RAPID SOFTWARE PROTOTYPING INTO LARGE SCALE CONTROL SYSTEMS*

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Abstract

The programmable spatial shaper (PSS) within the National Ignition Facility (NIF) reduces energy on isolated optic flaws in order to lower the optics maintenance costs [1]. This is accomplished by using a closed-loop system for determining the optimal liquid-crystal-based spatial light pattern for beamshaping and placement of variable transmission blockers. A stand-alone prototype was developed and successfully run in a lab environment as well as on a single quad of NIF lasers following a temporary hardware reconfiguration required to support the test. Several challenges existed in directly integrating the C-based PSS engine written by an independent team into the Integrated Computer Control System (ICCS) for proof on concept on all 48 NIF laser quads. ICCS is a large-scale data-driven distributed control system written primarily in Java using CORBA to interact with +60K control points. The project plan and software design needed to specifically address the engine interface specification, configuration management, reversion plan for the existing 0% transmission blocker capability, and a multi-phase integration and demonstration schedule.

INTRODUCTION

In 2010, the PSS devices were installed within NIF to mask optic flaws with programmable black blockers. This has allowed NIF to continue operating until an opportune time to allow the optics to be replaced and/or refinished to eliminate the flaws. It was recognized that this same hardware could be used to correct hot spots in the quad beam profiles through arbitrary beamshaping. This has the potential to increase peak power by 5%-15% due to the final optic intensity/fluence restrictions. It was also recognized that energy could be further increased by using the PSS to place variable transmission blockers (a.k.a., grey blockers) to mitigate shadow flaws that would be lost by using opaque blockers (a.k.a, black blockers).

The responsible scientist for the PSS had developed a software prototype for beam shaping and grey blocker placement using MatLab on a laptop with dedicated camera and PSS hardware. The prototype was successfully demonstrated in a laboratory environment, and on a single NIF laser quad. However, the software architecture and hardware interfaces were not compatible with ICCS. There was still considerable risk in the prototype since it was not qualified on all 48 NIF quads. Several scientific and engineering challenges were identified as part of the prototype design and testing that needed to be addressed prior to approving the software for use during production shots. Qualifying the prototype directly on all 48 quads was not practical as it required several hours of hardware reconfiguration and testing, required re-cabling of commissioned PSS and camera hardware, and could only partially complete the necessary testing to assure quality. Merging the prototype with ICCS was highly desirable to avoid a significant investment prior to proof of concept.

DESIGN AND ARCHITECTURE REQUIREMENTS

The primary focus of the software design requirements was to allow for semi-autonomous updates to the prototype software and to minimize the effort and risks for integration into ICCS. Figure 1 illustrates the agreed upon high-level system architecture with the prototype software process identified as the engine. The existing stand-alone mode operation using dedicated hardware is maintained to allow for rapid updates and testing without the required infrastructure and lengthy release process required for ICCS. Within ICCS, all front-end processors (FEPs) encapsulate and isolate the hardware communication protocol and operating platform from the hardware clients. Interaction with the FEPs is achieved using either Java or Ada95 over CORBA. A C/C++ CORBA object request broker (ORB) interface layer was unproven on NIF. Therefore, obtaining images from the input sensor package (ISP) camera or updates to the PSS LCoS is requested by the engine and supplied by ICCS. An approved configuration management controlled interface specification identifies the messaging format to allow for communication between the two independent systems.

The original prototype software was originally developed using MatLAB. Launching compiled MatLAB software from within the Java based control system has not been attempted within ICCS and would add risk due to this unknown. Therefore, while the supporting ICCS software to run the engine was under development, the responsible scientist ported the engine to C/C++ coupled with OpenCV image processing libraries. The timing and resource allocation of the parallel development activities allowed the porting to remain off the project's critical path.

The engine is its own standalone executable that is launched internally by the ICCS PSS coordinator. Each request to start blocker placement and/or shaping results in a new engine process that would terminate upon completion of its required task or upon failure. Keeping

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the PSS engine as a stand-alone executable rather than using the Java Native Interface (JNI) to directly integrate the two systems maintains the loose coupling of the two systems. Java's removal of pointers, buffer overrun prevention, and bounds-checking makes this software far less susceptible to memory segmentation faults as compared to C/C++ source code. Providing a direct interface to the C/C++ software over a JNI link would have resulted in the entire JVM failing, which would bring down the ICCS PSS coordinator along with the engine process. Keeping the two systems decoupled allows the coordinator to gracefully handle any engine process crashes.

The commissioning process is estimated to take several weeks. During this time ICCS is required to continue supporting NIF operations using the current black blocker capability. Through configuration data changes, ICCS can switch between running the existing black blocker only mode, and the new engine on a per quad basis. The out-of-the-box ICCS configuration uses the existing black blocker capability with the engine disabled.

SOFTWARE DESIGN

All LCoS updates and ISP camera requests between the engine and coordinator are made over the standard out and standard in streams. Each message requires a response, either the requested image or a completion status. The Portable Network Graphics (PNG) format was used for the 1920x1080x16bit LCoS masks as it is a lossless compression format, and has image processing libraries available within Java and C/C++. TIFF is the ICCS standard format for images and was selected to store the 1392x1040x16bit ISP camera images and the requested beam shaping masks. All images are stored and accessed directly from the file system with the image locations passed either on the standard streams or specified within configuration data files. Stderr is used to provide engine status updates and result status. All communication with the engine is logged in the coordinator's ICCS log files which are retained for troubleshooting.

PSS hardware variances is one of many variations that need to be addressed on a per laser quad basis. To address these variations, several parameters used for tuning the filtering, loop feedback gain, thresholds, etc. were stored in individual configuration controlled data files. ICCS stores the NIF hardware configuration, along with operating parameters and sequences as adaptable data within an Oracle database. By using data files for the engine, it again isolates the engine from ICCS but still maintains configuration management requirements on the data.

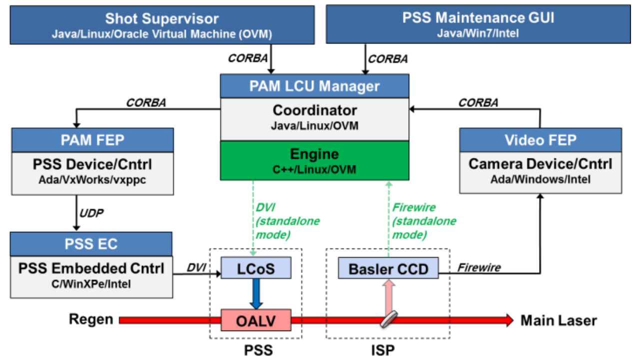

Figure 1: PSS system layout.

CONFIGURATION MANAGEMENT

Both the engine and ICCS source code are controlled using the Accurev software configuration management application. Both products are stored within their own product streams to support parallel and distributed software development. Quad based configuration data files are also stored within the CM system.

Software change requests are tracked within the Jira software product which provides customizable workflows for the creation, resolution, delivery, and verification of issues. ICCS and engine software changes are tracked as separate projects within the Jira product. Issues are linked to Accurev version history to provide full traceability of resolved issues to modified source code.

Except for changes to documented interface dependencies, each system follows their own independent release cycle. This allows for rapid correction to beam shaping and blocker placement functionality outside of the ICCS's extended release cycle which is the result of its size and highly integrated software architecture. NIF has strict configuration management control and work control processes within the facility due to various personnel and machine safety hazards. Both ICCS and the PSS engine are compliant with these work control processes, and allow for graded approaches for deploying minor patches vs. major releases of the software. A formally controlled checklist is utilized for work authorization in regards to turning on the engine within the NIF facility for both commissioning and production experiments.

PROJECT PLAN

The development of the integrated products consisted of parallel development tracks for both ICCS and the engine. A stubbed version of the engine was used for unit testing of the ICCS PSS coordinator. The engine was tested in stand-alone mode in a laboratory using dedicated video and PSS hardware.

A failure mode and effects review identified any possible failure modes and their intended impacts on NIF operations. The consequences of failure resulting from a software failure included the loss of a production shot due to lower than expected, and non-uniform energy delivery to an ignition target, and damage to optics within a quad

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of lasers. The primary mitigation for the identified risks is verification of the resulting energy profile following non-amplified rod shots by the Laser Performance Operations Model (LPOM) software [2].

A high-level design review of the beam shaping and blocker placement algorithm was held with the responsible scientist, and image processing subject matter experts. After approval of the design and near code completion a code walkthrough of the PSS engine source code was held. Several image processing, FEP, PSS, and other ICCS developers participated. Issues pertaining to reliability, maintainability, and product integration were identified, documented, and addressed prior to final integration of the systems. A thorough final system design review was held with all stakeholders and technical experts to approve the system for commissioning within NIF.

System integration was performed within the laboratory environment following the installation of the required infrastructure to support a minimal ICCS configuration to run the PSS.

Commissioning and approval for use of the PSS engine on all 48 quads is broken into four phases each with their own work authorization checkpoint. The first two checkpoints are to authorize the engine for use during manual and automated low-energy system shots within NIF. Authorization requires that all actions taken from the previous design reviews are complete, and to assess operational readiness. The final two checkpoints authorize beam shaping and grey blockers for operational use during NIF production experiments following the successful completion of the commissioning test procedures.

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CONCLUSIONS

The implementation of the PSS spatial shaping and grey blockers is currently starting its commissioning phase within the NIF facility. The ability to insert the prototype engine into ICCS has been critical in being able to quickly take a scientist's implementation of these capabilities and insert them into a production environment for qualification. The loose coupling of the systems allows for rapid changes to the algorithm directly from the subject matter expert. A similar development model is being used for additional enhancements to NIF's diagnostic capabilities that are currently in the requirement definition phase.

To support future maintenance of the engine by the ICCS development team, the engine is scheduled to be ported into the ICCS architecture and design once the engine's algorithm has been successfully qualified. This was necessary to ensure that the software matches the skill set of the development team that is responsible for supporting NIF over its thirty year lifespan.

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