

Retrofitting the Canada-France-Hawaii Telescope for remote operations

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ABSTRACT

In 2007, the Canada-France-Hawaii Telescope (CFHT) undertook a project to enable the remote control of the observatory at the summit of Mauna Kea from a control room in the Headquarters building in Waimea. Instead of having two people operating the telescope and performing the observations from the summit, the goal of this project was to allow one operator to remotely control the observatory and perform observations for the night.

CFHT has now transitioned to routine remote operation of the observatory. This required the development of tools for remote assessment, monitoring, notification, and control of observatory systems that are necessary for observing and other critical observatory functions. Many changes were needed to allow remote operations of an observatory that was designed without that intent.

This paper will describe how systems engineering concepts have shaped the design of the project structure and execution, as well as some of the resulting changes to observatory systems that were implemented.

Keywords: automation, remote operations, remote observations, systems engineering

1 INTRODUCTION

The Canada-France-Hawaii Telescope is a non-profit organization that operates a 3.6m telescope atop Mauna Kea. The Observatory headquarters are located in Waimea (also known as Kamuela). The OAP was an undertaking to augment the efficiency of the observatory by implementing remote observing capabilities. This has enabled the replacement of the previous two person night shift at the summit, Observing Assistant and Service Observer, by a single Remote Observer operating from the remote observing room in Waimea. Routine Waimea based remote observations were implemented in early 2011 in a manner that had minimal impact on the robustness and reliability of the operations at the summit with no compromise to the safety of the personnel.

A systems engineering approach was taken for this project to ensure that changes made to existing mechanical, electrical, hydraulic, software, and control systems would be smoothly integrated while maintaining operations each night. One of the main goals of the project was to implement remote observing without requiring any down time.

2 APPLICATION OF SYSTEM ENGINEERING CONCEPTS

2.1 Scope

The OAP addressed the science and technical requirements of all systems required for remote operations. This allowed the observatory to operate with more efficient use of resources without compromising science goals.

The project included the development of tools for remote assessment, monitoring, notification, and control of observatory systems that are necessary for observing and other critical observatory functions. It is assumed that remote operations will only be provided with instruments that do not require nighttime physical intervention. This includes the

instruments that are operated by the Queue observing system, including MegaCam, WIRCam, and ESPaDOnS, as well as any future instruments that have been designed to meet remote operating requirements.

2.2 Requirements analysis

As is the first step to solving any problem, it was first necessary to understand exactly how remote operations would impact the operation of the various observatory systems and what remote control and monitoring would be required. The requirements identified were prioritized and the scope was solidified. Managing the scope was important to ensure feature creep did not negatively impact the implementation schedule. The focus was on modifications to the systems that were needed for remote operations. While this did improve several of the systems, this project was not to be used as an opportunity to further enhance existing systems.

With the requirements signed off, they were allocated into functional building blocks. In this case, twenty-one subsystems were identified and mapped to the requirements they would satisfy as listed below.

1. Audio and Video Subproject
 - a. Record and archive video
 - b. Audio and video monitoring in critical areas
2. Compressed Air System Subproject
 - a. Monitor pressure, flow and temperature of dry air system
 - b. Control of compressors, including automatic starting and switch over to backup system
3. Dome Drive Hydraulics System Subproject
 - a. Remotely monitor dome drive hydraulics
 - b. Remotely control dome drive hydraulics
4. Dome Louvers Subproject
 - a. Remotely monitor dome louvers
 - b. Remotely control dome louvers
5. Dome Shutter Subproject
 - a. Remotely monitor dome shutter position
 - b. Remotely monitor health of shutter motors, drives, and cable reels
 - c. Remotely control dome shutter
6. f8 Remote Monitoring and Control Subproject
 - a. Remotely monitor f8 secondary mirror
 - b. Remotely control f8 secondary mirror
7. Fifth Floor Entry Monitoring Subproject
 - a. Ability to identify if anyone is in dome
 - b. Prevent entry of unwanted guests
8. Fire Alarm System Subproject
 - a. Remotely monitor fire alarm system
9. Mirror Chilling System Subproject
 - a. Remotely monitor primary mirror chilling
 - b. Remotely control primary mirror chilling
 - c. Eliminate need to disconnect cooling hose from telescope
10. Mirror Covers Subproject
 - a. Remotely monitor position of mirror covers
 - b. Remotely monitor mirror cover pneumatic system
 - c. Remotely control mirror covers
11. Panel F Subproject
 - a. Remotely control reset in case of power failure
12. PLC Infrastructure Subproject
 - a. Integrate PLC control systems
 - b. Standardize PLC software and hardware development
13. Primary Mirror Support Monitoring Subproject

- a. Remotely monitor primary mirror electronic and pneumatic systems
14. Remote Control of Lights Subproject
 - a. Remotely turn off lights that could impact observing
 - b. Remotely turn on/off lights for building checks or troubleshooting
15. Remote Operating Environments Subproject
 - a. Modify summit observing room to facilitate remote operations
 - b. Modify headquarters observing room to facilitate remote operations
16. Remote Telescope Control System Subproject
 - a. Remotely control telescope console controls
 - b. Remotely control Cass Guider Camera for ESPaDONs
 - c. Remotely monitor and control f8 focus
 - d. Remotely monitor and control telescope locking pins
 - e. Remote emergency stop
17. Software Infrastructure Subproject
 - a. OAP control server
 - b. OAP control GUI
 - c. Front door status screen
 - d. Autonomous shut down
18. Standard Operating Procedures Subproject
 - a. Document operating procedures with Observing Assistant and Service Observer
 - b. Define Remote Observing position
 - c. Provide observing scenarios for test cases
19. Telescope Hydraulics System Subproject
 - a. Remotely monitor and control telescope hydraulic system
20. Weather Sensing Subproject
 - a. Provide information on summit environmental conditions remotely
 - b. Identify precipitation
 - c. Identify dust or particulate
 - d. Identify temperature, humidity and wind
21. Windscreen Subproject
 - a. Remotely monitor windscreen
 - b. Remotely control windscreen

2.3 Subproject lifecycle

A team was assembled to address the design of each of the subsystems, with a lead engineer assigned to oversee the subproject. Figure 2 illustrates the lifecycle that each subproject followed. There are many examples throughout this project that demonstrated time invested in the early design phases was essential in managing the many interfaces between systems and resulted in no rework or redesign. Careful planning in the implementation and installation phase of each project allowed the changes to be made during the day with a working observatory each night.



Figure 1. Subproject lifecycle

Design documents define the design and assist in the review process. These documents evolve through the lifecycle of the subproject and are living documents that are maintained in the company wiki. They typically contain the following information:

- Overview
- Requirements

- As is documentation - schematics, drawings, as appropriate
- Design alternatives – “to be” options from which one is chosen for the detailed design
- System design
- Interface definition
- Implementation and test plan
- Draft spares list
- Safety implications
- Time and resource estimates

2.4 Project planning

The OAP was managed by a systems engineer/project manager. A detailed work breakdown structure (WBS) provides the coordination between the subprojects and maintains the overall schedule and resources.

To assist with costing and time estimation, similar projects were used to help establish a realistic WBS. As subsystems were completed, the estimates for upcoming subprojects were refined and the WBS updated.

2.5 System integration

At the systems level, as each subproject completed its subsystem level testing it moved into integration with the OAP environment. Standard Operating Procedures were examined to identify where there are differences between operating the observatory from the summit and operating remotely. Use cases and test plans were developed from the operating procedures to guide testing that was representative of nighttime operations.

2.6 Risk management

Risk management is another systems engineering task that guided the development of the project. To be able to accurately assess the impacts of having no staff at the summit during the night, a log of all technical issues that required summit intervention in the previous 18 months was compiled. The risk of needing similar interventions had to be avoided, controlled, accepted or transferred. Avoided means that the issue is addressed through additional functionality provided by one of the OAP subprojects. Controlled means that changes made through OAP have reduced the risk imposed by the issue to an acceptable level. In some cases, the risk is simply accepted either because the occurrence is very low or the issue will require a trip to the summit regardless. A risk outside the scope of OAP is transferred to the appropriate group to be addressed.

3 RESULTS

An incremental implementation of remote capabilities resulted in a smooth transition to routine remote operations, which began in February 2011. After successful system testing of each subsystem, it was integrated into the OAP environment. Once it was accepted, the system was operated in its remote mode during nighttime operations. This provided our Remote Observers the opportunity to gain experience with the new monitoring and control of the systems, and allowed technical staff to identify any outstanding issues well in advance of operations from the headquarters. The addition of one system at a time has also allowed a gradual transition that has proven to aid in a smooth adjustment to changing job duties and operating procedures. During the final period of summit operations, the Remote Observer operated all of the systems in their remote mode from the control room, just as it would be done from Waimea.

The following subsections highlight some of the significant changes to observatory systems that will enable remote operations.

3.1 OAP software architecture

The following figure illustrates the overall system architecture for the Observatory Automation Project (OAP) from a high-level control perspective. The arrows in the diagram serve to illustrate how information flows between the different components. The shaded blocks in the diagram illustrate the subsystems and pieces of software that were created as part of this project. A brief overview of the primary components is included in the following sections.

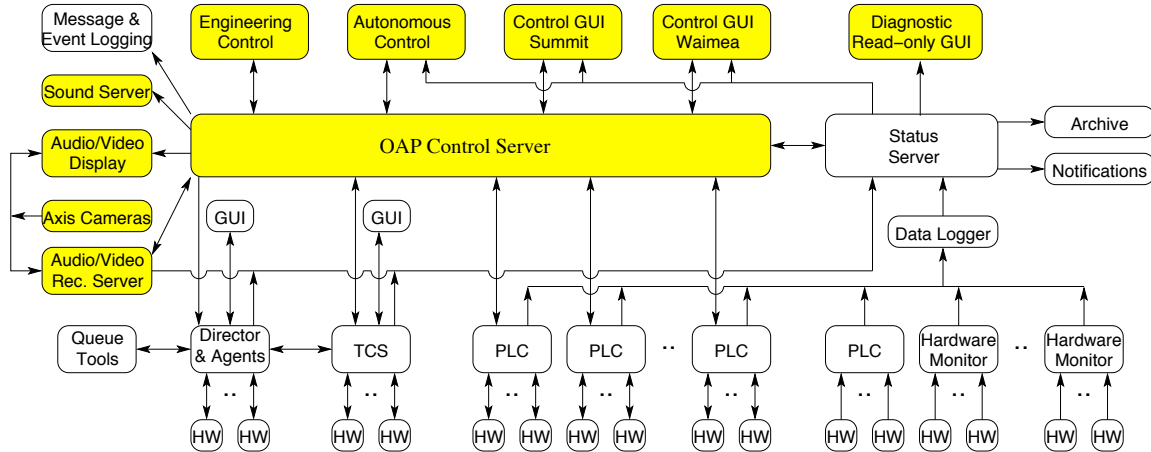


Figure 2. Software architecture

3.1.1 Control Server

The Control Server receives commands over a TCP/IP socket connection. These commands are used to trigger a change in the low-level hardware. Commands to the Control Server can be received from any one of the following systems.

- Waimea Control GUI
- Summit Control GUI
- Telescope Control System (TCS)
- Autonomous Control Client
- Engineering Control Interface

By centralizing the control of the hardware into a single software component it is much easier to manage the business rules and interactions between systems. For example, if a request is made to perform an end-of-night shutdown the Control Server interacts with the various systems to ensure that operations are performed in the correct sequence. In addition, the Control Server initiates the necessary audio/video recordings and camera manipulations in order to help the observer follow what is happening.

3.1.2 Autonomous Control

When remote observing is in progress, there may be situations where communication is lost between the observatory and the Waimea remote observing room. In such a situation there is no guarantee that the weather will remain good until communication is re-established. As a result, safeguards must exist to close the dome and protect mirror, telescope, and observatory in such a situation. The box, shown in the diagram as “Autonomous Control”, contains a set of pre-defined business rules dictating whether an autonomous closing situation is warranted and sends commands to the Control Server to request an observatory shutdown sequence, if necessary. The triggers for autonomous shutdown include high humidity, precipitation, wind, time of day, and network or power loss.

3.1.3 Control Graphical User Interface (GUI)

A user interface is available in order to control the various systems necessary for remote observing. In addition to providing control capabilities, the GUI also provides status information to indicate the current state of the various subsystems. Status information is also available for those systems that are only monitored and not controlled. The GUI has been standardized to use the same colors, status states, and a consistent look and feel for each system.

The control GUI is available both at the observatory and the Waimea remote observing room. However, only one GUI may have full control at a time. The figure below shows the GUI tab that is used to monitor entry into the dome.

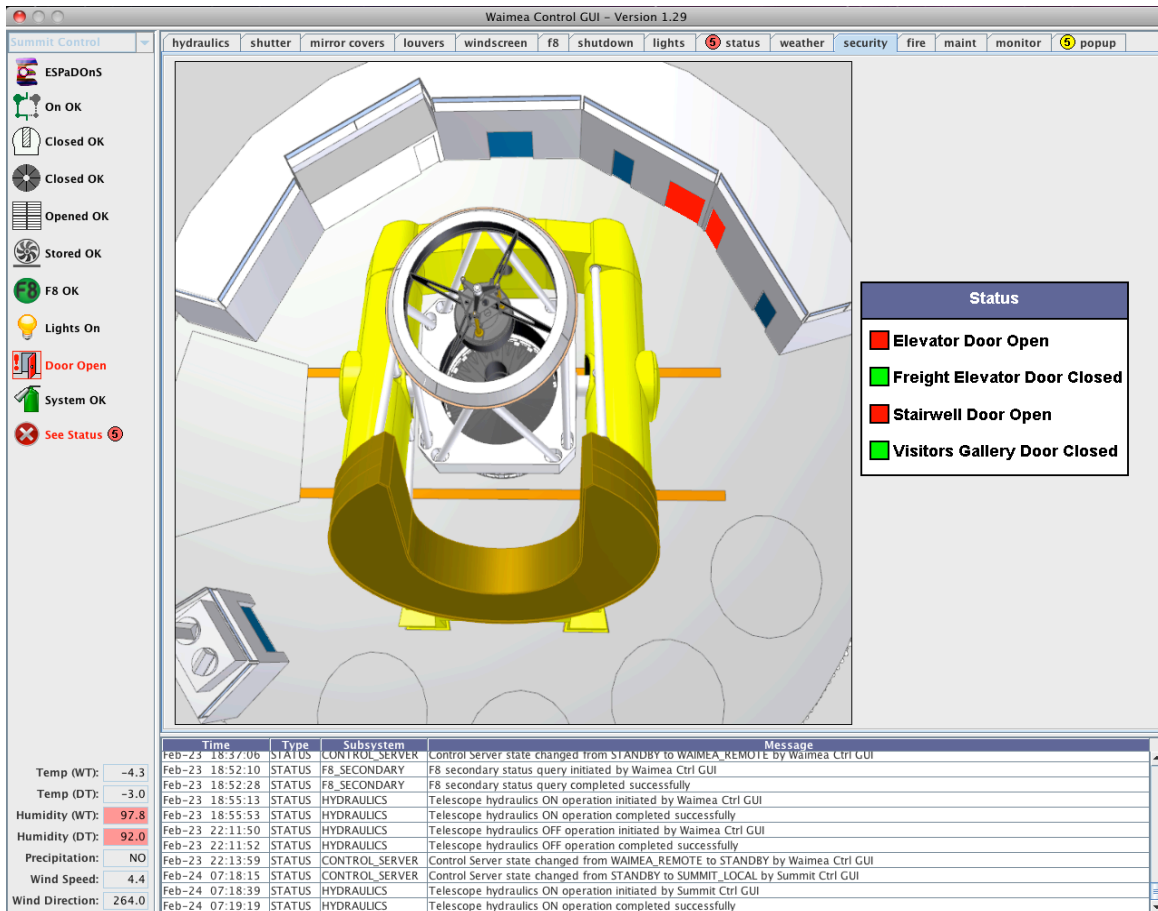


Figure 3. Control GUI

3.1.4 Status Server

The Status Server is a repository of status and state information. With the change to remote observing, the Status Server is used to hold status and state information for the various subsystems that are controlled and monitored via the OAP. In some cases, the hardware or controlling subsystems pushes information out to the Status Server and in other cases a bridging process is used to transfer information into the Status Server.

The advantage of storing information in the Status Server is that it becomes possible to leverage the existing infrastructure used for archiving and plotting of data. In addition, a notification engine exists to monitor Status Server objects and generate alerts based on either time or value based rules.

3.1.5 Audio/Video Recording Server

The Audio/Video Recording Server records both audio and video information from Axis brand video cameras and video servers. Before hardware operations are initiated, the Recording Server is instructed to start recording from one or more audio/video devices. The Recording Server was designed to generate time-lapse recordings from still images as well as recording MPEG-4 streams.

3.1.6 Audio/Video Display

A dedicated display was developed containing all the available camera views. The display allows the remote observer to choose and manipulate a particular camera. In addition, the current view is automatically modified whenever an operation is initiated via the Control Server. A screenshot of the camera display is shown below.

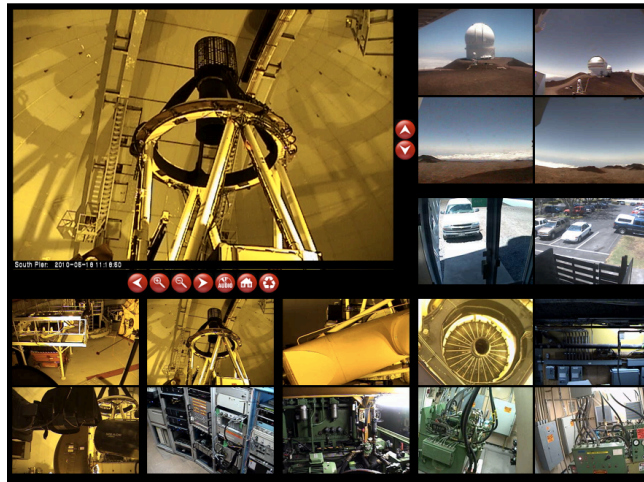


Figure 4. Camera display

3.2 Summit and Remote Operation

It must be possible to operate the observatory both from the summit and Waimea. For safety reasons it is very important that the operation of the facility from Waimea be prevented whenever remote observing is not desired. In addition, it is very important that the facility is only controlled from one place at a time.

3.2.1 OAP Observing States

A set of states was defined for the Control Server. The following state diagram indicates the possible states that the Control Server can be in. The diagram also indicates the transitions that are allowable from both the Summit Control GUI and the Waimea Control GUI. The labels corresponding to the lines on the diagram are control points for allowable state changes.

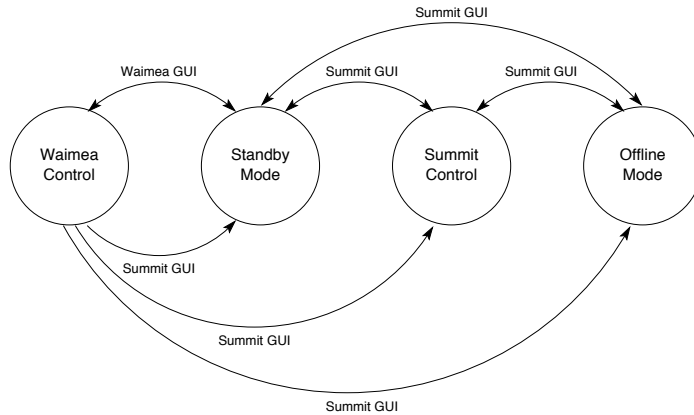


Figure 5. Control states

As one can see from the diagram, the options for changing state from the Waimea Control GUI are somewhat limited. This is important, because it can help prevent an inadvertent activity from being initiated remotely. While this protection is not designed to replace lockout/tagout, it is designed to allow the summit personnel to completely take over control of the facility. The diagram also helps illustrate that if remote observing is to take place after personnel have been at the summit, the Control Server state must be set to standby mode. If it is not set to standby mode, it will not be possible to observe remotely without some form of manual intervention.

3.3 Observing Environments

The design philosophy for the summit control room modifications and the remote control room design was to make the observing environments as similar as possible to ease the transition between the two. Modifications to the summit control room included the addition of status screens, and the addition of the OAP console. The remote observing room in Waimea gained the same status screens, an emergency stop button that is connected directly to the summit, and OAP, Instrument, and TCS consoles for the Remote Observer to work with. The figures below show views of the observing environments.



Figure 6 (a) Summit control room



(b)Waimea control room

3.4 Mirror covers

The first system to be modified in preparation for remote operations was the mirror covers. The existing system was operated by a push button from the summit control room. It was based solely on a timer relay and did not take into consideration the status of individual mirror cover leaves; that sometimes resulted in the system getting out of sequence and jamming.

The changes required for remote operation of the system resulted in improvements to the control system. Limit switches were added to each of the mirror covers and the control system was upgraded to a Programmable Logic Controller (PLC) that utilizes the status of the leaves as opposed to simply waiting a specified time. Much more information is now available on the system, and a web camera was installed to provide a remote view of the system, so that the operator now has a much more complete understanding of the status and operation of the system.

The implementation of the system was planned in a way that allowed work on the system during the day, while still providing a fully operational system each night. The successful completion of the design phases, testing and implementation, and transition to regular nighttime operation set the example for each of the subsystems to follow. For almost 2 years, normal operation of the mirror covers has been via the OAP GUI, and the modifications have greatly improved the reliability of the system.

3.5 Dome shutter

The existing system was operated from a local control panel at the mezzanine level located next to the dome shutter. Remote operation of the shutter was required, including remote monitoring to replace the eyes and ears of the local operator. The implementation included an upgrade to the PLC, the addition of voltage/current sensors to profile and map the health of each of the shutter drive motors, and zero-speed limit switches on the cable reels to assist in determining the shutter position and detect a malfunction in the cable reel operation.

Automatic audio and video monitoring system records each opening and closing of the shutter to provide feedback to the operator during these motions and provide additional information when troubleshooting any problems.

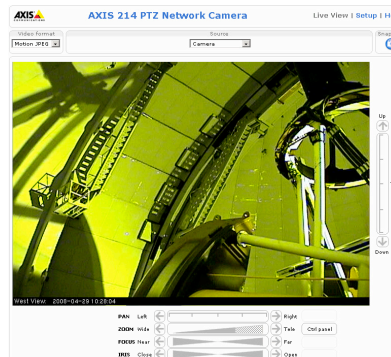


Figure 7. Example of audio and video feedback

A phased approach was taken to integrate the remote operation of the dome shutter into regular nighttime operations. This allowed the Remote Observers the opportunity to gain experience with the differences between the remote operation and monitoring and controlling the system at the local panel. After the system was tested at the engineering level, for a period of time one of the night staff operated the shutter from the summit control room as the other person monitored the movement from the local panel location in the dome. Once it was determined that the remote system was providing the right information for safe and reliable operation of the dome shutter, it was released for regular remote operation. The system has been functioning reliably for many months in remote mode. An additional benefit that has been realized is a better understanding of the health of the dome shutter drive units, which has improved the maintenance schedules for the system.

3.6 Weather sensing and environmental monitoring

The ability to accurately sense the weather conditions on the summit from the remote observing room is critical to the successful and safe operation of the telescope. Without the ability to step out onto the catwalk to assess conditions, the Remote Observers need instrumentation that informs their decisions about opening and closing the dome and observing strategies. This project included the installation of additional sensors and the collection of the information from all the sensors into a status page in the OAP GUI.

The weather sensors installed include those to sense: wind speed, wind direction, relative humidity, air temperature, precipitation, barometric pressure, and temperatures of various surfaces of the dome. The Remote Observer also has other tools available to help assess the sky conditions, including SkyProbe, a cloud sensor, an all-sky infrared camera

that helps to detect cloud cover, low light cameras to replace the utility of night vision goggles, and satellite images on status screens in the control room.

More monitoring also means that we have more information to effectively trigger autonomous actions. Policy was set to enact automatic closing of the observatory once certain limits were reached. The remote observer has the ability to override the closing for a short period of time under specific conditions that they have determined it to be appropriate.

3.7 Telescope hydraulics

Operation of the telescope requires a telescope hydraulic system that provides fluid to the hydrostatic bearings at the telescope support pads. The telescope hydraulic system is now capable of being controlled locally and remotely. This subproject included the implementation of a PLC control system that was integrated into the existing hardware control system. The addition of flow, pressure, and temperature sensors in the system, as well as ammeters on the motors has provided remote status information on the system that was before only available on local gauges. The ability to capture this data over time will improve the understanding of the system and the maintenance program.

3.8 Compressed air system

The Compressed Air System was completely overhauled in preparation for remote operations. The existing system required physical intervention to switch from the main system dryer to the back up system. A PLC control system was designed and installed to provide remote monitoring and control, providing the ability to switch to the back up system from the remote control room. Additional sensing was installed including flow sensors, pressure transducers, and a solenoid valve.

3.9 Remote control of lights

With no staff at the summit at night it is important to be able to remotely control lights at the observatory that can impact observing, or are required for troubleshooting. WebRelays were implemented to provide remote control of the lights while maintaining the ability to control the lights locally with switches. The status of the lights and the ability to remotely control them is now available through the OAP GUI.

3.10 Fire alarm system upgrade

Automatic monitoring of the facility for safety to personnel and equipment in the case of a fire was also required. An addressable analog fire panel was installed which utilizes digital communication protocol (DCP), intelligent communication with other devices, and an RS-232 interface that provides feedback and real-time monitoring of the system.

Using the interface capabilities of the panel, it provides notifications when heat detectors, smoke sensors, manual pull stations, or the main observatory computer room fire suppression system has been activated. The notifications are sent out as alerts to staff in the form of text messages and emails and the observing control GUI interface alerts the remote telescope operator with a map showing the location of the fire occurrence and type of device that has been triggered.

3.11 Telescope Control System (TCS) modifications

In order to perform remote observing it is necessary to be able to remotely control the existing Telescope Control System (TCS). The TCS is an evolving system and consists of parts as much as 30 years old. It was designed and implemented before the idea of an automated observatory was conceived. There were several steps in the normal TCS operation that required an individual to use hardware controls located in the summit control room. Modifications were also needed to

create the permission scheme to ensure safe operation of TCS from more than one location. The figure below illustrates the hardware and software components that required modifications to enable remote operations of TCS.

Also going through the TCS system are the sounds that provide feedback to the Remote Observer about events at the summit, as well as sounds that play in the dome, warning anyone who may be there when the telescope or dome are moving under remote control. This sound system is also used to broadcast messages to those who have been detected entering the dome unexpectedly during remote operations.

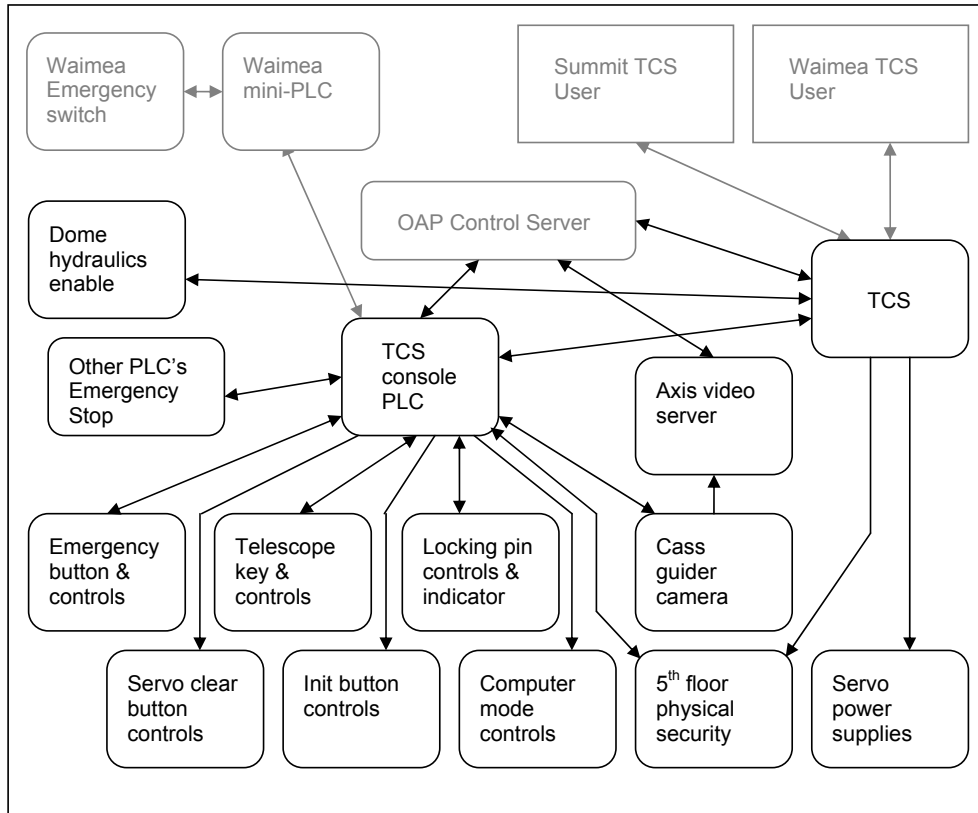


Figure 8. Hardware and software portions of the TCS remote operation plan

3.12 Dome drive system

The cost of providing the necessary instrumentation for remote monitoring, and the obsolescence of several components of the aging hydraulic dome drive system prompted an investigation of upgrade options for the system. An electric dome drive system was selected for its reduced operation costs, improved reliability, and modern monitoring and control system. The electric drive system is currently in its implementation phase.

3.13 Windscreen

The windscreen is currently operated from the control panel in the dome. Instrumentation was added to provide encoding for the position of the windscreen, and the PLC control system was upgraded for remote operation. All of the pertinent information for operating the windscreen is now compiled on the OAP GUI, including the windscreen position, wind speed and direction, and where the telescope is pointing. This has greatly simplified and improved the operation of the windscreen.

4 CONCLUSION

Retrofitting CFHT for remote operations was completed on time and budget, with existing staff, without telescope downtime, and almost no impact on observing. CFHT is now remotely operated at night with no one at the summit, with a reduced nighttime staff working in a more comfortable environment. The goal of obtaining the same high quality data with fewer resources was realized.

Systems engineering concepts formed the foundation for the OAP project. This allowed the modification of legacy equipment and the smooth integration of new control and monitoring instrumentation throughout the observatory. By approaching the observatory as a system, as changes were made to individual subsystems they were designed to work together as a whole.

The project has resulted in technical benefits including improved reliability, maintainability, and remote diagnostics of the observatory. Engineers now have more remote diagnostic tools and status information available to be able to provide support to operations and troubleshoot problems. Smart phones allow monitoring and control of the observatory from anywhere. Technical staff members are notified by alerts and warnings via text or email when any conditions of the systems that are continuously monitored are out of limits. Improved control systems have increased the reliability of several of the systems, and improved understanding of operation conditions of equipment will inform maintenance plans.