Path to Ignition at National Ignition Facility (NIF) – The Role of the Automated Alignment System (AA)

ICALEPCS Oct 09, 2023

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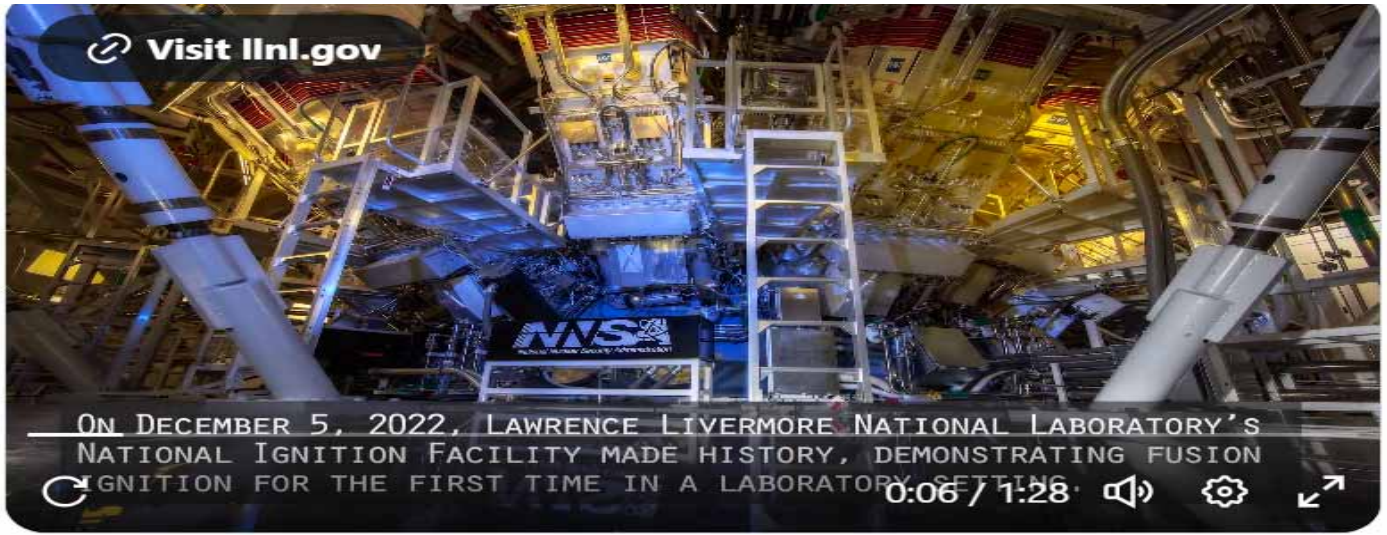
Lawrence Livermore National Laboratory

U.S. Department of Energy @ENERGY · Dec 13, 2022

BREAKING NEWS: This is an announcement that has been decades in the making.

On December 5, 2022 a team from DOE's @Livermore_Lab made history by achieving fusion ignition.

This breakthrough will change the future of clean power and America's national defense



US scientists achieve net energy gain for second time in nuclear fusion reaction

The Lawrence Livermore National Laboratory's National Ignition Facility achieved the feat using lasers to fuse two atoms

US scientists have achieved net energy gain in a nuclear fusion reaction for the second time since a historic breakthrough in December last year in the quest to find a near-limitless, safe and clean source of energy

Scientists at the California-based Lawrence Livermore National Laboratory repeated the breakthrough in an experiment in the National Ignition Facility (NIF) on 30 July that produced a higher energy yield than in December, a Lawrence Livermore spokesperson said.

l being analysed, the spokesperson added.

lves smashing together light elements such as hydrogen nents, releasing a huge burst of energy in the process. h gives rise to the heat and light of the sun and other

A second spark: US scientists repeat fusion ignition milestone

SUSTAINABILITY - U.S. scientists at the Lawrence Livermore National Laboratory in California have once again made history by achieving a net energy gain in a fusion reaction.

NEWS 9 AUGUST 2023

The Lawrence Livermore National Laboratory has announced a groundbreaking accomplishment in nuclear fusion research. For the second time since December, they reported a net energy gain from a fusion reaction, marking a significant milestone in n fusion energy a viable power source. While commercial fusion is expected to require reactions generating between 30 and 100 times the energy in the lasers, this achieve provides a promising insight into the future of clean power. Fusion energy, unlike fissi produces minimal nuclear waste and does not emit harmful greenhouse gases, makin potentially revolutionary source of low-carbon electricity.

Highlights

- US scientists reported a second energy gain from a fusion reaction.
- It's the second time the American researchers achieved this milestone.
- With minimal nuclear waste generation and without emitting greenhouse gases, nuclear fusion has the potential to be a revolutionary source of low-carbon electricity.

A major leap forward

U.S. scientists at the Lawrence Livermore National Laboratory in California have once again made history by achieving a net energy gain in a fusion reaction. This was not the first instance of such a breakthrough; a similar milestone was reached in December 2022. During that experiment, the scientists, working at the National Ignition Facility (NIF), used 192 laser beams to provide 2.05 megajoules of energy to a deuterium-tritium fuel pellet. The fusion reaction output was a substantial 3.15 megajoules of energy, demonstrating the scientific viability of inertial confinement fusion energy.

Fusion achieved again on July 30, 2023

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BREAKING NEWS: This is an announcement that has been decades in the making.

On December 5, 2022 a team from DOE's @Livermore_Lab made history by achieving fusion ignition

Fusion ignition a big breakthrough

The Hans India

Hans News Service | 19 Dec 2022 5:38 AM IST

The New York Times

Scientists Achieve Nuclear Fusion Breakthrough With Blast of 192 Lasers

The advancement by Lawrence Livermore National Laboratory researchers will be built on to further develop fusion energy

d what they have called a major breakthrough in a lon
n nuclear fusion.The US Department of Energy said on
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y had to put in.

THE TIMES

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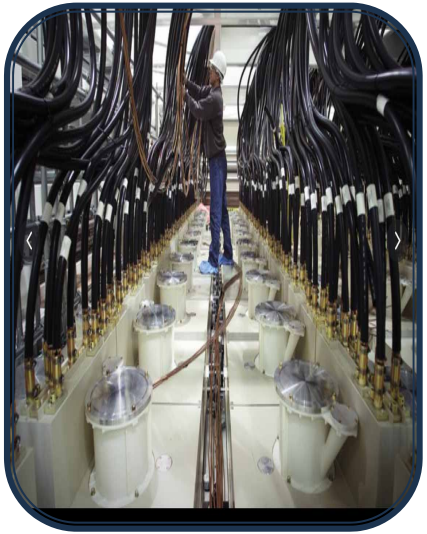
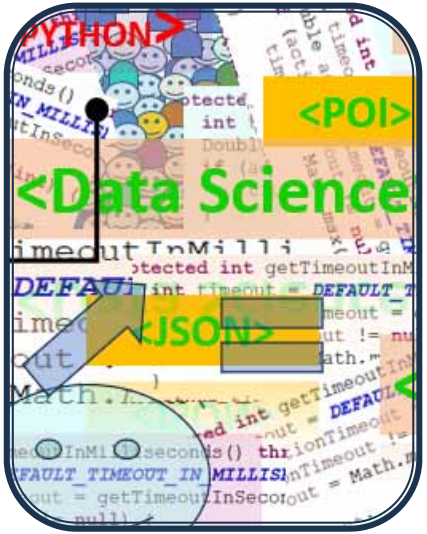


Hardware



Software

Automatic Alignment is a vital part of NIF and provided major contribution towards this achievement.

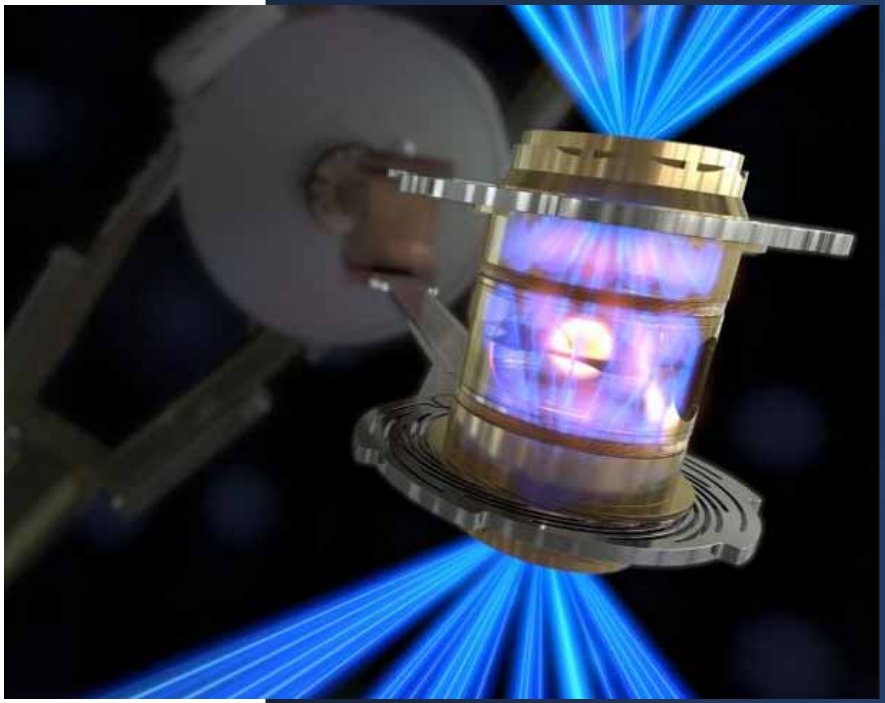
To Produce Fusion

- NIF 192 high powered Laser Beams are concentrated in 1 cm sized hohlraum containing a tiny BB sized target encapsulating heavy forms of hydrogen.

Alignment Requirements

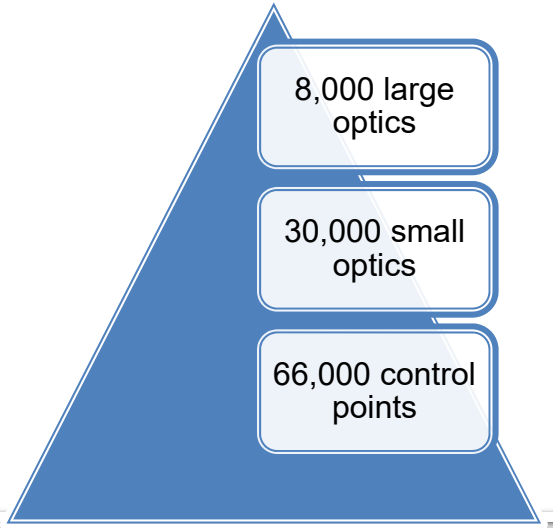
Each High Yield shot requires NIF 192 laser beams

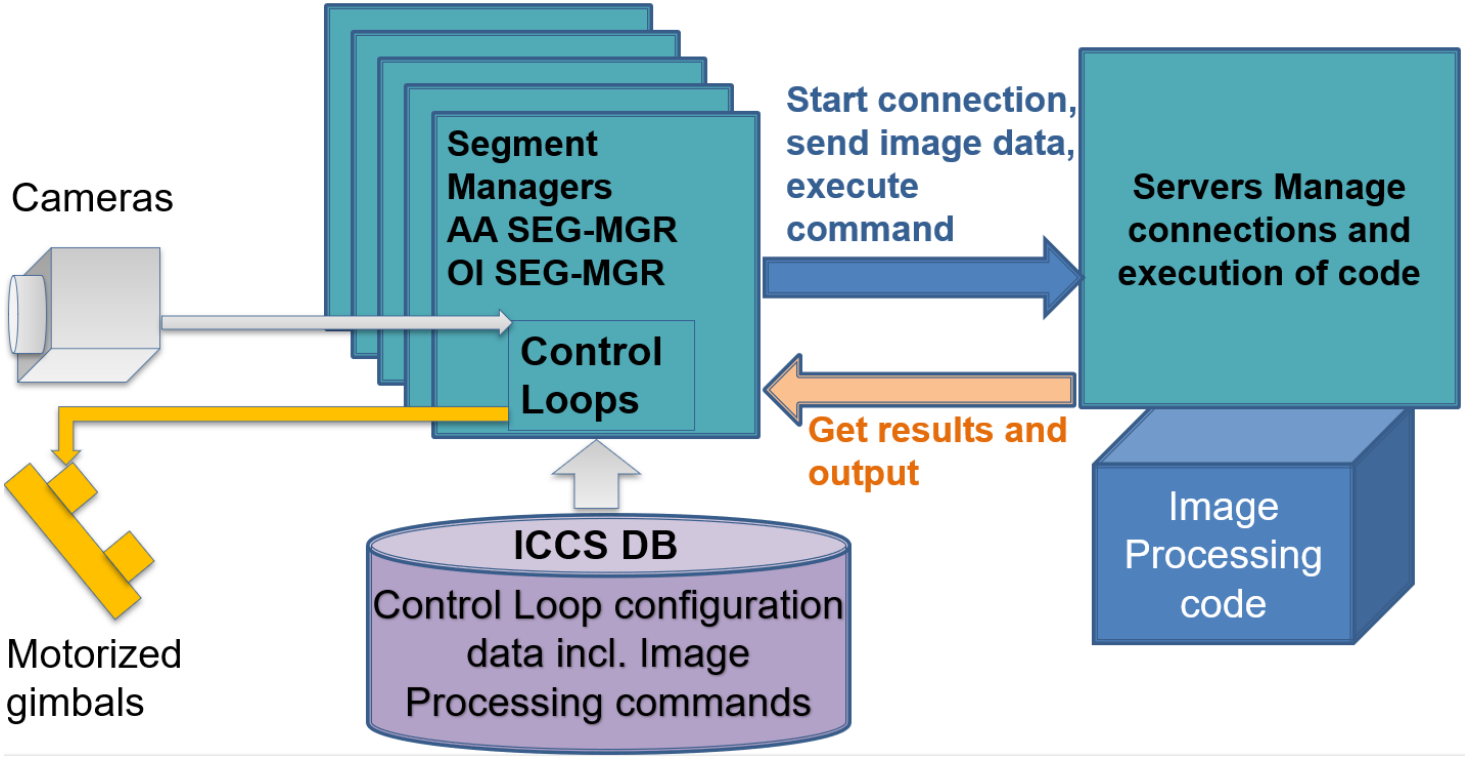
- Arrive at the target within 30 pico-secs
- Align within 50 microns
- Correct wavelength and energy



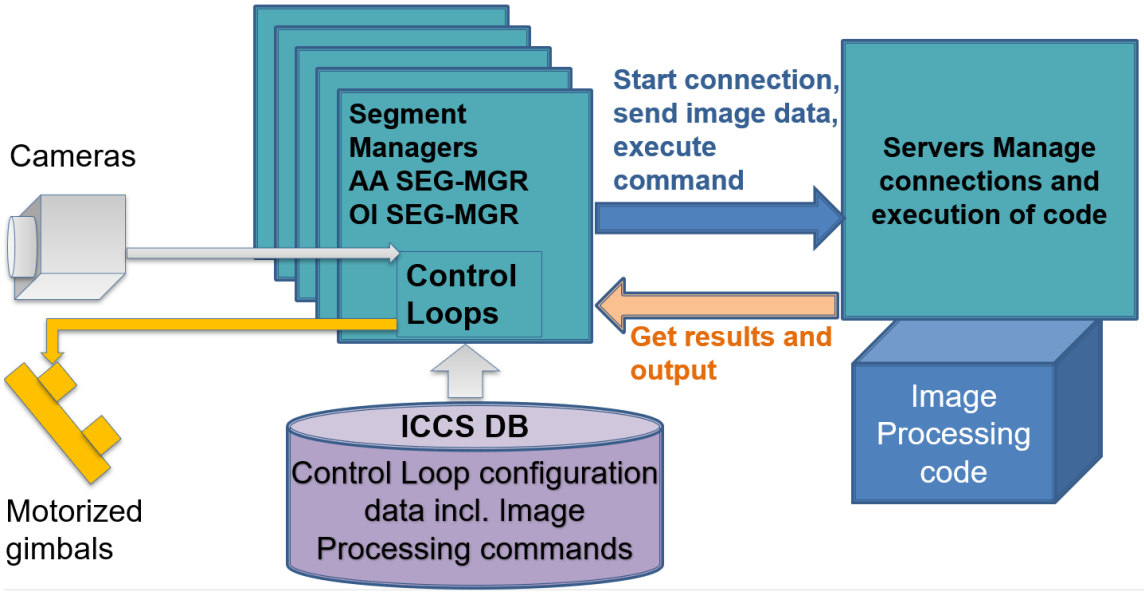
Automatic Alignment makes it possible to align and fire 192 NIF laser beams efficiently and reliably several times a day.

The success of a fusion shot is contingent on precision alignment of thousands of mechanical and optical components as the lasers are guided towards the target all of which is controlled by the AA system.





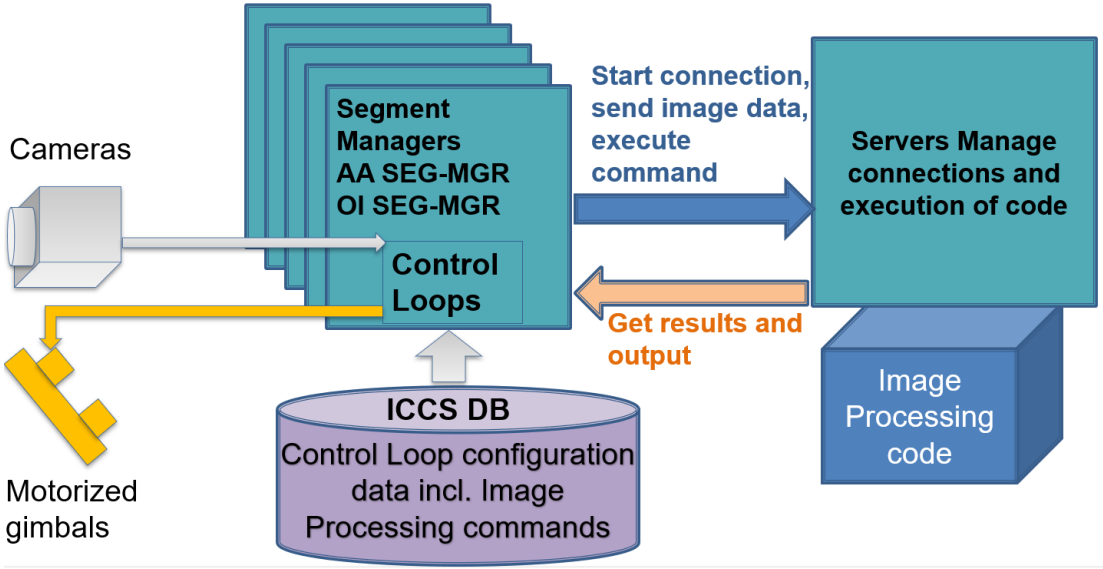
Automatic Alignment Software Architecture



Automatic Alignment Software Architecture

NIF AA system

- Data driven software framework
- Ability to position optical and mechanical devices and
- Ability to align 192 high power laser beams accurately and consistently
- Minimal or no human interaction
- Complete shot cycle in timely manner
- Capable of operating at high repetition rates without influencing experiment results



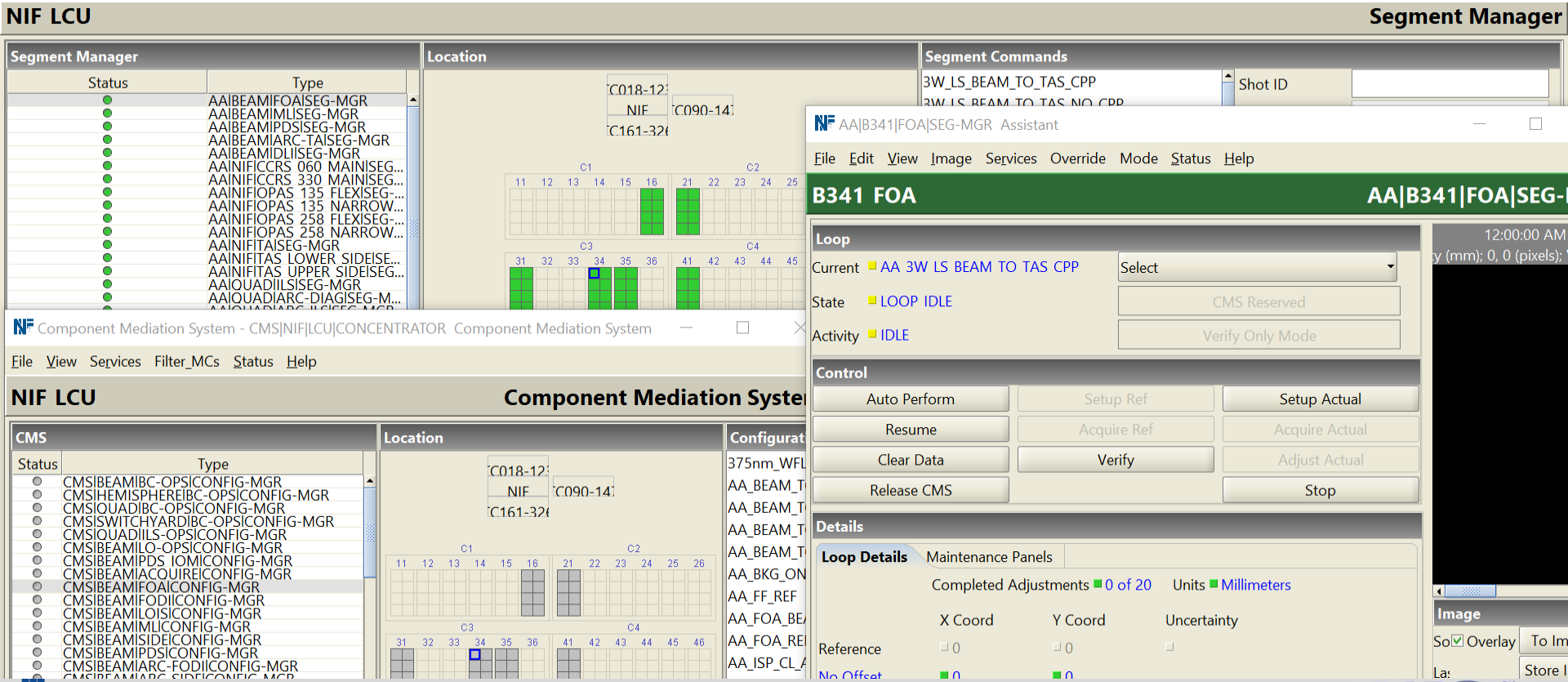
Automatic Alignment Software Architecture

NIF AA has 6 main components:

- Segment managers
- Database retrieval
- Component mediation system (CMS)
- Loops
- Image processing
- Data analysis

Each component has its own software platform and can run independently if needed.

NIF AA has a sophisticated user interface(UI) built on multiple layers, complex algorithms, testing framework and, Maintenance and Commissioning toolset.

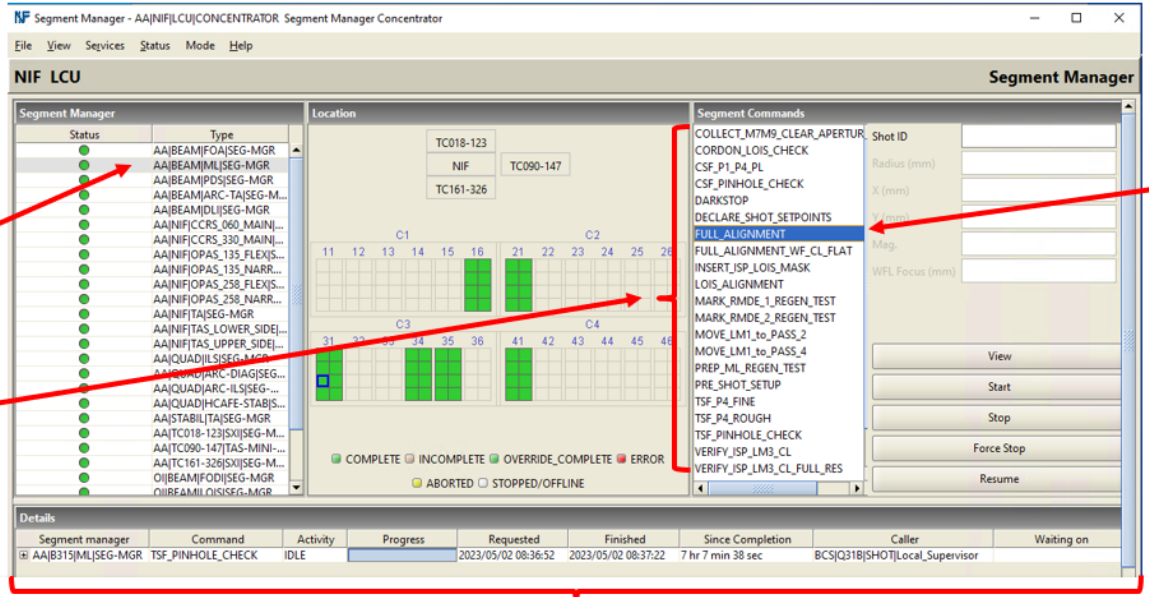


Segment Manager

Segment Managers occupies the topmost layer in the Automatic Alignment architecture and orchestrates all processes and devices in the AA process.

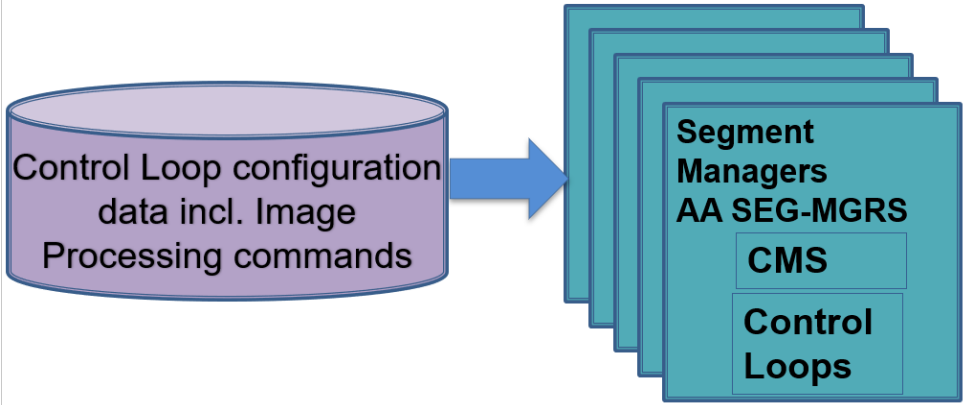
Automatic Alignment is comprised of multiple segment areas that contain commands containing many control loops

Each Segment Manager listed on the left has multiple segment commands and loops



AA Segment Manager interface

Each control loop employs image processing to determine reference and beam locations



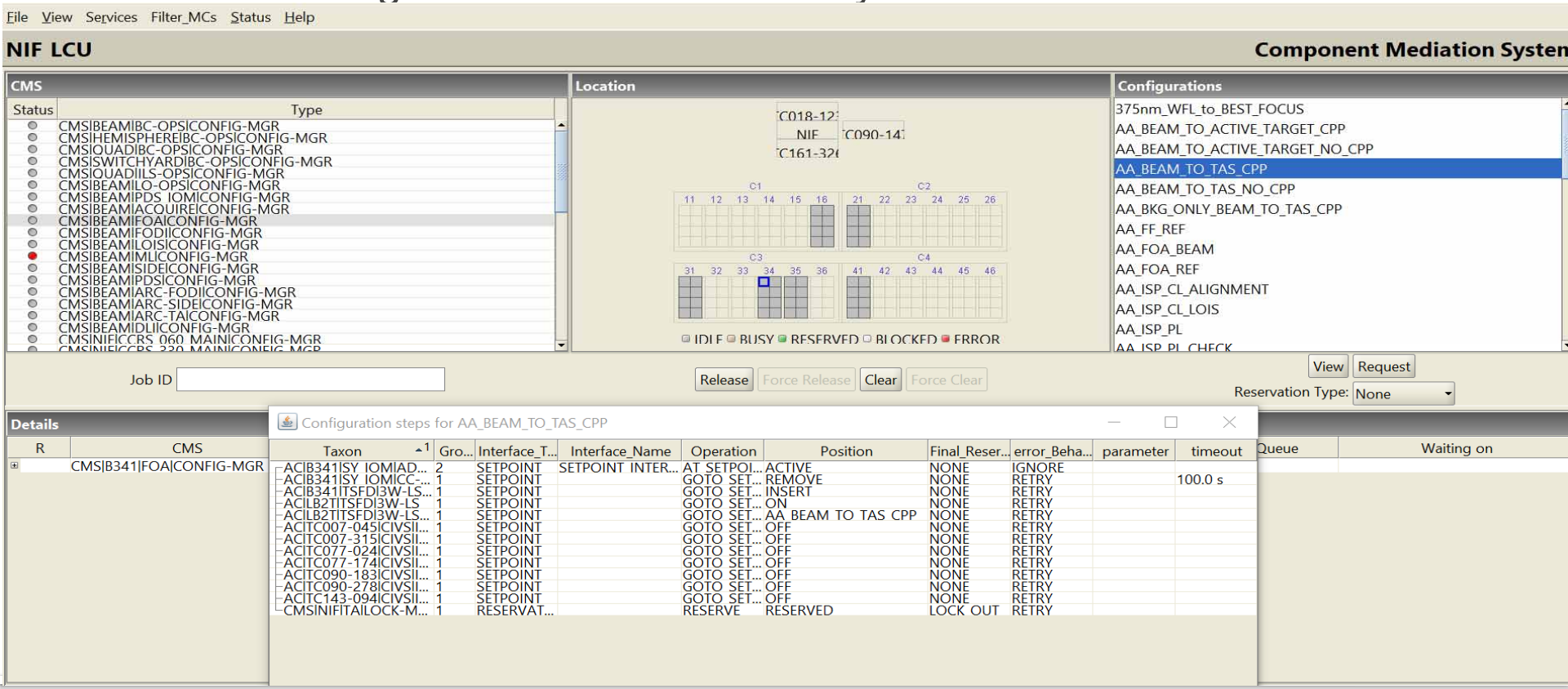
Data Retrieval

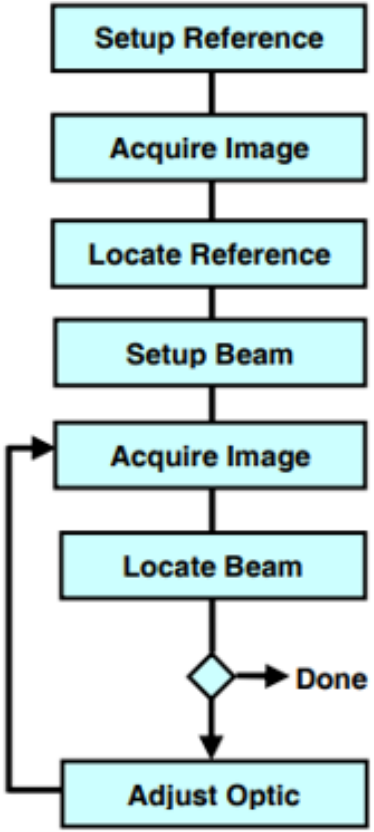
Data taken from the database includes

- Execution plan to complete the entire alignment
- Initial positions of the devices that is required for the process to run
- Loop configuration data
- Image processing commands

Component Mediation System (CMS)

CMS contains configurations for mediation systems





Generic loop execution

Loops

- Loops manage all actions required to adjust an optic
- There are more than 600 loops that provide these functions for specialized requirements of the different laser area
- All loops have a loop type for their individual function and are assigned a camera, a gimbal and CMS configuration based on its type
- All loops go through a finite number of iterations

Loop Types

As per the operations the Loops manage, they are categorized into different types.

Example of loop types are

- Centering Loops
- Pointing Loops

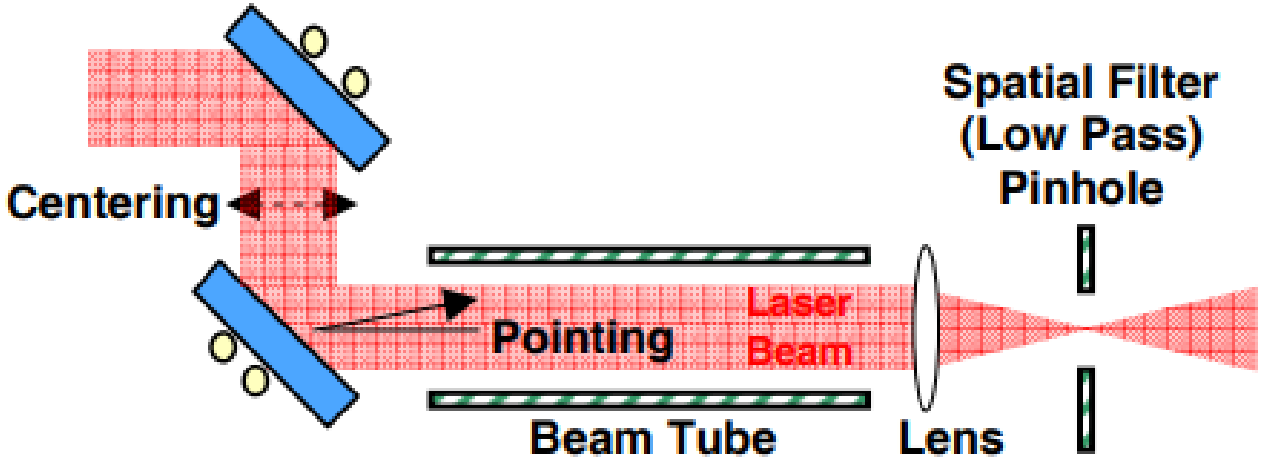
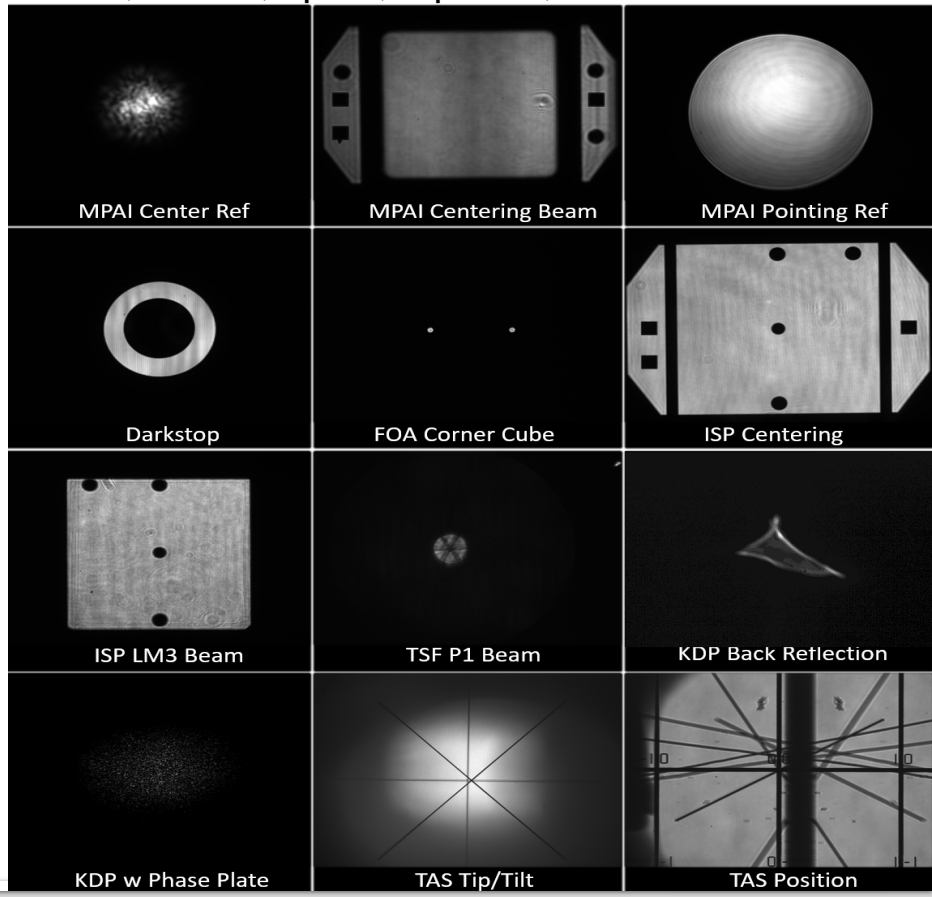


Image Processing - challenges of real-time image analysis

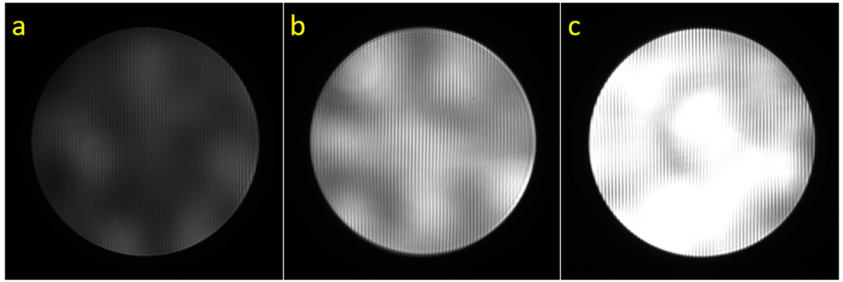
- Processing images with various types of noise
- Distortion
- Obscuration
- Imaging artifacts

Sample of various images and fiducials including lines, circles, spots, squares, etc.



Data Analysis

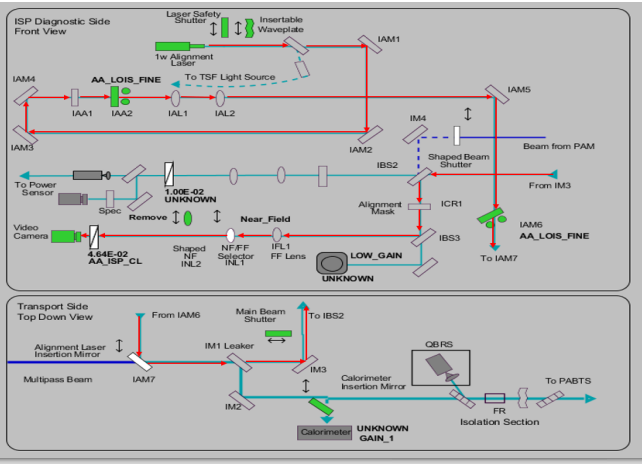
- 8-bit images of the back-lit Cavity Spatial Filter (CSF) pinholes illustrating marginal, nominal, and saturated signal levels.
- The images were archived for the same loop but different beamlines and are representative of the variation in signal levels across the system during alignment on a given shot.



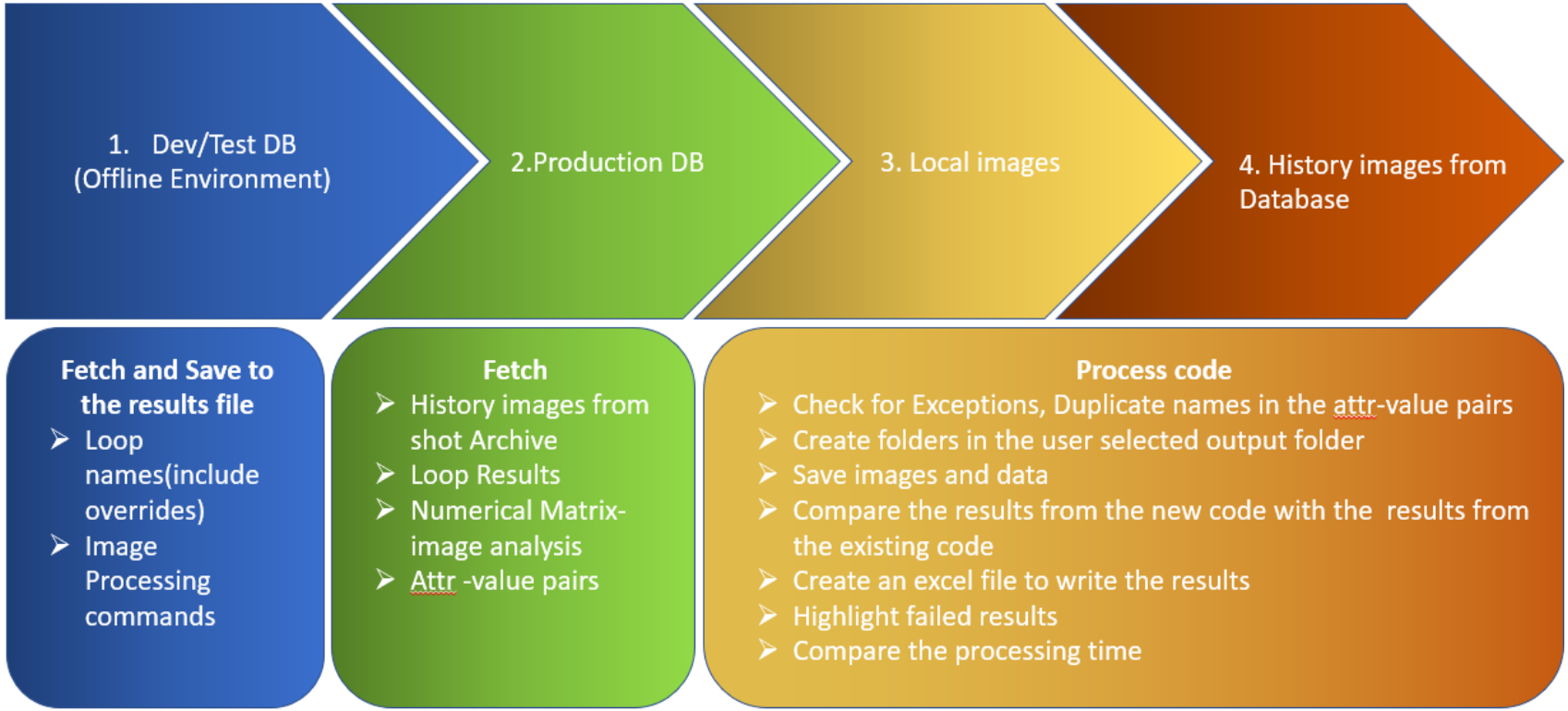
Analyzing critical data archived during AA operations helps to identify anomalies, improve planning, and evaluate overall performance critical to the NIF alignment system.

NIF Shot Setup

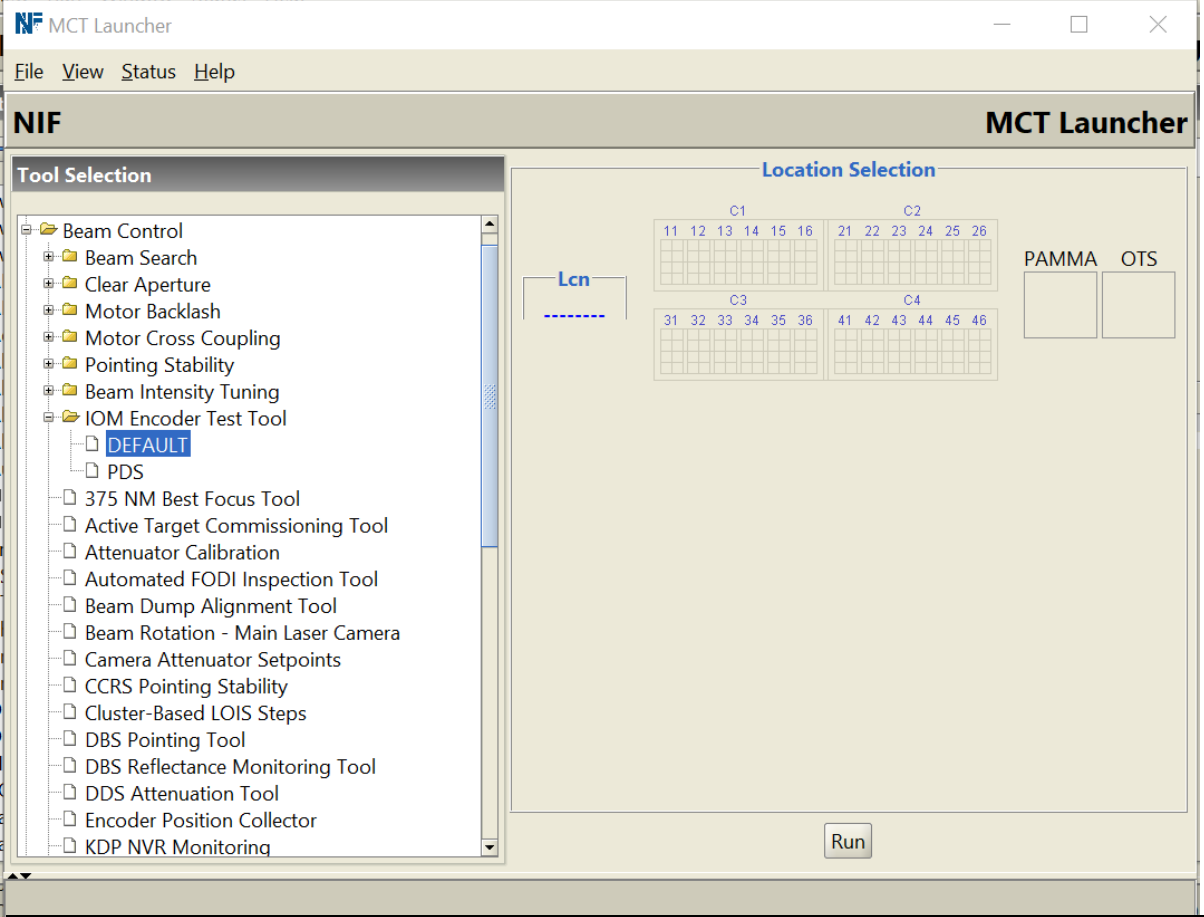
The entire setup of automatic alignment can be viewed and controlled from a single computer using an interactive UI



Given the fact that NIF AA is complex and interdependent, it is critical to check the effects of any code change on the overall alignment process.

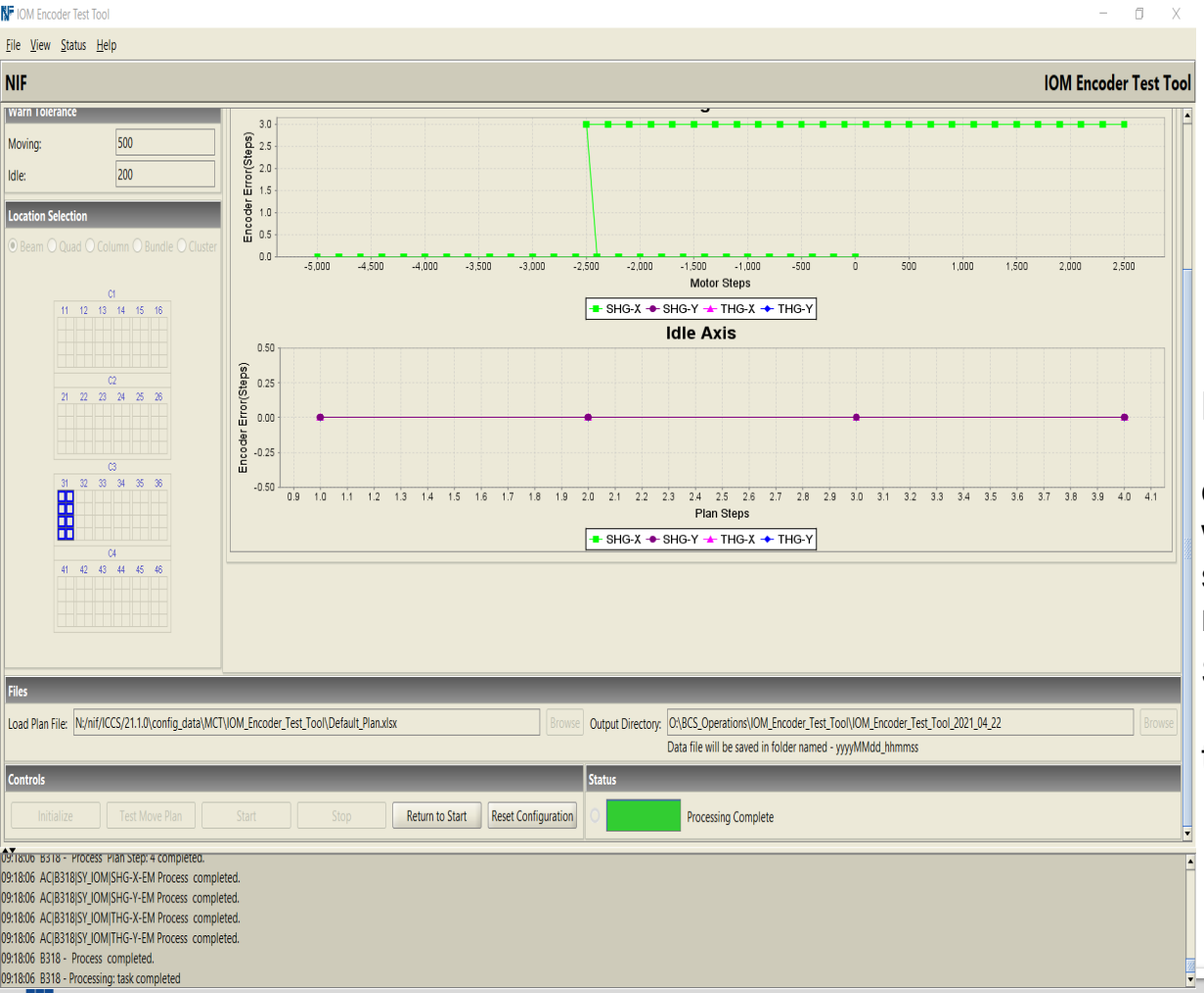


Online Maintenance & Commissioning toolset (MCT) developed to support AA



- Retrieves and analyzes data
- Determines motor and device problems, as well as optimizing operational parameters due to system variation
- Alleviates performing manual maintenance which can be time-consuming and inaccurate

MCT is comprised of 98 tools which can be run frequently and efficiently

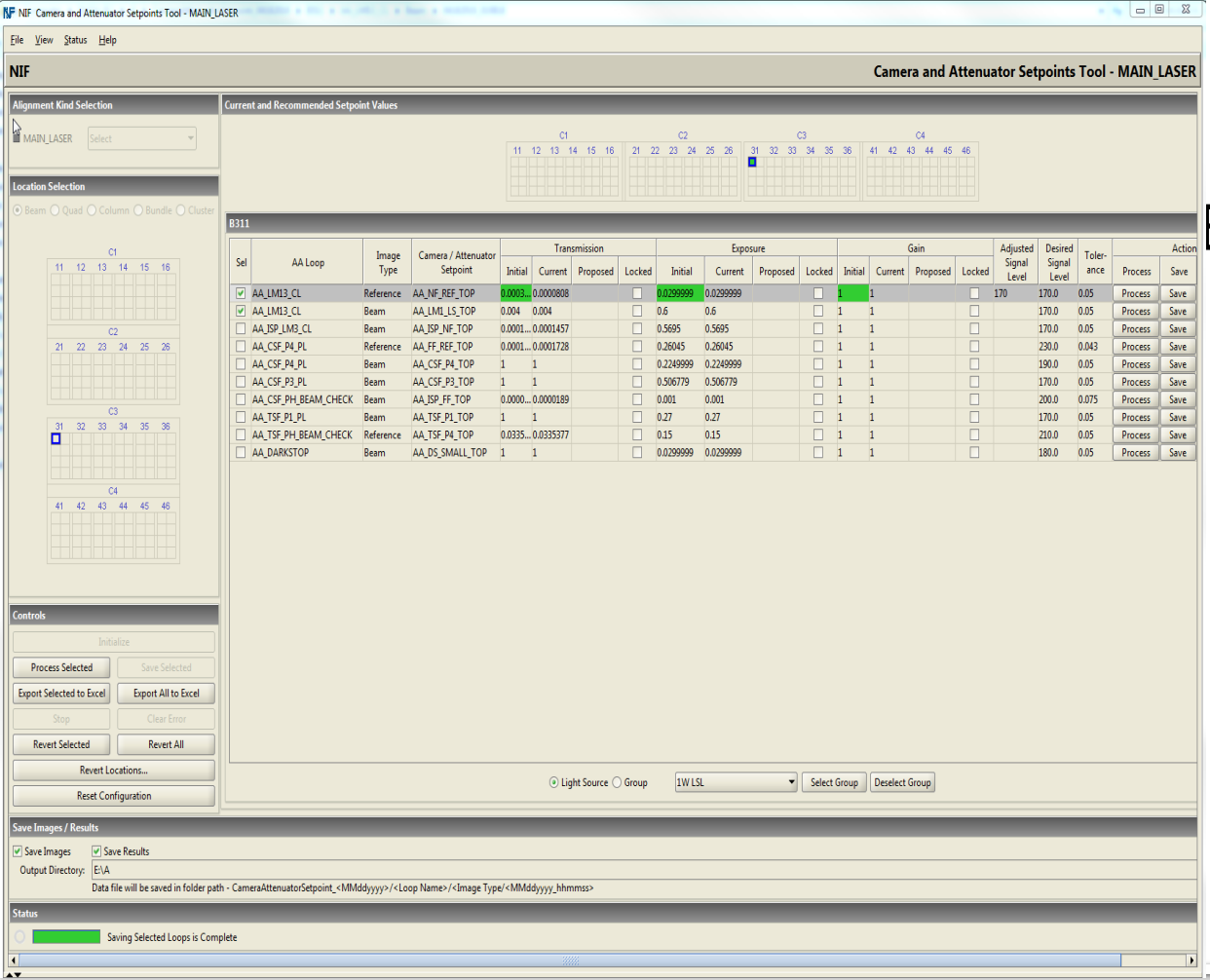


Example MCT – IOM Encoder Test Tool

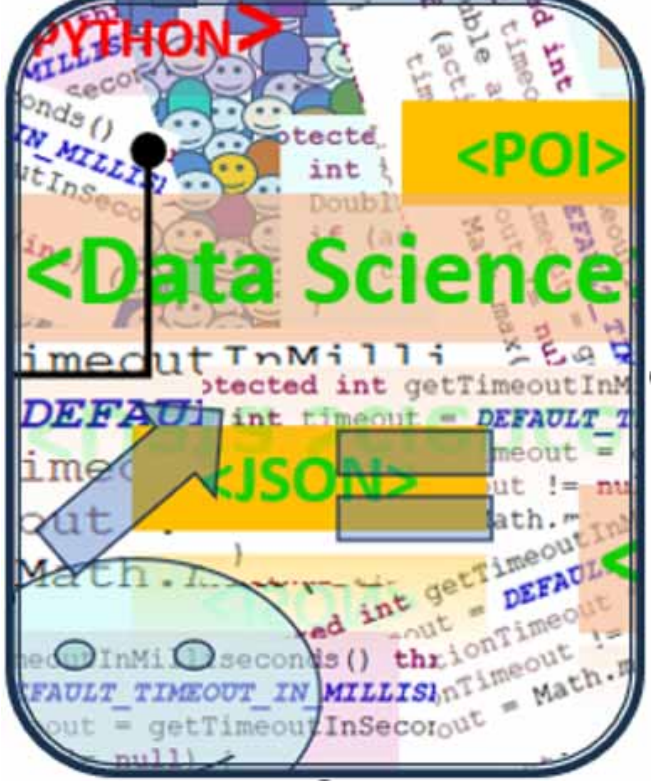
Problem: The motorized gimbal in the Integrated Optics Module (IOM) had occasional mechanical issues which were hard to detect. This caused significant operations time spent in malfunction identification.

Solution: IOM encoder test tool ran 192 beams in parallel and identified the problems in minutes.

Example MCT – Camera & Attenuator Setpoint tool



This tool automates the settings for the camera parameters, so that images with optimal signal to noise ratio can be passed to AA for processing and process camera and attenuator parameters for multiple beamlines in parallel and completes in a minute or two.



Future Sustainability and Modernization Plan

The Focus and Goals

- Identifying and optimizing technology and tools
- Determining resources and flexibility
- Balancing future development and modernization
- Maintaining accuracy and execution
- Verification test plan

The Future Sustainability and Modernization Plan is aimed at a long-term plan to keep up with constantly evolving technology and maintain current NIF Automatic Alignment requirements.

Thank You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