National Ignition Facility

CAD Model-Based Visual Control System for the National Ignition Facility Target Area Positioners

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NIF concentrates all the energy in a football stadium-sized facility into a mm³

NIF is 94% complete, on schedule and budget

Matter
Temperature >10⁸ K
Radiation Temperature >3.5 x >10⁶ K
Densities >10³ g/cm³
Pressures >10¹¹ atm
NIF is a 192 beam laser organized into quads, bundles and clusters with a 10m diameter chamber.

Quads are the basic building blocks of a NIF experiment, 4 beams with same pulse shape and time delay. Each quad enters the chamber through the final optic assemble.
The Integrated Computer Control System (ICCS) orchestrates complex automated shots

- 60,000 control points are installed in over 6,000 line replaceable units
- ICCS is deployed on 850 front-end processors, servers, and workstations
- A CORBA-based software framework was developed to deliver 1.8M SLOC
- 192 beams precisely aligned on target to 10 microns over a 300-meter optical path

Shots fired every few hours culminate in a nanosecond laser pulse in lock-step with diagnostics timed to 30 picoseconds
Ten target and diagnostic positioners are precision aligned for each shot.

Diagnostics insertion manipulator (DIM)

Streak X-ray imager (SXI)

Target positioner

Alignment sensor positioner

Optics damager inspection positioner

Future DIM

Cross-chamber reference system (CCRS)

Cryo-Target positioner
The target positioner (TARPOS) inserts the mm-scale fuel capsule with five degrees-of-freedom.
TARPOS extended inside the target chamber
The alignment sensor views the target for precision alignment.
Diagnostic instruments manipulators (DIM) position physics packages at chamber center

Four DIMs precision align a diverse suite of diagnostic instruments
The seven-floor target bay contains the vacuum chamber, final optics system, and target diagnostics.
Each experiment requires careful coordination of the motion control system

- Limited chamber access requires remote control and sensing
- Positions maintained to accuracies of 10 microns
- Varied 3D geometries and alignment scenarios
- Complex motion sequences involving multiple devices
- Absolute encoder and video feedback
- Potential collisions must be avoided

A CAD model-based control system with integrated video feedback meets these requirements
Collision avoidance protects positioners that reach 6 meters into the chamber

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Situational awareness provided by the surveillance cameras is less than ideal.

Wide Field-of-View

Narrow Field-of-View

Chamber Wall

High viewer magnification limits the field-of-view to a small central region.
Camera views of the chamber interior

Wide FOV

Narrow FOV
Collision-free positioner routes are calculated using model-based analysis and tracking tools

- **Pro/ENGINEER***
  - CAD tool used to design NIF’s mechanical hardware
  - Leveraged to derive the control system model

- **DIVISION MockUp***
  - 3D simulation of the chamber and all positioners
    - Based on experimental set up
    - Used for real-time controls during operations
  - Live visualization of positioner operation
    - Delivers sub-millimeter accuracy
    - High-precision servo motors with encoders provide hardware feedback
  - Determines distances between points or/and positioners
  - Calculates collision free routes
  - Video overlays for manual control

* Pro/ENGINEER and DIVISION MockUp are a registered trademark of Parametric Technology Corporation (PTC)
The 3D model “sees” the chamber mechanical arrangement at all times.
3D simulation and analysis tool coded in Java proved the model-based concept.
Simulation integrity is verified in real-time by comparison to the view generated by MockUp.
Visual assisted control

• Calibrated video
  — Virtual 3D axes are defined using cross-coupling matrices
  — Video views are calibrated to these axes

• Video integrated control
  — Calibrated videos provide a live-video integrated control by dragging movement commands on the screen

• Operator aids
  — Live-video overlays
  — Alignment markers
  — Zoom, etc.
Movement commands are “dragged” across the live video display using calibrated views

- Reference point and transformation matrix
  - Maps any point \((x,y)\) in the camera coordinate system to \((x,y,z)\) in chamber coordinate system
- Scale and rotation factors
  - Maps video pixels \((x,y)\) to positioner coordinate system
- 3D virtual-axes
  - Defined along camera field-of-view using cross-coupling matrices
Routing is analogous to driving directions given by Google Maps.
The offline test lab integrates special hardware simulators and cameras

- **Hardware-based testing**
  - Multi-axis encoded hardware simulators on an optics table
  - Calibrated cameras
  - PLC motor end-of-travel monitoring and shut-down system
  - Configured to mimic the NIF target chamber

- **Software-based testing**
  - Emulated virtual positioners
  - Provides for multiple concurrent tests

The test lab ensures software quality, assesses usability, and helps train operators
Hardware-based testing is supported by five-axis positioner simulators that have the same range of motion as the real positioners.
Calibrated video cameras

Simulator undergoing acceptance tests

Test Lab
Conclusion

• Enhanced real-time video feedback provides operators with metrology and controls in real physical dimensions

• Model-based visualizations provide a complete control environment in support of complex operations in the limited access chamber

• Model validation assures the system accurately represents reality

• Automated controls ensure interference-free and repeatable coordinated motion sequences

• Status
  • Video-assisted controls are deployed to NIF
  • CAD model-based system is on schedule for delivery next year