases of a cryogenic deuterium-tritium (DT) target with tens-of-picoseconds temporal resolution at the most critical phases of an inertial confinement fusion (ICF) shot. ARC also will enable new experiments in frontier science and high-energy-density (HED) stewardship science

X-ray movie of target phase change diagram

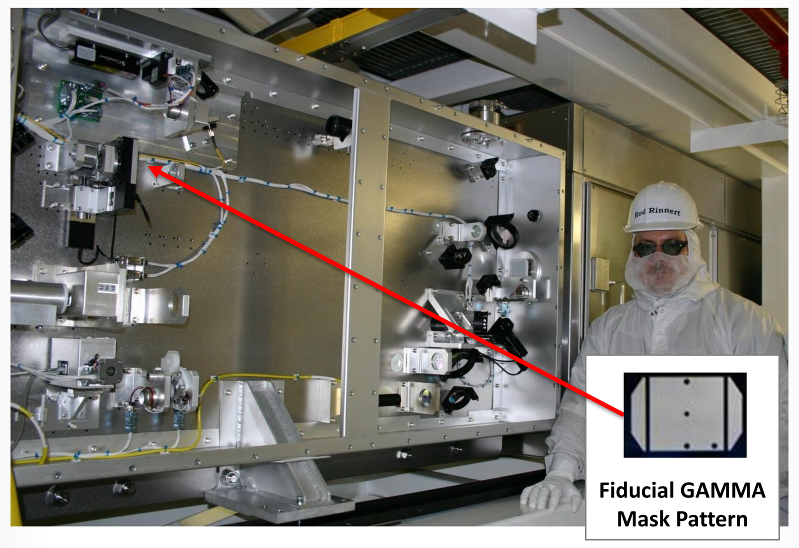


ARC will conduct multiframe, hard-x-ray radiography of NIF capsules during compression and ignition phases. Using ARC, NIF researchers will be able to record the physics of targets the rate of 50 billion frames per second.

DESIGN CHALLENGES

During NIF laser alignment, the Input Sensor Package (ISP) hardware utilizes a chrome-on-glass fiducial pattern (GAMMA pattern) on the ISP alignment mask.

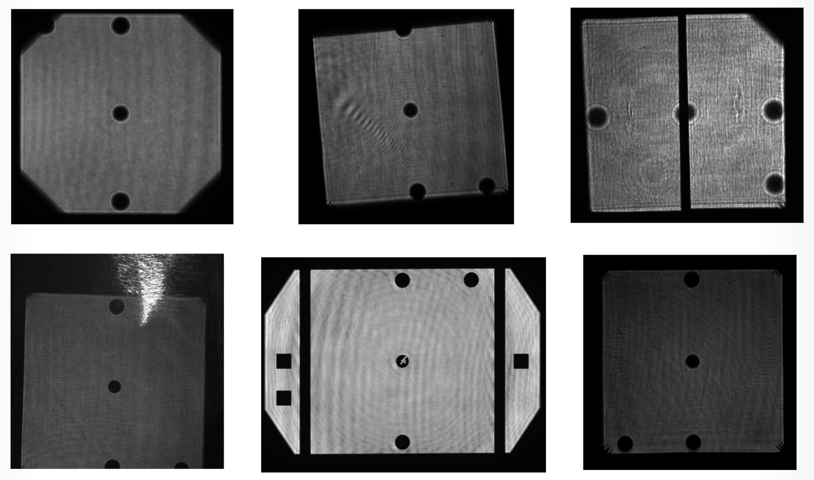
CURRENT NIF INPUT SENSOR PACKAGE (ISP)



Four circles in 'L' pattern comprise the current ISP fiducial pattern used in NIF for alignment. Wings may or may not be present in some images.

ARC's split beam design created a dark vertical bar the alignment images that partially blocked the GAMMA pattern. The blockage and other issues raised uncertainty and motivation for a new mask patter design.

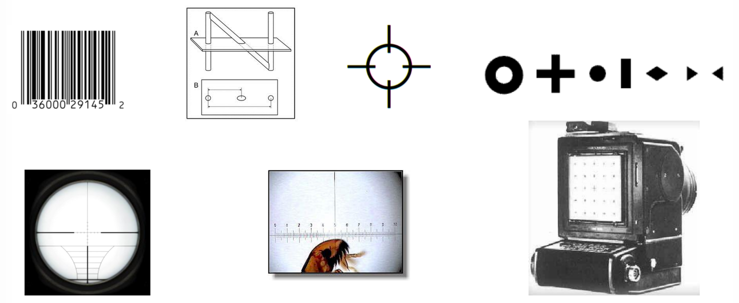
ARC SPLIT BEAM DESIGN NECESSITATES NEW MASK PATTERN



Clipping may occur in some images (top left, middle). Beamlets in ARC introduce blockage covering and distorting center spot (top right). Images may also contain glints due to stray reflected light (bottom left, center) or contain intensity gradients (bottom right).

Requirements for a beam alignment pattern design include separate measurement estimates of horizontal and vertical image magnification, horizontal and vertical image center, rotation, and asymmetry (image may be flipped, rotated, or transposed). The new design was not restricted to spot fiducials, however high contrast fiducials with low footprint and high 'pixels per feature' were preferred for measurement estimates with low uncertainty.

FIDUCIAL MARKER TYPE SELECTION

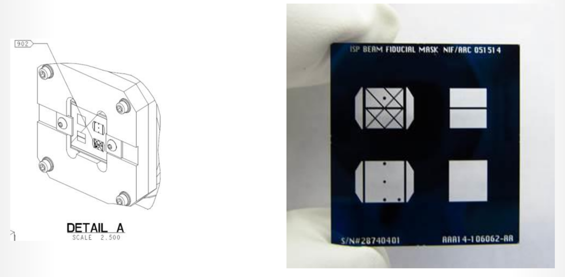


There are a wide variety of fiducial types including UPC bar code (a), N-localizer used in 3d medical applications, registration marks used in printing, fiducial markers for printed circuit board manufacturing (d). In optics, crosshairs are commonly used as seen in sniper rifle scopes (e), microscopes (f) and in the NASA Hasselblad Lunar Surface Camera fitted with a Reseu plate (g).

DESIGN APPROACH

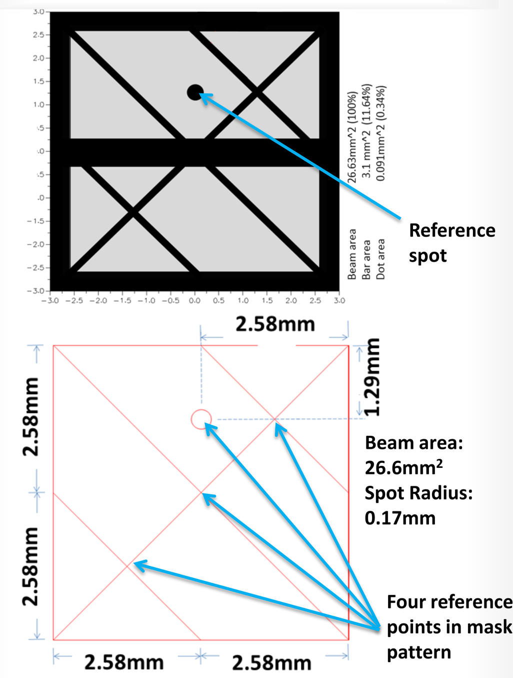
A minimum of four reference points were required to meet all of ARC alignment requirements. Points were comprised of carefully selected reticles or lines whose intersection provided three of the four reference points. The last reference point was a circle or spot in the image. The spot allowed for unique registration or orientation of the pattern within the image. One advantage of using lines across the image is that line intersections that are blocked can be reliably found by extrapolating the lines through the blocked area

ISP GLASS PLATE CONTAINS CHROME ALIGNMENT PATTERNS

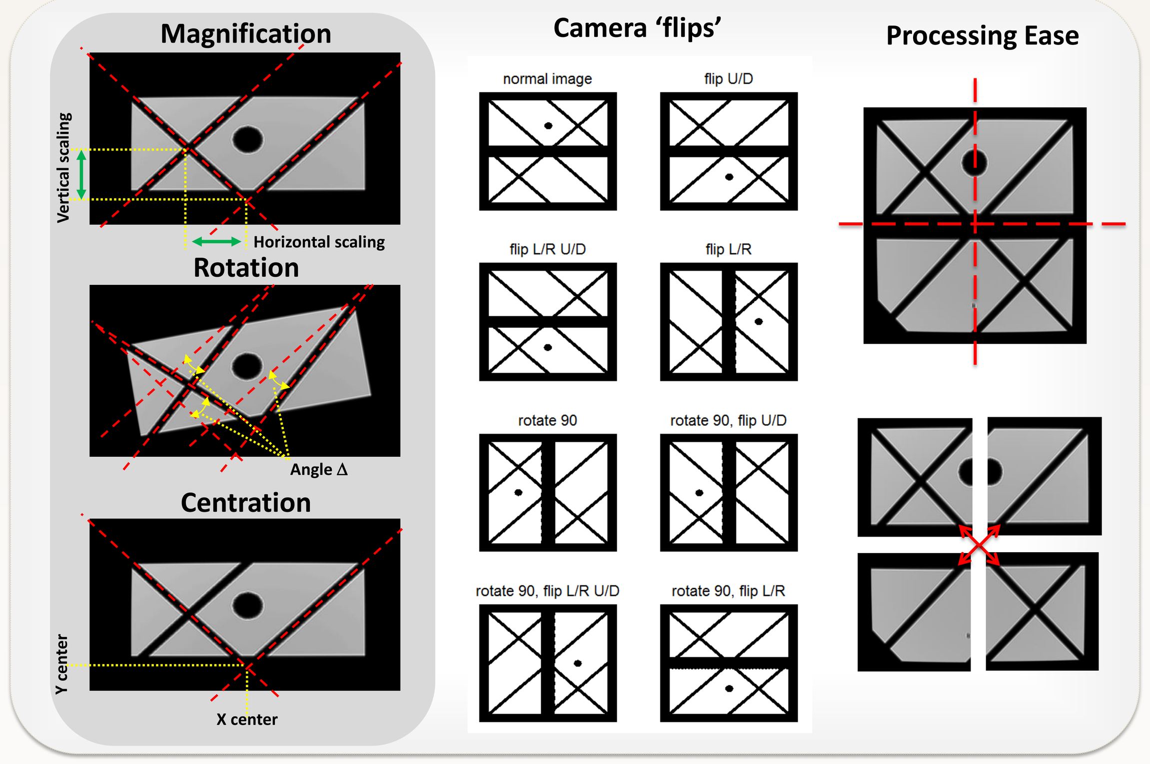


Original alignment patterns on the mask were re-positioned and the ARC fiducial pattern was added to the mask. A drawing of the mounting for the glass plate is shown on the left and a photograph of the plate is shown on the right. The ARC alignment chrome-on-glass fiducial pattern is the upper left pattern in the photograph.

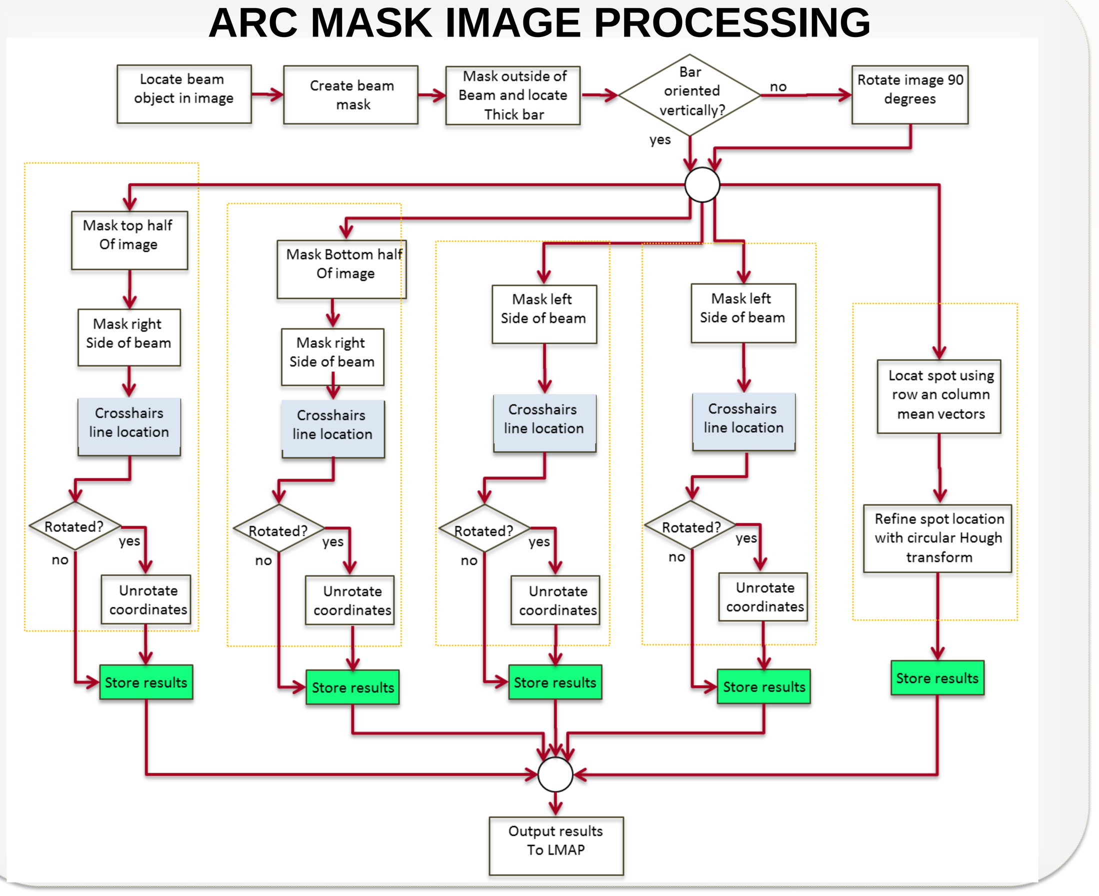
DIAGONAL CROSSHAIRS RETICLE FIDUCIAL SELECTED FOR ARC



Diagonal crosshairs reticles and a single spot were selected to meet the design requirements for ARC.



ARC MASK IMAGE PROCESSING



ARC MASK IMAGE PROCESSING (cont.)

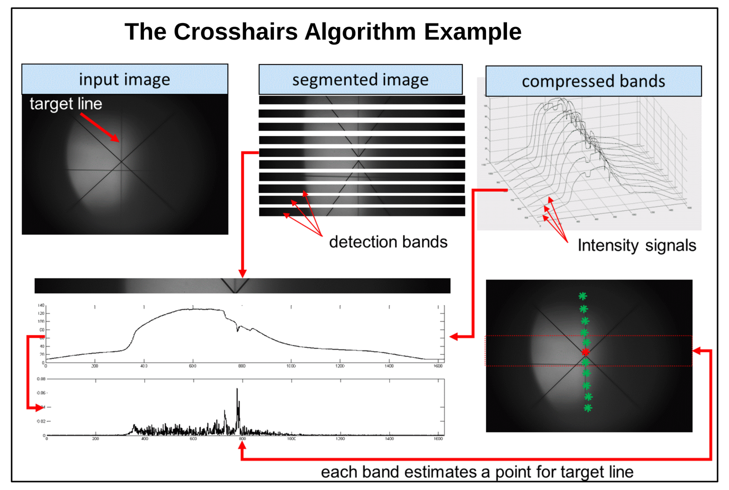
REFERENCE CROSSHAIRS IMAGE PROCESSING

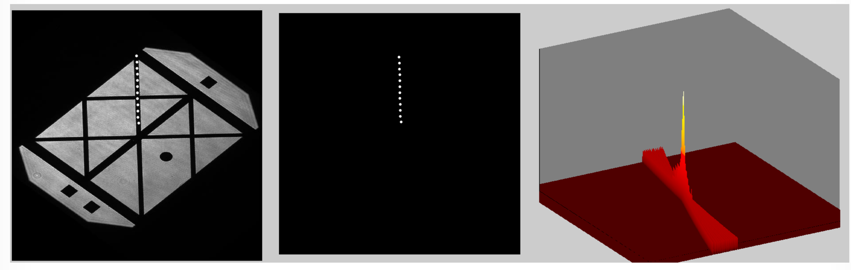
The Crosshairs Algorithm is used to locate the center of the reference pattern which appears as two diagonal dark bands in the image. This algorithm is commonly used in NIF for line and edge estimation where automatic alignment requires precise location of line objects.

CROSSHAIRS ALGORITHM

1. Orient image to a uniquely angled target line
2. Segment image into detection bands
3. Transform bands into set of intensity vectors
4. Estimate location of target line edges in each vector
5. Perform series of tests to remove outliers
6. Perform linear fit to remaining points

The Crosshairs Algorithm Example

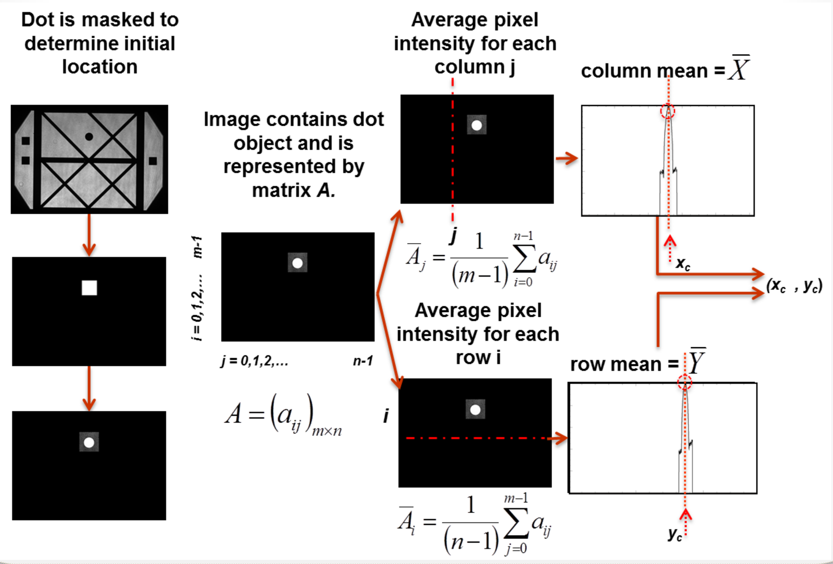




ARC Mask line fits are performed using the Hough Transform. Rotated and processed ARC image (left) produces a set of line position estimates seen as white dots. Using the positon of the dots, a binary image is created (center). The resulting accumulator space from the binary image yields a fast and accurate line fit to the data as seen in the high sharp spike (right)

IMAGE PROCESSING TO LOCATE SPOT REFERENCE CIRCLE

Initial estimate of the location of the spot reference circle uses a mask to isolate the spot and then normalizes the image to isolate the location of the spot. The location is then refined using an iterative, verctorized circular Hough transform..



SUMMARY

Image processing for the new ARC mask design provides four reference coordinates which can be used to provide estimates of horizontal and vertical magnification, centration in the x and the y direction, rotation, and symmetry. Camera issues or off-normal conditions can be measured. In addition the design is simple (4 lines, 1 spot) with minimal light blockage. It is easy for the human operator to evaluate by eye, but can also be processed autonomously. Uncertainty is generally low due to the high degree of pixels per feature, particularly for the line objects. Finally, the long reticles in the image minimize or lessen corner blocker interference.

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NIF