



Case Study

Liquid Fueling Facility Control System

Developed for Wallops Flight Facility/Virginia Spaceflight Authority

Case Study – Wallops Liquid Fueling Facility Control System

Introduction

CCT recently completed delivery of a portable Liquid Fueling Facility control system to the Virginia Spaceport Authority through NASA Wallops Flight Facility. This system will be used by the spaceport authority to provide LOX, LN₂, and high pressure gas control capabilities in support of potential commercial launch vehicle that will operate from the facility. The primary goal of the system was to provide a minimum configuration that could control LOX and LN₂ processes in a safe and accurate manner. The system provided all stated requirements for under \$80,000 with a delivery schedule of about 30 days.

Problem Overview

Inert gas and cryogenic operations utilizing LOX, LN₂, and helium can often be performed manually with safely designed equipment and thoroughly trained personnel. However, the unique requirements of the presence of LOX, kerosene, and unmanned rated pressure vessels increase the need to contain safety risks. Cryogenic ground operations must be designed to minimize human exposure to potentially hazardous operations utilizing sound practice and automation for such capabilities as remote control and emergency shutdown and safing. The Liquid Fueling Facility (LFF) Control System is designed to address this need by providing a means of remote control of liquid fueling operations.

The LFF Control System provides a turnkey solution for control and monitoring of operations of the LFF. The LFF Control System is composed of Phoenix Contact hardware for low level data acquisition and control, a Panasonic Toughbook laptop for hosting the control system software (referred to as the “Host PC”), and the Command and Control Toolkit™ as a framework for the control software.

Although this is a custom system, it is largely based on the Command and Control Toolkit™

software. The Command and Control Toolkit™ product is a data acquisition and commanding software package that can be tailored to a wide range of command and control applications. The product, also known as CCTK, provides a customizable client/server environment designed to meet the performance requirements of mission critical command and control operations. The CCTK client/server environment can be easily expanded from a single display console to any number of networked display consoles.

LFF Control System Overview

This section provides an overview of the LFF Control System architecture and its major hardware and software components.

Control System Architecture

The control system architecture integrates LFF active fueling operations under one coherent system that can be controlled locally or remotely via a single laptop. The laptop, designated as the Host PC, hosts the control system software that continuously monitors and controls LN₂/LOX tanks and pumps, pre-chiller, and vehicle tanks via integrated sensors and effectors. Automated sequences provide for fueling, de-fueling, emergency shutdown, and safing to be performed autonomously or via human in the loop.

A modular control system design is used to accommodate LFF reconfiguration and expansion, such that addition of new I/O or automation requirements will not significantly alter the system architecture.

Figure 3 below describes the control system architecture. It is comprised of two major subsystems: the Host PC, and the System Control Interface Unit (SCIU). The two subsystems are integrated together via the remote or local control network.

Hardware Components

As shown in Figure 3, the major hardware components consist of the following:

- Host PC
- System Control Interface Unit (SCIU)

- **Networking**

This sub-section provides a brief description of each hardware items listed above.

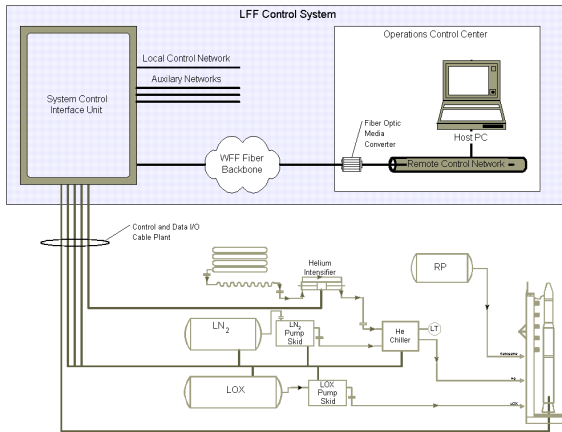


Figure 1 Control System Architecture

Host PC

The Host PC is based on the Panasonic Toughbook™ 72 shown in Figure 4. It hosts the primary control and monitoring software described below.

The Toughbook model is a semi-rugged laptop PC that will provide for both local operation at the LFF, and desktop operation at the remote operation control center. Some of the major features include:

- Daylight-readable display
- Spill-resistant keyboard and touch pad
- Magnesium alloy LCD case and inner chassis with carry handle
- 1.8 GHz Pentium 4 processor
- 256 MB SDRAM
- 30 GB Hard drive
- DVD / CDROM drive
- 13.3" 1024 x 768 (XGA) TFT active matrix color LCD
- USB Optical Wheel Mouse and Keyboard Touch Pad



Figure 2 Panasonic Toughbook Control Computer

System Control Interface Unit

The SCIU houses the low level I/O electronics that interfaces directly with sensors and effectors located throughout the LFF. It also interfaces to the Host PC via standard Ethernet communications. The SCIU is based on the Interbus™ SCADA product line from Phoenix Contact Corporation. The SCIU is contained within a NEMA 4X weatherproof enclosure that is mounted on the LFF control trailer. The SCIU enclosure assembly is shown in figure 5 below.



Figure 3 SCIU Assembly includes all I/O Points and power conditioning

Major features of the SCIU include:

- Hoffman NEMA 4X stainless steel enclosure
 - 48 x 36 x 8 dimensions
- Low level analog and digital I/O
 - 24 Digital Input signals that support sensing LFF switch and control relay closures
 - 14 24VDC Digital Output signals that provide end-item control commands

- 2 Analog Output signals that provide speed control for AFD motor drives
- 17 Analog Input signals that support monitoring of pressures, temperatures, tanks levels, etc.
- Isolation and surge protection for each digital and analog I/O point
- Supports 50% I/O expansion and is field modifiable
- Supports fiber optic and local 802.3 control network interfaces
- Auxiliary network expansion

Note: Interbus is commonly referred to as "IBS" in this document.

Networking

The Host PC and the SCIU communicate using standard network communication protocols. Both fiber optic and copper physical transports are supported enabling both remote and local LFF communications.

The fiber optic interface will support 100 Mbit/s network connectivity distances over 10,000 meters using 1300nm wavelength single mode fiber with less than .7db fiber attenuation (see Phoenix Contact FL Switch 4TX/FX technical reference manual for specifics).

A 100 Mbit/s Omnitron 4333-1 Flexpoint 100 Fx/Tx fiber media converter, shown in Figure 6, is provided to convert remote fiber back to standard Ethernet copper media at the remote Host PC (See Flexpoint 100 User Guide and Specification documentation for details).



Figure 4 Flexpoint 100 Fiber Media Converter

A standard RJ45 copper Ethernet interface connection is built in to the side of the SCIU for convenient access during local LFF operations. In addition the SCIU contains one auxiliary 10/100 Base T Ethernet port that provides future expansion connectivity. The auxiliary port may also be optionally used for local operation.

Software Components

The LFF Control System software is primarily composed of COTS software products, such as CCTK, and Linux; but it also contains LFF-specific customization for LFF operations support including graphical displays and automated sequences. Graphically represented in Figure 7, this sub-section discusses each these major software components in more detail.

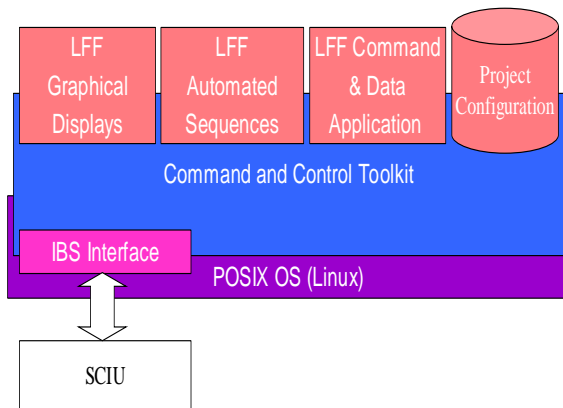


Figure 5 Major LFF Software Architecture Components

Command and Control Toolkit™

CCTK provides the architectural framework and supporting services for the LFF control system software and runs on the Host PC.

The CCTK product is a data acquisition and commanding software package that can be tailored to a wide range of command and control applications. The product provides a customizable client/server environment designed to meet the performance requirements of mission critical command and control operations. The CCTK client/server environment can be easily expanded from a single display console to any number of networked display consoles, although only one display is required for LFF operations.

CCTK provides the following major functional features for the LFF control system:

- Interbus (IBS) SCADA interface supports data acquisition, and end item commanding using commercial I/O components and industry standard protocols.
- Built in applications for visualization and control such as user configurable quick look displays, messaging, and health monitoring.

- Optional user development environment for customization that includes C/C++ CCTK programming library, scripting environment based on Tcl.
- GLG GUI builder for creating dynamic graphical control and monitoring displays.
- An integrated simulation environment that supports user application development, missing element modeling, and user training scenarios.
- Master time acquisition, synchronization, distribution, and general-purpose user timer.
- Modular data processing scheme that allows processing algorithms to be dynamically chained together and extended with user custom modules.
- XML configuration databases for management of interfaces, commands, measurements, and resources in an open, extensible manner.
- Digital command, measurement, and message recording, and retrieval for post mission data reduction and analysis.

LFF Control System Custom Software

The LFF custom software components include graphical displays, automated sequences, and specialized command and data applications. In addition, a Project Configuration database serves as a repository for managing mission-to-mission configuration parameters.

The graphical displays are all built using the GLG™ graphical builder from Generic Logic Corporation. GLG is integrated with CCTK to enable graphic widgets to be linked to real-time data and commands, such that the sensors and effectors from LFF end-items are logically bound to dynamic widgets on the displays. For example, data from temperature and pressure sensors can be linked to graphical dials and gauges, or push buttons can control the position of a flow valve or speed of a pump. Figure 8 shows some example LFF Control Systems displays. The LFF Host PC provides a menu of display options for the control system operator that includes interactive control and monitoring of LOX, LN2, and Helium systems as well as control of automated sequences. In addition to a menu of displays, each graphical display contains a common head-up display panel that presents general go/no-go status for all systems

and emergency safing controls. Refer to the GLG and CCTK User Manuals for more information on building and using graphical displays.



Figure 6 Example LFF Graphical Displays

The LFF automated sequences were created using the CCTK C/C++ application development environment. The LFF automated sequences include:

- LOX fill and drain – Automatically fills and drains the vehicle LOX tank and initiates safing sequence if critical limits are violated.
- Emergency Safe – Initiated by automated sequences or human operator. Automatically returns all effectors to safe state.
- Shutdown – Automatically returns all effectors to normally un-powered state.

The LFF custom software includes a specialized command and data application that supports the future addition of command interlocks when they are eventually defined. It also provides for derived calculations of the data such as pump differential pressures. Like the LFF automated sequences, it is built using the CCTK C/C++ application development environment.

CCTK is a generic, re-configurable tool that can perform a variety of control and monitoring tasks. Information describing a particular configuration is captured in a persistent repository called the configuration database. Each instance of a configuration is identified as a “project”. The LFF Control System includes a predefined LFF project that supports control system operations and includes definition of all data acquisition decommutation information, data, commands, data processing, linearization coefficients, etc.

Linux Operating System

The Host PC software is built on top of Linux Red Hat 7.3 along with the KDE 3.0 graphical desktop. The KDE graphical desktop is functionally similar to Microsoft Windows. Any user with a working knowledge of the Windows desktop should be able to use the KDE desktop without special training.

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