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Automated Optics Inspection Analysis for NIF*

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Abstract

The National Ignition Facility (NIF) is a high-energy laser facility comprised of 192 beamlines that house thousands of optics. These optics guide, amplify and tightly focus light onto a tiny target for fusion ignition research and high energy density physics experiments. The condition of these optics is key to the economic, efficient and maximally energetic performance of the laser. Our goal, and novel achievement, is to find on the optics any imperfections while they are tens of microns in size, track them through time to see if they grow and if so, remove the optic and mitigate the single site so the entire optic can then be re-installed for further use on the laser. This paper discusses the image analysis used for detecting, measuring, and tracking sites of interest on an optic while it is installed on the beamline via *in situ* inspection and after it has been removed for maintenance. In this way, the condition of each optic is monitored throughout the optic's lifetime.

This overview paper will summarize key algorithms and technical developments for custom image analysis and processing and highlight recent improvements. (Associated papers will include more details on these issues.) We will also discuss the use of OI Analysis for daily operation of the NIF laser and its extension to inspection of NIF targets.

Key Words: NIF, laser, optics inspection, automated, optics lifetime, recycle optics

Highlights

- Automated inspection of optics for high power lasers
- Image analysis for tracking optic performance
- Optics recycling through automated inspection followed by refurbishment

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Introduction

Custom image processing and analysis algorithms have been developed over the past 10+ years for the automated inspection of optics for NIF. As each inspection system came into existence, tailored analyses were designed and built to automate the analysis of acquired images and additional techniques have been applied to track information from system to system and over time. Recent advancements improve our ability to exclude false alarms and to ensure that optics can be mitigated efficiently and thus recycled for extended life and reduced cost.

Here we describe the main benefit of each analysis and how the results are used for daily operations of the NIF laser, thus ensuring optimal performance of the optics.

1.0 Optics Inspection Systems

For the purpose of monitoring optics on NIF, images are routinely acquired from cameras in the following scenarios and then analyzed.

1.1 The Main Laser. Cameras are housed within sensor packages for the main laser and “look” into the beamline via relay optics (like a periscope). The optical system is telecentric, providing constant magnification over varying optical working distances. The images of these optics are obtained by backlighting each optic or mirror using a continuous wave (CW) laser. This provides what is known as a bright field illumination. Just like the pulsed laser light of NIF, the bright field illumination bounces off of mirrors and passes 4 times through the optics of the main laser and so we can see up to 4 instances of any site on a given optic. The exact distance between the different instances of site, and the configuration of pinholes used to control which passes are visible, uniquely determines the distance from the camera and thus the optic on which the site resides.

1.2 Final Optics. A precision imaging system is mounted at target chamber center on a highly mobile positioner. This instrument’s articulated telescope can be directed, via a script, to aim down each beamline to focus and acquire an image for each cascaded optic sequentially. The images of these optics are obtained using edge injected illumination. This takes advantage of the properties of total internal reflection, keeping the light effectively trapped inside the optic until it encounters a defect on the optic surface from which the light can escape. Individual optics can be selected and imaged using this technique. The light escaping from a scattering site on the surface appears like a dark field image and since only one optic at a time is illuminated, the impact of information from other optics is reduced. See Figure 1.

1.3 Switchyard. Transport mirrors redirect light from the linear paths of the main laser to the radially-directed beamlines that carry light to target chamber center. These mirrors can be imaged and inspected with bright field and dark field imaging using the CW light source from the main laser and the final optics imaging system at the target chamber center, described earlier. Resolution of feature on these mirrors is reduced because they are further from the camera.

1.4 Off-beamline laboratories. Unlike the above inspections, which are *in situ* on the NIF beamlines, optics also undergo many inspections in more controlled laboratory conditions. They are inspected upon arrival from the manufacturer to verify the demanding NIF specifications are met and also during various preparation processes to ready the optics for installation on a NIF beamline. Various lighting and acquisition schemes are used in the laboratory inspection, ranging from bright or dark field imaging to specialized gradient and interferometric imaging. Analysis for the specialized imaging techniques is not described in the analysis methods.

2.0 Analysis Methods

A single custom detection algorithm provides the basis for accurate detection in nearly all of the different images acquired from different inspection systems described in section 1.0. This algorithm is called the Local Area Signal-to-Noise ratio (LASNR) algorithm [1]. It assumes that sites of interest are brighter than their surroundings, as is the case with dark field images. In order to also use this algorithm on bright field images, we simply invert the images before beginning analysis. This way, all images can flow through the detection and subsequent analysis steps without consideration for their original illumination.

Once all candidate sites are detected, a number of measurements are computed for each (area, intensity statistics, signal-to-noise ratio, background statistics, etc.) and all these are stored in a database. These measurements become the features with which we can define the classification of each site found. This classification helps dramatically to identify relevant sites and reduce false alarms. We have applied the Avatar Suite of Machine Learning tools (WP Kegelmeyer, Sandia National Laboratories, [2]) with very high accuracy (>98% 10-fold cross validation) for classifying sites into various categories and eliminating false alarms [3].

In order to track detections through time the analysis relies on tiny, unique point patterns that were placed in optic corners during the optics' production. Finding and matching this pattern to the known drawing, or model, allows us to register the images to the physical optic and track detections through time and from system to system regardless of whether the inspection was on the beamline or in a laboratory. These point patterns are critical for the automated nature of the inspection analysis. Without them, even establishing optic orientation from system to system would be daunting, and tracking through time would be severely limited.

3.0 Data flow

Optics Inspection for NIF is a large, multi-disciplinary effort requiring specialists from many fields. Physical optics scientists and designers specify and guide optics production to ensure proper coating, cleaning, performance evaluation and installation of the unique point patterns needed for optimal inspection analysis results.

Control systems engineers have devised an intricate and advanced control system for all of the various camera inspection systems to automatically acquire the high-precision images and send them for analysis.

Once received by the analysis codes, the images automatically travel through a series of computations to parse data, create detections, make measurements, track sites of interest and then load all of the meta-data and results into a relational database. The images are loaded into a specialized database that is designed to handle the archival of large quantities of data. A team of database specialists designed and implemented the database schema, constraints, data flow and archival.

A configuration management team provides tools and manages deployments to be sure that each software release is controlled respective to previous releases and a testing team insures that all intended changes are implemented and functioning properly.

Next, data visualization specialists extract data from the database and present it to scientists and decision-makers at NIF so they can use the optics inspection information that has been computed to decide on the next shot. This is a combination of raw image data, enhanced images, summary statistics, reports and status grids. Many of the inspection systems have a specific, custom visualization application with which to review results.

Lastly, the database is queried by other software applications that use the OI Analysis results for downstream computations and further decision-making.

4.0 Decision-making and optics recycling

Optics Inspection Analysis results yield information to ensure that optics can perform optimally during the firing of the NIF laser. Individual sites on an optic surface can be detected early and tracked. While still very small, individual sites can be treated (mitigated), saving the time and cost of re-polishing an entire optic, or even replacing it. Recycling optics lengthens their lifetime and limits the need to replace them.

An example of a NIF summary for a laboratory inspection to verify specifications is shown in Figure 2.

Results and Conclusion

OI Analysis for NIF is a sophisticated, multi-disciplinary and relatively mature effort that automatically produces reports on the condition of optics. We have found that we can classify sites of interest and track them at a very small size from inspection system to inspection system through time – even years.

Discussion

It is likely that high-energy laser facilities will come to rely more and more heavily on the automated inspection of optics in order to maintain financial viability of the facility. Not only does inspection allow for mitigation and recycling of optics, extending their lifetime and reducing operating costs, but it ensures optimal performance of the laser which is critical for High Energy Density and other physics experiments.

References

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Note: Figures will be sent in a separate file, but are included below for reviewer's convenience.

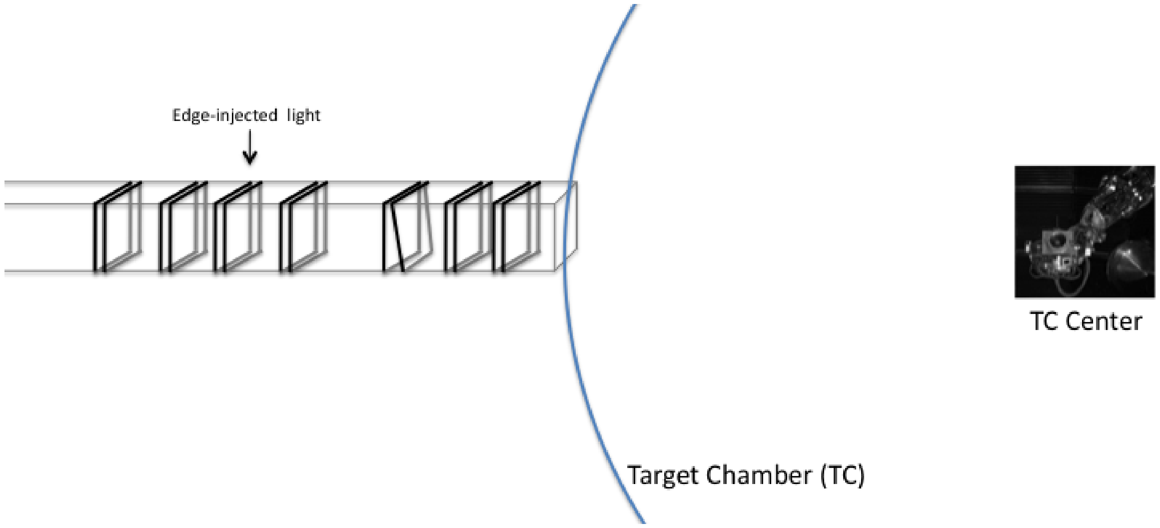
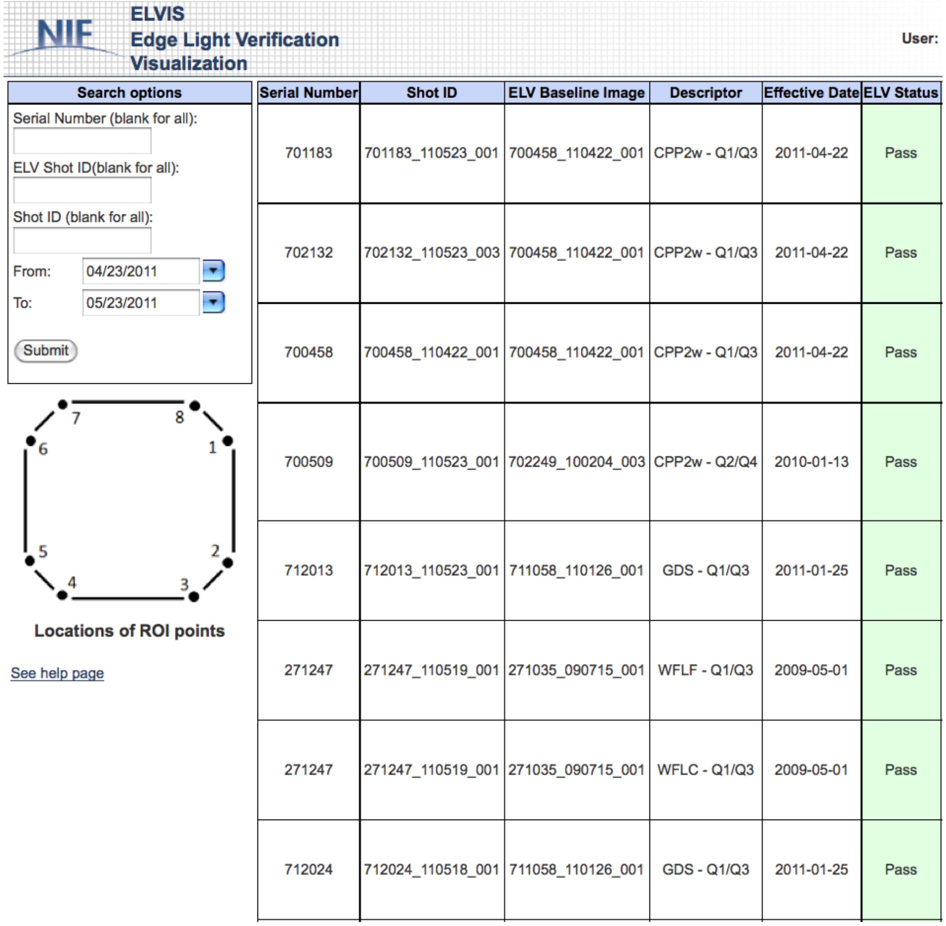


Figure 1. Inspection of the final optics assembly involves 1) positioning the camera precisely to be aimed and focused on one optic, 2) illuminating just that one optic, and 3) capturing that image. This is repeated as the camera positions to image each optic in one beamline sequentially and then to each beamline.



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702132	702132_110523_003	700458_110422_001	CPP2w - Q1/Q3	2011-04-22	Pass
700458	700458_110422_001	700458_110422_001	CPP2w - Q1/Q3	2011-04-22	Pass
700509	700509_110523_001	702249_100204_003	CPP2w - Q2/Q4	2010-01-13	Pass
712013	712013_110523_001	711058_110126_001	GDS - Q1/Q3	2011-01-25	Pass
271247	271247_110519_001	271035_090715_001	WFLF - Q1/Q3	2009-05-01	Pass
271247	271247_110519_001	271035_090715_001	WFLC - Q1/Q3	2009-05-01	Pass
712024	712024_110518_001	711058_110126_001	GDS - Q1/Q3	2011-01-25	Pass

Figure 2. This summary report gives the status of individual optics and their edge illuminators as evaluated before they are placed on a beamline.