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Target Diagnostic Instrument-Based Controls Framework for the National Ignition Facility (NIF)*

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ABSTRACT

NIF target diagnostics are being developed to observe and measure the extreme physics of targets irradiated by the 192-beam laser. The response time of target materials can be on the order of 100ps—the time it takes light to travel 3 cm—temperatures more than 100 times hotter than the surface of the sun, and pressures that exceed 10^9 atmospheres.

Optical and x-ray diagnostics were developed and fielded to observe and record the results of the first 4-beam experiments at NIF. Hard and soft x-ray spectra were measured, and time-integrated and gated x-ray images of hydrodynamics experiments were recorded. Optical diagnostics recorded backscatter from the target, and VISAR laser velocimetry measurements were taken of laser-shocked target surfaces. Additional diagnostics are being developed and commissioned to observe and diagnose ignition implosions, including various neutron and activation diagnostics. NIF's diagnostics are being developed at LLNL and with collaborators at other sites.

To accommodate the growing number of target diagnostics, an *Instrument-Based Controls* hardware-software framework has been developed to facilitate development and ease integration into the NIF *Integrated Computer Control System* (ICCS). Individual WindowsXP™ PC controllers for each digitizer, power supply and camera (i.e., instruments) execute controls software unique to each instrument model. Each hardware-software controller manages a single instrument, in contrast to the complexity of combining all the controls software needed for a diagnostic into a single controller. Because of this simplification, controllers can be more easily tested on the actual hardware, evaluating all normal and off-normal conditions. Each target diagnostic is then supported by a number of instruments, each with its own hardware-software instrument-based controller.

Advantages of the instrument-based control architecture and framework include reusability, testability, and improved reliability of the deployed hardware and software. Since the same instruments are commonly used on many different diagnostics, the controllers are reusable by replicating the hardware and software as a unit and reconfiguring the controller using configuration files for the specific diagnostic. Diagnostics are fully integrated and interoperable with ICCS supervisory and shot controls using these configuration files to drive the diagnostics' instrument-based controllers.

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EXPERIMENT CONTROLS FOR THE NATIONAL IGNITION FACILITY

The *Integrated Computer Control System* (ICCS)[1] provides supervisory and front-end control of the NIF laser and laser diagnostics, and target diagnostics—the focus of this paper. Refer to Figure 1. NIF control room functions for the laser, target diagnostics and all support systems are controlled through ICCS. ICCS software, for other than Instrument-Based Controllers, is written in *Ada* and executes on Sun™ Solaris servers.

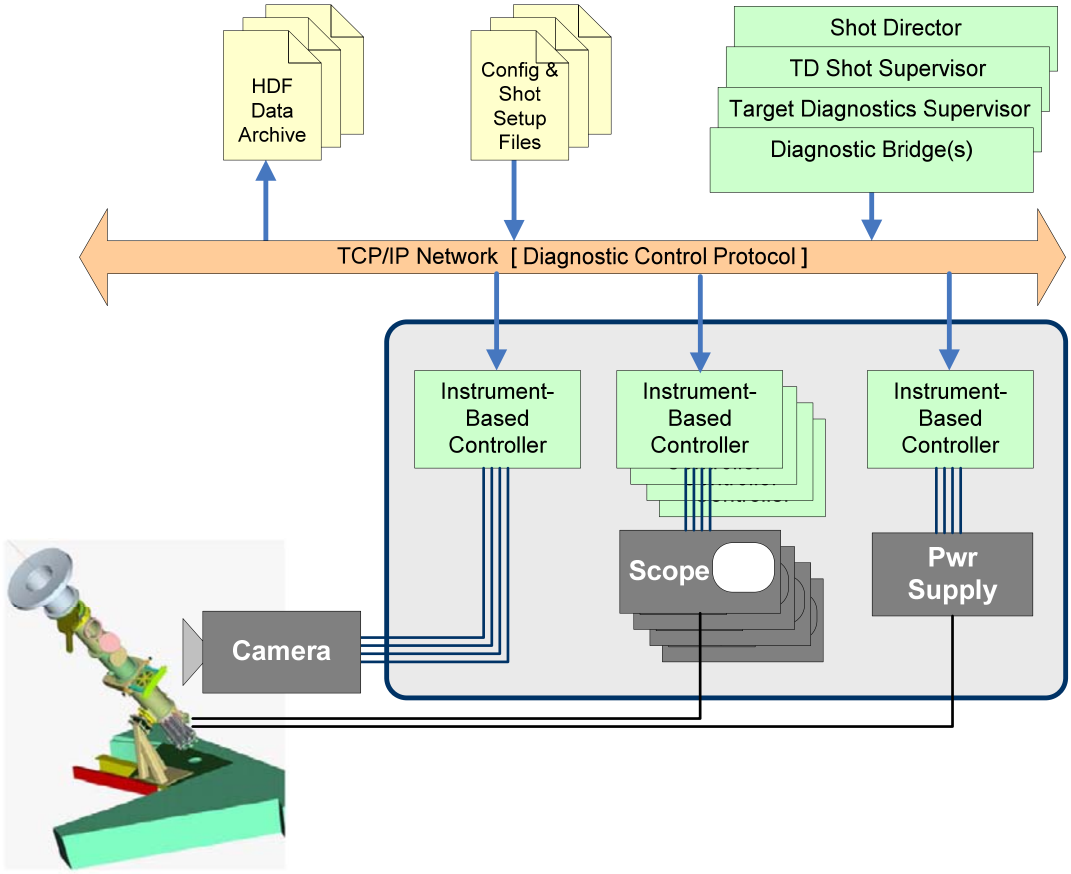

Figure 1. ICCS computers run software to control and acquire data from target diagnostics—the Dante soft x-ray spectrometer in this illustration. A hierarchical set of computers provide supervisory control over Instrument-Based Controllers (I-BCs). I-BCs setup and control the cameras, scopes, and power supplies, and acquire experiment data after the shot. Acquired experiment data is archived for later data reduction and off-line analysis.

Controls for target diagnostics fall into the ICCS high-level architecture. However, target diagnostics have a unique requirement to allow self-contained standalone operation of a diagnostic outside of the NIF control system environment. This enables a diagnostic to be operated or calibrated in facilities other than NIF. A loosely coupled interface to the ICCS hardware and software architecture was designed to meet this requirement.

THE NATIONAL IGNITION FACILITY

The National Ignition Facility (NIF)[2] is developing into an extraordinary tool for understanding laser-driven ignition and high energy-density physics. NIF is located at Lawrence Livermore National Laboratory in California and is well on its way to completion. When completed NIF will routinely direct up to 192 beams (up to 1.8 MJ of 351 nm light) onto targets suspended at the center of a 10 meter diameter target vacuum chamber. Laser pulse shapes can be controlled in detail with pulse lengths between 0.5 and 33.0 ns. Targets may consist of cryogenically cooled tritium-deuterium filled spherical capsules inside a cylindrical hohlraum, or a variety of planar, cylindrical or spherical structures of different materials.

In 2004, four of NIF's 192 laser beams were used in first experiments. In this first campaign of experiments,[3-10] referred to as *NIF Early Light*, a nominal 16 kJ of 351 nm laser light was put on targets. NIF's early capabilities were successfully demonstrated, and many important lessons were learned to better enable completion of the facility and its effective operation.

NIF TARGET DIAGNOSTICS

NIF experiments are planned to better understand the physics of energetics, laser-hohlraum interaction, hydrodynamics, and equation of state of materials. A variety of diagnostics are needed, each with its unique controls requirements. Optical diagnostics[11-14] observe backscattered light from targets and provides insight to energy conversion, and they are used to measure shock velocity. X-ray diagnostics can be an integrating camera,[15] a gated camera to capture a snap-shot of the target experiencing laser-driven shock, [16, 17] a streaked image,[18] or a spectroscopic measurement.[19, 20] Neutron imaging, time of flight, and spectroscopy are used in diagnosing ignition experiments. Below is a chart with the basis set of target diagnostics currently planned for NIF (Table 1).

Diagnostic System		Units
Optical	Full Aperture Backscatter	2
	Near Backscatter Imager	2
	VISAR	2
X-Ray	Dante X-ray Power w/ imager	2
	Hard X-ray Spectrometer	1
	X-ray Streaked Detector	2
	X-ray Gated Detectors	2
	Static X-ray Imager	2
	Hard X-ray Imager	1
Neutrons and Gammas	Neutron Time-of-flight w/ yield	7
	Neutron Imaging	1
	Gamma BangTime	1
	Magnetic Recoil Spectroscopy	1
	Activation	1
	DT Yield	1
	Total	28

Table 1. Optical, X-ray, Neutron and Gamma diagnostics, and the cross timing system that supports them, are each controlled by 1-20 Instrument-Based Controllers.

THE DIAGNOSTIC CONTROL SYSTEM AND NIF EARLY LIGHT EXPERIMENTS

The controls and data acquisition for the suite of diagnostics used for NIF Early Light experiments followed a very traditional, though very formal, computer controls development process. Each diagnostic was controlled by a *Diagnostic Control System* (DCS) computer controller. The various power supplies, cameras, digitizers/scopes—referred to as instruments—used by a diagnostic were interfaced to the computer controller. Each controller was a 4U (7 inch; 17.8 cm) high rack mountable computer with a disk running WindowsXP™. Controls software applications were written in Java, a modern objectoriented language. The software development cycle for each DCS controller—i.e., for each diagnostic—included:

- Developing Software Requirement Specifications that specified what instruments were to support the diagnostic, and how they were to be used
- Designing software specific to the diagnostic's use of these instruments
- Writing Java code to control required instruments
- Testing the code for function and performance
- Independent off-line Verification & Validation (V&V) testing of the DCS controller
- On-line Operational Qualification of controls with the diagnostic hardware on NIF
- Configuration management of the hardware and software control system

The DCS controllers worked very well during the NIF Early Light campaign of experiments. Availability of diagnostics and data capture reliability approached 100%. After NIF Early Light, we had an opportunity to review lessons learned and adopt a controls philosophy to better serve the needs of NIF target diagnostics in the coming years while still providing the needed performance and reliability.

INSTRUMENT-BASED CONTROLS

The goals established for this new approach to controls development included:

- Cost-effective development and on-going support over the lifetime of the diagnostic; leverage lower hardware costs to reduce software investment
- Increase quality and efficiency by enabling software developers to specialize
- Isolation of diagnostic from the ICCS supervisory controls
- Independence from ICCS supervisory control for off-line testing
- Reduced V&V testing
- After a possible initial investment, quicker turn around of controls for new diagnostics
- Independence from software developer to software developer—developers could come and go from the project and quality would be maintained

The Instrument-Based Controls (I-BC) architecture achieves these goals. A diagnostic's supporting instruments (i.e., power supplies, cameras, and/or digitizers) are each supported by a dedicated I-BC computer controller with controls software specific to that instrument. For example, the *Dante* soft x-ray spectrometer diagnostic uses 1 I-BC controller with software and interface hardware specific to the model PS-350 power supply; 1 I-BC specific to the model Agilent 6653A power supply; and 18 I-BCs specific to the model Tektronix™ SCD5000 oscilloscope. Twenty-six different I-BCs are being developed to support the variety of instruments used by NIF target diagnostics.

The collection of various I-BC computers are mounted in standard 19 inch (48.3 cm) electronic racks located in one of four Diagnostic Mezzanine equipment rooms adjacent to the NIF Target Chamber Area, along with associated power supplies and digitizers. The I-BCs for each diagnostic's instruments are connected to the ICCS network through network switches. The I-BCs are diskless, booting off a file server over the network. Experiment data are collected from a diagnostic's cameras and digitizers by their I-BCs and transferred to the file server for processing and archiving.

I-BC COMPUTER CONTROLLER

A total of 161 I-BC computer controllers will support the projected 28 individual target diagnostics, with their power supplies, cameras and digitizers. Reliability and maintainability with this number of computers is of importance. The selected I-BC computer controller needs to have a reliability of $\geq 99\%$, and availability for NIF shots of $\geq 99\%$, and maximum time to repair or replace of 4 hours.

Hardware interfaces to power supplies, cameras and digitizers are reduced to a limited number of GPIB (IEEE 488), ethernet cables, custom PCIA interfaces, and a few RS232 serial line interfaces. A computer capable of supporting two Ethernets was needed, one for direct connect to instruments (e.g., Tektronix™ oscilloscopes) and another for connection to the ICCS network and access to the I-BC file server. Thus, isolation and independence goals for I-BCs can be achieved.

An exhaustive review of the current commercially available 1U (1.75 inch; 4.45 cm) rack-mountable diskless WindowsXP™ computers was performed. Two leading candidates were chosen for testing against I-BC requirements, including stress testing and endurance testing. From this process, the ARCOM™ APOLLO ICE computer was chosen as the hardware platform for I-BCs.

THE I-BC FRAMEWORK, TARGET DIAGNOSTIC SUPERVISOR AND ICCS

The I-BC Framework is an objected-oriented Java-based modular software library that provides all the major functions necessary to create controls software for specific target diagnostics. The I-BC Framework is composed of software classes that perform functions such as:

- Reading **xml** configuration and setup files
- Creating **HDF** data archive files
- Management of data-sets (e.g., polled instrument status and states)
- Automatically generating remote graphical user interfaces on ICCS operator consoles
- Providing access to device drivers and implementing the Diagnostic Control Protocol (DCP) that loosely couples the I-BCs to the ICCS control system

ICCS' interface to I-BCs is comprised of *TD Shot Supervisor* software, *Target Diagnostics Supervisor* software, and *Diagnostic Bridge* software. The *TD Shot Supervisor* executes macro steps that are defined in the NIF Shot Model for participating diagnostics on any given shot. The Target Diagnostic Supervisor provides the primary operator interface on the Target Diagnostic console in the NIF Control Room. The Target Diagnostic Supervisor uses Diagnostic Bridges to get status and provide control for each I-BC, and groups the I-BCs for each diagnostic. Diagnostic Bridge translates the DCP protocol from each I-BC into ICCS CORBA objects. Instrument configuration for a specific diagnostic, on a specific NIF shot, is set up in ICCS *Configuration and Setup Files* by the engineer responsible for the diagnostic.

The DCP is a TCP-based protocol, specific to communications between ICCS Diagnostic Bridge and the I-BC. It passes commands and parameters to set up the I-BC. DCP is used to communicate the I-BC status (e.g., health of the I-BC or errors) and report the state of the controller (idle, ready, setup, countdown, armed, triggered, archive). Errors are asynchronously sent from the I-BC to the ICCS Diagnostic Bridge using DCP. Countdown *ticks* are passed to the I-BC through the DCP to execute commands defined during setup and transition to minor states. Diagnostic instruments are setup and armed by the I-BC during the countdown. Real-time triggers for instruments are hardware generated.

Configuration and setup of the I-BC is defined by **xml** files. Pointers to the setup files are passed to the I-BC using DCP while in the setup state for use during countdown. Configuration and setup files define 1) what constitute error conditions, 2) any instrument command to be executed during any state or any countdown tick, and 3) what acquired data is to be archived.

STATUS AND EXPERIENCE TO DATE

The chosen hardware and software architecture is expected to meet the requirements and goals derived from target diagnostics' needs, and from interface requirements to integrate I-BCs into the ICCS supervisory environment. Development and V&V of I-BCs is focused on the instrument and is comprehensive in supporting all features of the instrument. Developers are allowed to specialize on instrument types—families of power supplies and model lines of cameras and oscilloscopes. This is leading to efficiencies in development and fielding controls for target diagnostics.

The modular I-BC approach has enabled closer cooperation between diagnostic hardware engineers and technicians with the I-BC software developers and testers to create a close-knit team that more easily work together.

By standardizing on I-BC supported instruments, the cost of bringing future diagnostics on-line will be reduced. Similarly, controls software for future diagnostics is expected to be more responsive as development time for new diagnostics is reduced through adoption of standard power supplies, cameras, and scopes/digitizers.

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