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Using Embedded Systems for the Remote Delivery and Recovery of National Ignition Facility Optical Line Replaceable Units

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ABSTRACT

This paper describes the design and development of the embedded control systems used to deliver and recover the National Ignition Facility (NIF) optical line replaceable units (LRUs). As part of the NIF Operations Special Equipment Control System (OSECS), the embedded control systems form a part of the front end processor (FEP) layer of the OSECS. During the start-up and operations phases of the NIF project, it is anticipated that a significant number of LRUs will be delivered to the laser beamline structure. The frequency of LRU delivery combined with the design of the facility pose severe constraints for "human-only" delivery and recovery operations. To reduce the risks to personnel and to allow for safe and efficient delivery of equipment, LLNL engineers are designing and developing embedded control systems for the low-level device control of NIF Transport and Handling mechanical delivery system components. The design of the embedded control system makes use of advanced PC-based motion control technology commonly found in industrial applications. The PC-based platform consists of commercial-off-the-shelf (COTS) hardware and software such as industrial computers, motion controllers, data acquisiton boards, sensors technology, networking capabilities, development languages and operating system. Wireless networking technology is also being employed in the design to achieve a distributed control architecture for operator mobility during operations. Additionally, the PC-based platform provides the greatest degree of flexibility in satisfying a diverse set of motion control requirements and will help to maintain low maintenance and future upgrade costs.

1. Introduction

The NIF Operations Controls Group is responsible for all control system activities for the NIF Operations Engineering Group, which encompasses both the Optics Assembly Building (OAB) and Transport and Handling (T&H) [1][2]. The primary tasks associated with the support of these groups are designing, fabricating, assembling, integrating, and testing the major electro-mechanical, computer, and software subsystems involved with assembling and installing the NIF LRUs. For example, with regard to the optics installation process, the NIF Operations Engineering Controls Group supports and/or aids in coordinating all the necessary high-level issues (such as information management), and also coordinates low-level control issues (such as motion control and sensor information signal processing). To satisfy such requirements, the NIF Operations Controls Group is in the process of designing and developing the NIF Operations Special Equipment Control System (OSECS).

1.1 OSEC System Description

The NIF Operations Special Equipment Control System (OSECS) is a multi-layered control architecture consisting of a supervisory system layer, a front end processor (FEP) layer, and a low-level device control layer (see Figure 1 below). Layer subsystems or components identified to date include the following:

- Supervisory system layer
  - Transport and Handling Operator Workstations
  - Traffic Management system (vendor supplied)
  - OAB Facility Workstations
  - NIF Information Systems

- FEP layer
  - T&H Controls and Diagnostics
  - T&H Safety Interlocks
  - OAB Controls and Diagnostics
  - Video System

- Low-level device control layer
  - Mechanical, electronic, control, and data processing components required for assembly and delivery of optics to the NIF beamline.

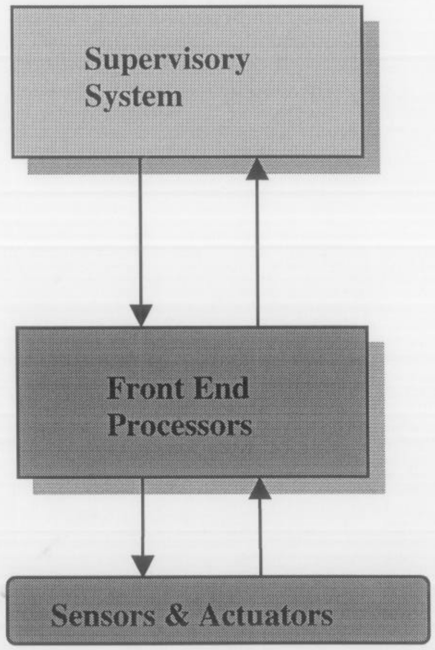

Figure 1. A distributed control architecture provides a modular and extensible design for long term NIF Operations.

The NIF OSECS design uses a distributed control system approach comprised of distributed hardware and software components to safely and efficiently assemble and deliver NIF LRUs. The supervisory layer consists of software modules that provide the general purpose interfaces to other integrated control subsystems and will be used primarily for data communications and control [3]. The FEP layer is comprised of electronic, control and data processing components that actuate motors, sense motions, acquire data, and communicate activity to the supervisory system for archiving. The low-level device control layer is comprised of mechanical subsystems, electronic components, and actuators.

1.2 OSEC System Functions

In general, the OSECS must establish and maintain data communications between NIF Operations Engineering control systems and NIF Information Systems, control of NIF T&H delivery systems, safety interlock monitoring, and control and diagnostics of OAB equipment to assist in the assembly and delivery of LRUs to the NIF beamline (see Figure 2). Operations must be accomplished in a time consistent with planned shot rates. Specific functions of each layer are:

- Supervisory functions
  - Distributed GUI applications
  - Device and automated control
  - Status, diagnostics, alerts

- Data archival and retrieval
- Traffic management
- Interface to FEPs, ICCS and Information Systems

- FEP functions
    - Local operator interface
    - Device control, motion control
    - Primitive diagnostics, alerts
    - Data acquisition/monitoring
    - Control loop logic
    - Interface to supervisory system

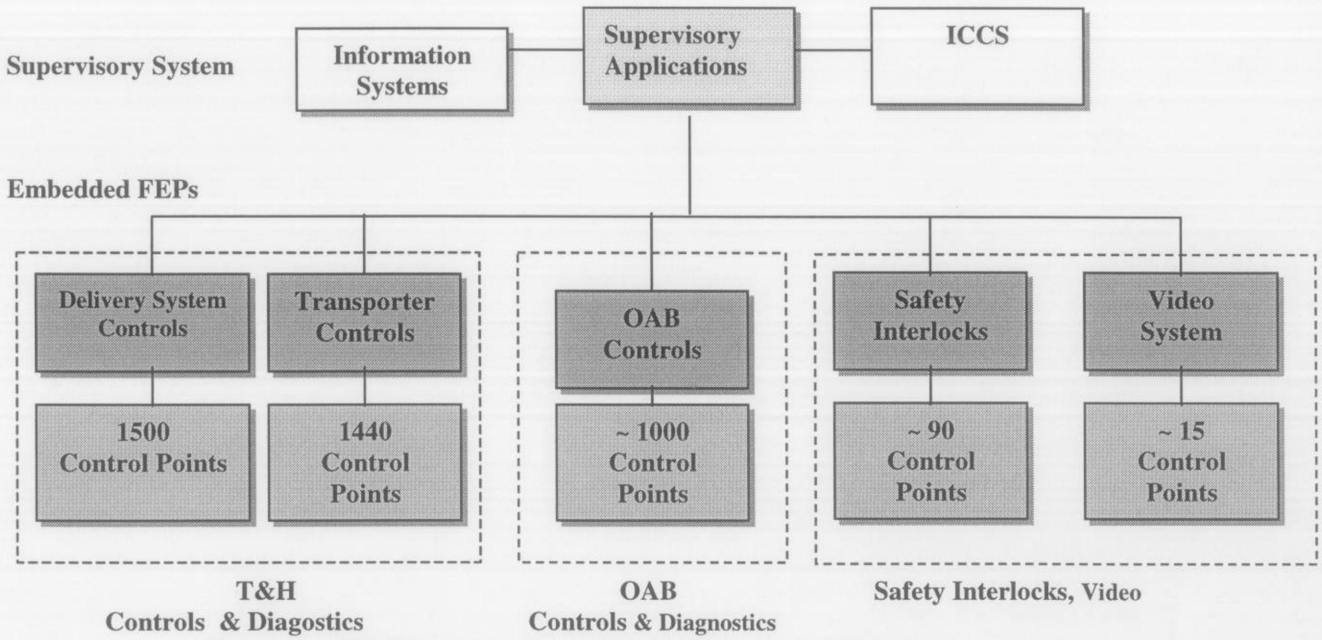

Figure 2. NIF Operations Special Equipment Control System

The remainder of this paper will focus on the design and development of the embedded control (FEP) systems of the OSEC system. More specifically, the paper will focus on the Transport and Handling (T&H) delivery system controls. A description of the delivery systems and their control requirements are discussed and is followed by a presentation of the electronic hardware and the software employed in developing the systems. Current test results and future enhancements are discussed briefly.

2. Delivery System Description

To safely and efficiently deliver and recover the NIF LRUs, we are currently in the process of designing and developing four different types of delivery systems: Bottom Loading (BL), Side Loading (SL), Switchyard (SY) and Top Loading (TL). The system names are derived from the method of insertion or recovery from the NIF beamline. BL units interact with the bottom side of the beamline and push/lower LRUs into/from the beamline structure, SL units interact with the side of the beamline and push/pull LRUs into/out of the beamline structure, SY units interact with external maintenance equipment, and TL units interact with the top side of the beamline and lower/pull LRUs down/up from the beamline structure.

These systems are responsible for transporting and handling a diverse set of NIF optical LRUs. Differences in the optical LRU shape, size, and weight present difficulties in the transport and handling process. Additionally, insertion locations are distributed throughout the facility and impose spatial constraints on the overall physical system envelopes. Nonetheless, commonality in design has been achieved across the four types of systems by employing a canister/skid mini-environment approach consisting of electro-mechanical devices responsible for airflow control, beamline cover removal operations, and insertion/removal tasks [2].

Controlling and monitoring the electro-mechanical devices in the canister/skid mini-environments is the responsiblity of the T&H front end processors (FEPs). The T&H FEPs are required to perform a diverse set of tasks including automated and semi-automated control of LRU insertion/removal processes, motion control, pneumatic control, data acquisition, vision system image processing, diagnostics, error handling, and network communications. Operationally, the T&H FEPs are responsible for controlling and monitoring such tasks as canister docking, cover removal, LRU insertion and removal, and airflow system control and monitoring.

The current system metrics of the the T&H FEP layer indicate the need for 21 FEPs, 100 input/output (I/O) boards, and 2,300 control points. The control points include system devices such as motors, actuators, encoders, sensors, pneumatic solenoids, relays, and I/O devices. Table 1 summarizes the metrics.

Table 1. T&H FEP system metrics

	Metric
Types of T&H systems	4
Number of FEPs	21
Number of I/O boards	100
Number of Control Points	2,300

To cost-effectively meet the diverse set of control requirements presented by the four different types of systems and to improve system integration and maintenance, we have selected a common embedded FEP design across all of the systems. Common hardware and software has been chosen and is being used to perform all operations. The following section describes the selected technologies.

3. FEP Layer System Design

The design of the canister/skid embedded control systems is based on well-established personal computer (PC) technology. PC-based control provides the benefits of improved connectivity, performance, and familiarity. In addition, the popularity and vastness of the PC market make it the most cost-effective solution and has the shortest lead times on needed hardware. Our PC-based control system design utilizes computer hardware components commonly found in PC-based industrial controls applications, including:

1.) Single Board Computer (SBC) Central Processing Unit (CPU),
2.) Motion controller,
3.) Data acquisition boards,
4.) I/O boards,
5.) Communications boards/cards, and
6.) an Industrial chassis with a connection backplane.

Additional electronics components used include:

7.) Sensors,
8.) Connectors and cables,
9.) Drive amps, and
10.) Controls system housing.

Additionally, the following software platforms are used to implement the necessary control algorithms:

1.) Operating System: Windows NT™
2.) Control Software Development Environment: LabWindows CVI™ and the C compiler.

Figure 3 below shows a typical servo control loop found in the canister/skid delivery systems and is applicable to all of the required axes of motion.

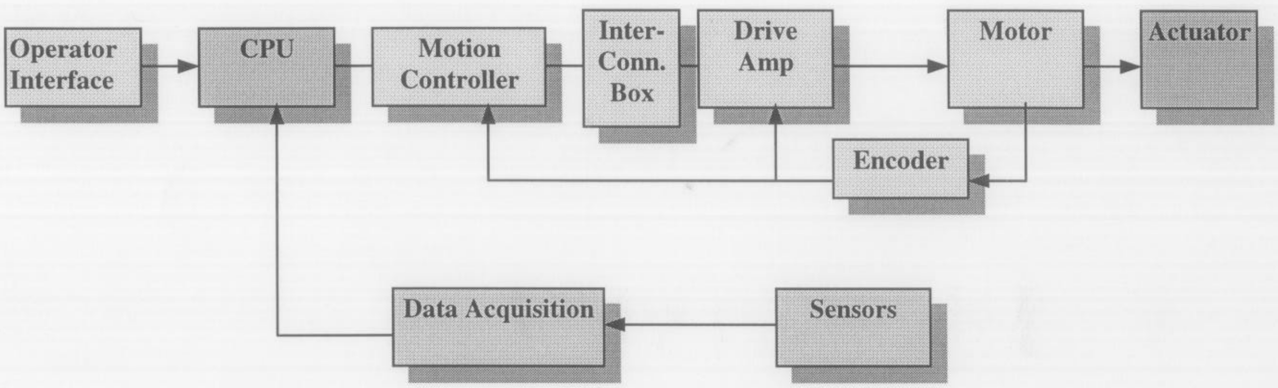

Figure 3. Typical T&H canister/skid servo control loop.

The following discussion contains a brief description of the computer hardware, electronics and software that are used in the embedded control systems.

3.1 Computer Hardware

- *Single Board Computer (SBC)*: The SBC provides the data processing, I/O, and communication capabilities for the control system. The SBC board comes equipped with all of the electronics necessary to function as a normal PC. We have selected a SBC equipped with a Pentium™ CPU (200 Mhz), 128 Mb DRAM, video interface, hard-disk controller, 512 Kb cache, and 4 Mb flash memory.
- *Motion Controller*: The motion controller is responsible for generating the motor control command electrical signals. Typical outputs are voltages that are proportional to the desired speed and acceleration. Components internal to this board include an embedded processor and I/O chips (Digital-to-Analog and Analog-to-Digital converters). A Galil 1780 motion controller is currently being used in the design.
- *Data Acquisition Board*: National Instruments data acquisition (DAQ) boards are being used to obtain the sensor information required for our control algorithms. The DAQ board comes with analog/digital I/O electronic components for interfacing the sensors to the CPU.
- *I/O board*: The I/O boards provide the control signals for general electro-mechanical components (excluding motors) such as solenoids, fans and valves.

- *Communications*: This board provides network communication to the delivery control system. Two boards will be used: one board will provide a wireless communications link and the other will support a direct hardwire connection. Communication will occur to the supervisory system as well as the mobile (operator) computer. We have identified the Proxim RangeLan™ Wireless Lan product and a 3COM Lan card.
- *Industrial Chassis*: An industrial chassis is used to house the electronic hardware described above. The chassis contains an electrical interface bus for data communication across all of the system boards, a power supply, and a hard-disk for local memory.

3.2 Electronics

- *Sensors*: We are currently researching sensor types as per the specified requirements. We have identified load cells, photoelectric proximity sensors, inductive proximity sensors, ultrasonics and limit switches available from different vendors. Cameras still need to be identified for use in the BL system and possibly in the TL and SL systems.
- *Drive amps*: The drive amps convert the motion controller command signals to the proper motor current and voltage requirement levels. We will be using the recommended B8001™ drive amp for the IDC servo motors and the appropriate drive amps for stepper motors (if required).
- *Cables and Connectors*: The cables and connectors required are dependent on the motor and sensor wiring. IDC motors are being supplied with connectors (vs. pigtail) at the motor to allow flexibility in cable and connector design. Hermetic connectors are identified where needed. The current connector approach is to use the feedthrough MS-style connector to ensure good electrical connectivity.
- *Controls System Housing*: All of the electronics hardware mentioned above and the drive amps are being housed in enclosures that are mounted to the canister/skid assemblies. Standard sizes are used where applicable to keep costs and manufacturing time at a minimum.

3.3 Software

- *Operating System*: The operating system is the software program responsible for controlling the communication between all of the electronic boards found in the chassis. The canister/skid embedded control systems are running Windows NT™.
- *Software Development Environment*: LabWindows/CVI™ by National Instruments is currently being used to develop the control algorithms and the graphical user interfaces (GUI) for the systems. The LabWindows/CVI software provides a C/C++ programming environment which allows code generation, run-time debugging, and visual editing. It also comes with a complete library of GUI and communications functions.

The figure below summarizes the development platform for the canister/skid delivery systems.

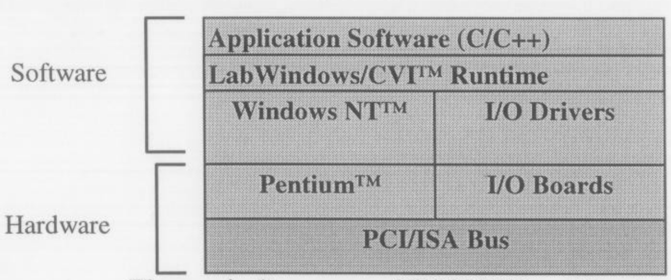

Figure 4. Summary of T&H FEP architecture

4. System Testing

Support of the prototype development of each of the T&H embedded control systems is currently on-going at the Lawrence Livermore National Laboratory NIF Operations prototype facility (see Figure 5). Performance of the PC-based control system architecture has proven successful in meeting the diverse set of motion control requirements. In addition to the testing of motors and sensors, we have been evaluating wireless network links for use in the final control system design and the use of LabWindows/CVI™ in a distributed environment.

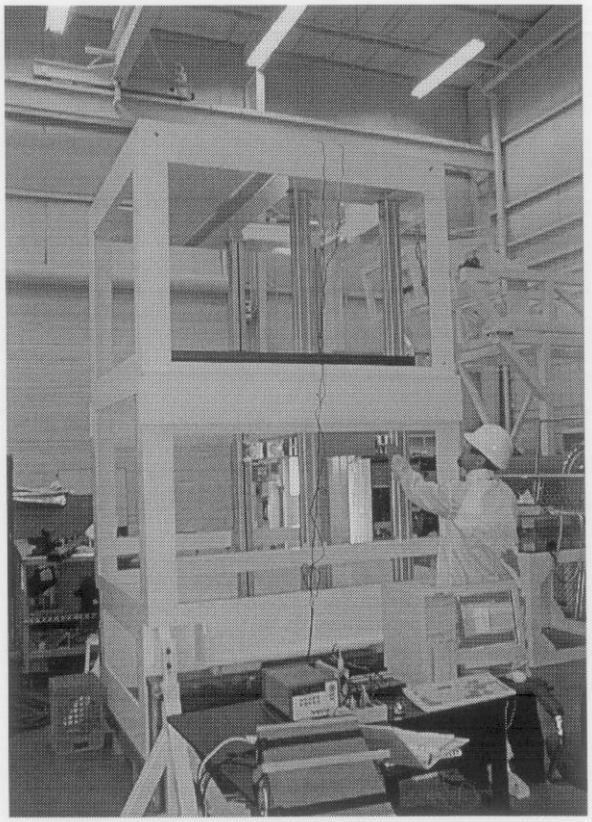

Figure 5. Integrated testing of the Transport and Handling embedded control systems.

The PC-based motion control platform is currently being used to perform motion control testing of motors and actuators prior to assembly and integration into the final prototype systems. To verify the successful operation of the motors and actuators, we are connecting them to existing PC-based motion controllers via the vendor supplied connectors and cables. System performance metrics such as resolution, speed, and latency have all been within acceptable limits.

In addition to the testing of the motion control requirements, tests of the wireless communications links are being done. Wireless connectivity is an additional benefit for T&H embedded FEPs and operator workstations because it is transparent to communications software (uses TCP/IP protocol), provides real-time access to data throughout NIF, and reduces installation and maintenance costs (cable vs. Access points). Additionally, the wireless LAN provides the capability to safely perform remote operations and is scalable to handle increased traffic. Robustness and reliability tests are currently being planned.

5. Conclusions

This paper described the design and development of embedded systems for the remote delivery and recovery of NIF optical LRUs. As part of the NIF Operations Special Equipment Control System, the embedded systems (front end processors) are responsible for a diverse set of control requirements including motion control, pneumatic control, data acquisition, and communications. To meet this diverse set of requirements, LLNL engineers have designed and developed an embedded control system based on common PC component technology that will satisfy all of the necessary requirements. The PC-based control system utilizes common-off-the-shelf components such as single board computers, motion controllers, data acquisition cards, development languages and operating systems. Performance tests have shown a successful integration of the technology into existing prototype systems. Further testing will be performed to ensure robustness and reliability.

6. Acknowledgments

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7. References

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