Fully Integrated Control System for the Discovery Channel Telescope

Oliver M. Wiecha, Electrical Engineering Manager; Thomas A. Sebring, Project Manager

Lowell Observatory
1400 W. Mars Hill Road
Flagstaff, AZ 86001-4499 USA

ABSTRACT

The Discovery Channel Telescope control system incorporates very demanding requirements regarding fast serviceability and remote operation of the telescope itself as well as facility management tools and security systems. All system capabilities are accessible from a central user interface anywhere, anytime. Although the mature stage of telescope control technology allows focusing more on science rather than on telescope operation, the time and effort needed to integrate a large suite of software modules still impose a challenge to which reusing existing software is one of the answers, especially for advanced subsystems with distributed collaborative development teams. DCT's large CCD camera presents enormous computational problems due to the overwhelming amount of generated data. Properly implemented preventive maintenance and reliability aspects of telescope operation call for historical and real time data in order to determine behavioral trends and permit early detection of failure factors. In this new approach utility monitoring and power conditioning and management are integral parts of the control system. Proposed real time spectral analysis system of sound and vibration of key mount components allows tracking mechanical component deterioration that could lead to performance degradation. Survival control cells and unmanned operation systems are other options being explored for operation in harsh climatic conditions.

Keywords: Telescope, Control Systems, Software Re-use, Collaborative Development.

1. INTRODUCTION

Lowell Observatory, in partnership with Discovery Communications, Inc. – DCI, is developing a 4.2 meter clear aperture, wide field telescope called Discovery Channel Telescope or DCT. This telescope will be located 44 miles Southeast from Flagstaff, Arizona, at Happy Jack, at an altitude of approximately 7700 feet. The site has exhibited 0.6 arcsec best quartile seeing and has been considered adequate for solar system and broad spectrum astronomical research. The telescope incorporates a flipping prime focus turret equipped with a 2 degree FOV camera on one side and a secondary mirror on the other, thus allowing switching very rapidly between the prime focus wide field camera and a 30 arcmin FOV interchangeable instrument placed at the Cassegrain focus.[1,8,9]

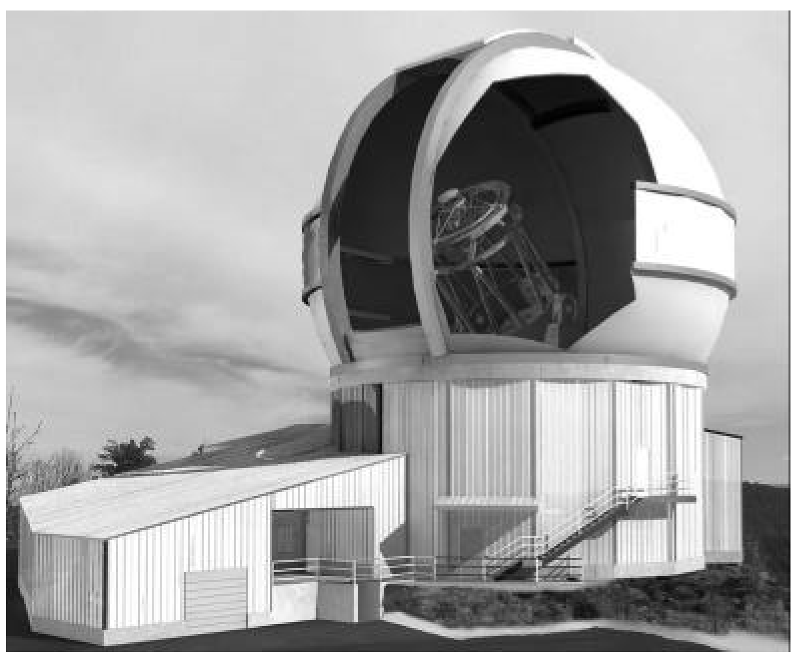

Fig. 1. Rendering of the DCT facility and mount.

Based on the very successful hardware and software design of the SOAR telescope control system,[2,3] the architecture of the DCT control system as well as the computer programs is planned to be an adapted implementation of the same concept. The deployment of such a system should be not only straightforward, but it will also allow to easily incorporate all the necessary modifications to meet our specific science mission requirements. At the time the DCT will be ready to start testing the control system, it will already be a fairly mature product, with many improvements that will necessary surface as the number of users from partner and other participating institutions increases.

A particularly important feature of an Ethernet based control system like the mentioned above is the inherent remote access capability, opening the door to a whole new world of remote control applications, frequently called "remote observing". This feature not only saves time and money by avoiding travel to the telescope site, but leads to a new class of observing tool by allowing the astronomers to work in the comfort of their home institutions or even their residences, without the burden of jet lags and other adverse effects of long trips.[4] A proper agreement is being drafted between the Lowell Observatory and the SOAR Consortium for enabling the DCT development team to generate the next generation of this remarkable telescope control system.

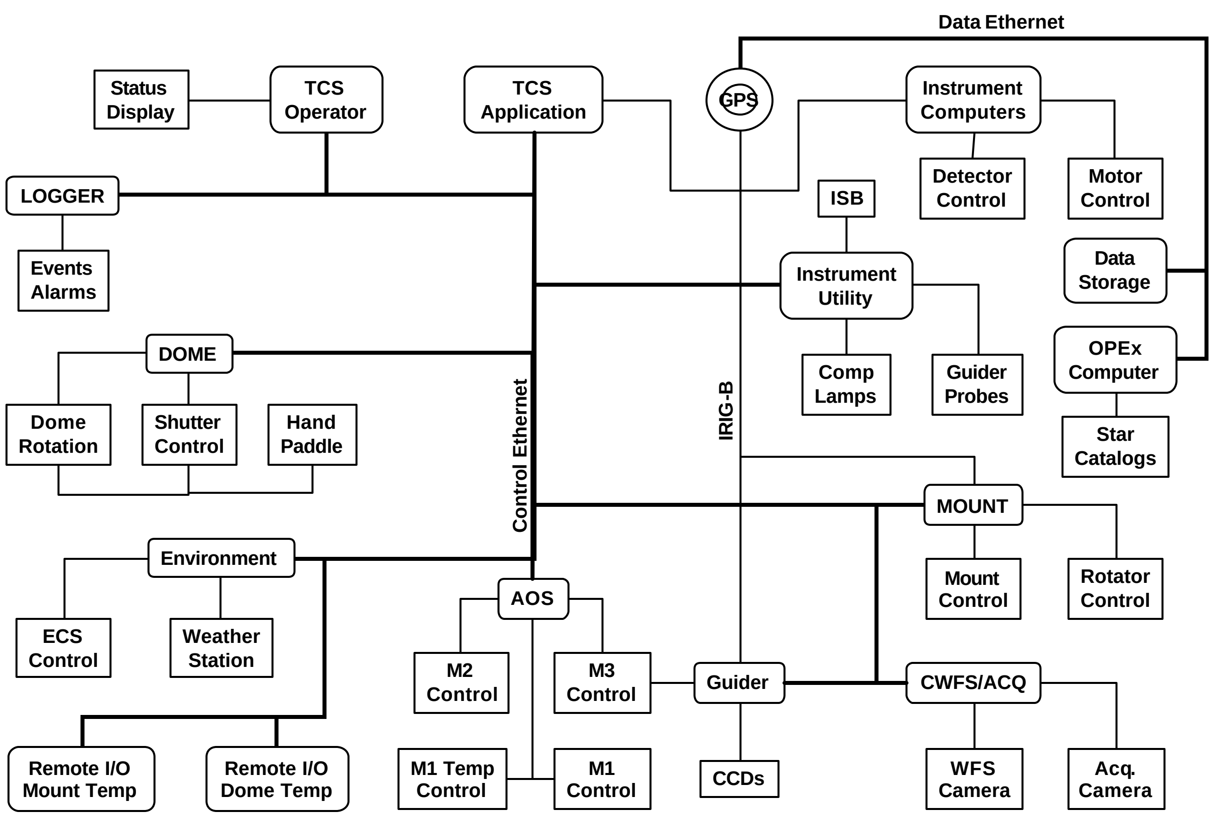

Fig. 2. SOAR TCS computer architecture overview, August 2002 revision.

From the computational standpoint, the most demanding apparatus of the DCT by far will be the gigantic ? gigapixel, 2 degree FOV wide field camera [5] with 2K x 4K CCDs configured in an array of 40, and generating 640 megabytes of data every 20 seconds or 1.4 terabyte per night. Handling amounts of real time data this large requires fast communications mechanisms and very reliable storage devices, in particular when considering keeping a huge data archive for periods of time as long as decades. The continuous trend for faster, cheaper and more capable equipment hoopefully comes to our rescue, so when the time arrives we expect to be able to choose between many proven, widely supported off-the-shelf options; nevertheless we will be dealing with one of the fastest growing databanks in the field of astronomy.

2. OBJECTIVES

Any modern approach to control systems calls for rapid development, flexible, cost effective solutions, supported by many vendors, based on stable, easily replicable, widely proliferated architectures, which hardware and software components are easy to maintain and update, and with widely available test and co-design tools. All functionality should be available locally as well as remotely, including telemetry and event reporting in the actual observing environment. Adding to this recipe some key, limited ingredients like budget, time and human resources, there is one idea that immediately appeals: collaborative development and re-use of proven, successful solutions.

This is in fact a very attractive proposition for all parts involved in the effort as everyone certainly profits in one way or another. The solution "provider" usually does not have time or other resources to continue working on much needed improvements, at least not at the desired rate, and the solution "seeker" realizes that some improvements could be made without jeopardizing the proven solution and obtaining better results by means of some additional work, always minimal when compared to implementing a completely new solution from scratch, with all the uncertainties and risks associated to it. In other words, there is always room for innovation without reinventing the wheel. This approach has already been used for intra-observatory projects in many places, and in this case we are planning to reach further away and basically implement most of the Southern Astrophysical Research (SOAR) telescope control system in both hardware and software. Of course some degree of adaptation is required in order to meet our science program goals, but this is one of the peculiarities of this control system in particular: extremely high modularity.

To make the control system fully integrated throughout the observatory, we are planning to extend the usual scope and include subsystems commonly left out like communications, preventive maintenance, calibration, and surveillance as to greatly improve serviceability and minimize unexpected downtime, and require a very modest technical support crew. An industrial, SCADA type, engineering level human-machine interface will also be added to provide immediate local access to any IT hardware component of the control system to check status, read sensors and eventually operate actuators for maintenance, monitoring and calibration purposes, independently of the high level telescope control system, to which access is more restricted. A positive side effect of this modification is a cleaner, more rugged and efficient client oriented architecture, yet all of the above will be accomplished using a single, high level programming language and toolkit, which in itself represents a further and stronger degree of integration.

Having such a rich interaction between different instances of the control system and so powerful tools to make available all kinds of information will greatly help the astronomer in order to optimize the experiment long before the real observation actually occurs. For this to happen, the possibility of simulating the telescope and instrument behavior has to be converted into an effective observing tool aid. Planning and fine tuning are an interactive process that offers the observer an exceptional opportunity to make the best use of the telescope, instrument and observing time and it is now possible to achieve those objectives without consuming any of those resources. Furthermore, it would be possible to evaluate how appropriate is this telescope for a particular observation and how useful is the data gathered by performing a given set of pre-scheduled activities or script.

3. IMPLEMENTATION

Considering the technological advances in electronic equipment occurring after the development of the SOAR telescope and the peculiarities of the DCT site associated with the requirements imposed to this project, we found important to first determine the plausible state of the art of some key devices that we expect to be commercially available around the commissioning phase of the telescope before making any decisions that might adversely affect the implementation of the control system or limit future scientific objectives. It is our intent to utilize off-the-shelf devices as much as possible to avoid incurring in additional expenses and development risks not associated with the project.

Except for a minor mining operation, Happy Jack has never been inhabited or otherwise developed. To operate a new telescope accordingly the most crucial utilities are electric power and communications. While high voltage transmission lines can be found less than a mile away, no suitable fiber optic links exist within acceptable distances, hence wireless communications need to be designed to reach Mormon mountain antenna farm, approximately 16.4 miles away, the closest location where a repeater could be placed, and then another 18.2 miles to Lowell Observatory in Flagstaff, AZ.

The challenge is to extend a license free wireless gigabit class Ethernet link that long so the data acquired by the wield field camera during the night can be transmitted to the Lowell Observatory at Mars Hill before the beginning of the next night. The fastest license-free wireless Ethernet link available today capable of covering such distances is 100Mb/s class, not fast enough to send 1.4 terabyte of data in less than 24 hours following the start of the observation. But fortunately recent developments in this field drastically expanded the limits of gigabit wireless links providing an increase of 75% over the actual range due to more sensitive receivers and new modulation and compression techniques that improve the signal to carrier ratio and signal robustness, thus increasing its integrity. Commercial license-free wireless gigabit transmitters available today cover 6.4 miles and will then soon cover more than 11 miles, so 5 years from now is hopefully sufficient time to introduce other significant improvements to greatly increase that distance allowing us to directly connect Happy Jack to Mars Hill in just one hop. The importance of this analysis relates to the way scientific data will be handled and stored and ultimately how the telescope mission will be accomplished as the alternate solution is to physically transport some type of media every day causing a significant delay in the data availability that could eventually interfere with potential applications of the telescope.

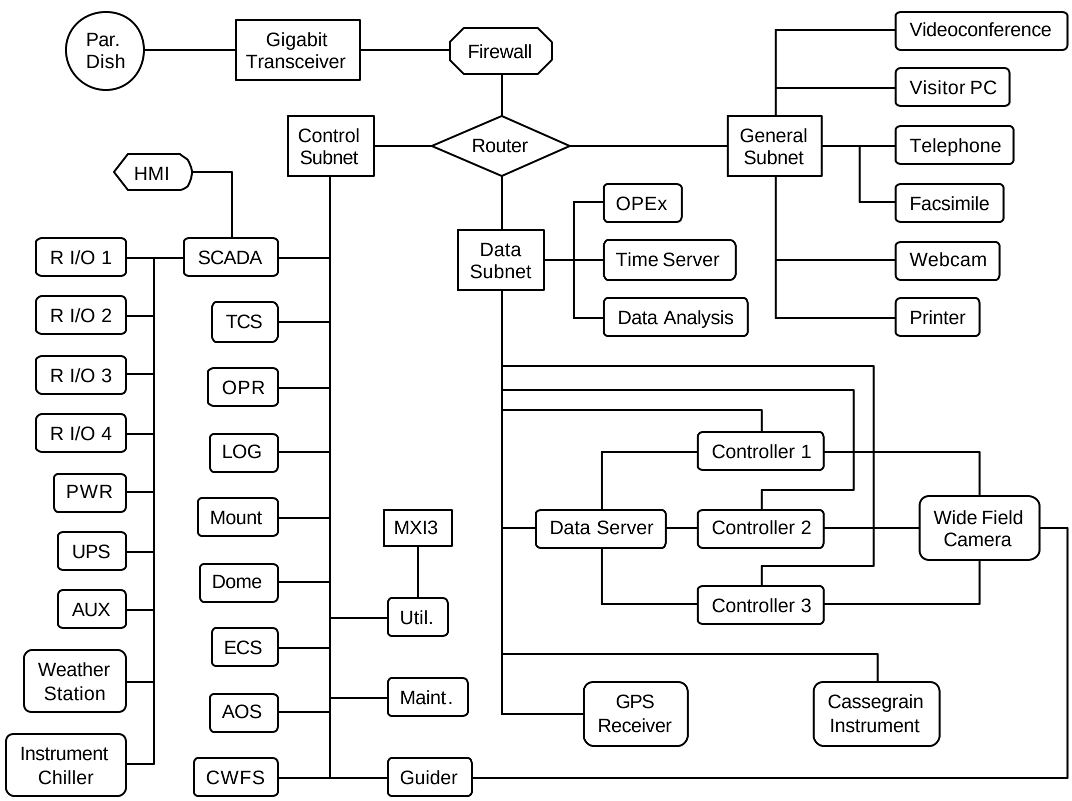

Fig. 3. View of the DCT control system network implementation.

3.1. Wide field camera.

Since the central piece of the DCT is the ? gigapixel wide field camera, which imposes most of the computational requirements due to the tremendous amounts of astronomical data, the Ethernet network has been optimized taking in account the recently released 10 gigabit standard that will be used at least for the switching infrastructure, while the 1 gigabit Ethernet will be the basic standard for computers running control software and scientific processing, although according to most conservative predictions we are already considering a computer platform based on 64 bit processors with 64 bit high speed buses, embedded 10 gigabit Ethernet ports and multiple head DVI video cards.
Figure 4 shows the distribution of the wide field camera 2K x 4K CCDs within the focal plane. The darker rectangles correspond to the 36 CCDs in the science array, which will be split into 3 groups of 12 each operated by an individual readout controller. The clearer rectangles represent the 4 guide and wavefront sensing CCDs; they will be operated by a separate controller. Science array readout rate is 2 μs/pixel from 24 outputs simultaneously per controller, for three

controllers. Each controller will have a computer associated with it that has to be able to deal with 12 megapixels/sec or 24 megabytes/sec during readout.

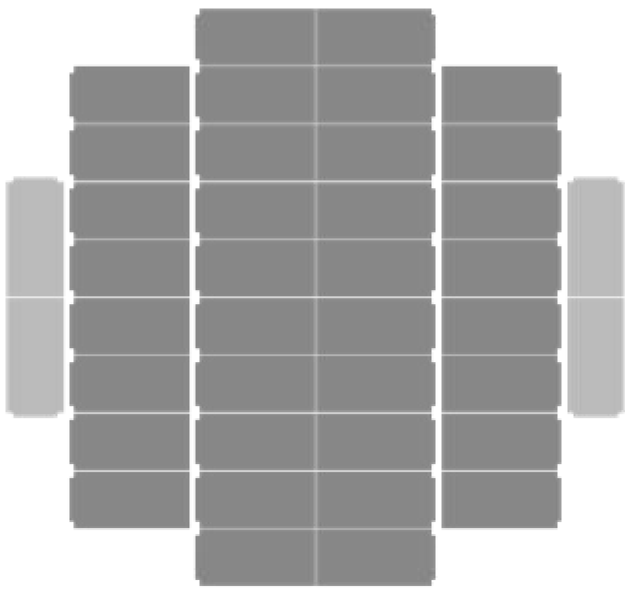

Fig. 4. DCT wide field camera concept.

In order to provide some immediate feedback to the observer, images coming from the three readout computers will be fed not only into the data server, but also to a data analysis computer, which will generate a snapshot of the region of the sky being captured by the science CCDs.

In case the wireless gigabit Ethernet link fails so we are unable to retrieve images stored in the data server, this data will still be available locally and provisions are being taken to include some kind of removable storage media for transport. As for today, if we were to use DVDs, it would be necessary to burn 300 of them to store 1.4 terabytes, or an array of 7 high capacity SATA hard disk drives configured as RAID 5, or an equivalent amount of tape cartridges in a tape library, all on a daily basis. As capacity of storage media increases, this problem will be less critical and less expensive to solve, but the long term storage or data archive will still remain an issue. A series of options are being studied, including outsourcing, and all of them involve very serious, reliable infrastructure.

There are several reasons that contributed to the success of the SOAR telescope control system hardware and software, and one of them was the ability to handle all type of devices, interfaces and processes. Since making fast Ethernet available throughout the system was very easy and inexpensive, it was the preferred network communications interface and subsequently the first choice when specifying all kind of equipment. Otherwise other communications interfaces were converted into Ethernet when needed. All facility actuators, sensors and switches are connected to remote I/O units with native Ethernet ports, and all major subsystems are built to be able to communicate over the Ethernet. Processes demanding synchronization with the universal time are directly hooked up to an IRIG-B network fed by a GPS satellite receiver, which also has embedded Ethernet based time server. Most process controllers are PC compatible computers with Ethernet network interface cards, not only low cost and very easy to replicate and maintain, but also benefit from the use of different operating systems like Linux and Windows. This allows dedicating one computer per major subsystem, thus also greatly simplifying the software development effort as there is no need to mix several systems in one computer. Systems hence are able to run and be tested independently.

3.2. Software tools.

The graphic programming language used for developing the SOAR control system software was LabView from National Instruments. It was selected as it has a large and increasing number of supporters among equipment manufacturers and its graphic interface makes coding a much simpler and more efficient task, much easier to understand and analyze. The suite of available functions and tools covers a vast list, including data acquisition, statistical analysis, complex mathematical analysis, embedded control algorithms and communications. It permits creating extremely flexible and rich graphic user interfaces with as many displays, charts and other indicators as necessary. Implementation of client oriented and web based applications is very straightforward and the use of plug-ins extends the functionality beyond the imaginable.

Regarding data visualization, astronomers are very demanding, one reason why telescope control rooms are usually heavily populated with proliferated computer and video monitors. Several factors contribute to limit the visual perception range of a person, making it impossible to stay in a single comfortable place, therefore information is not always exactly at a glance even being displayed on some screen. Consequently monitor switching technology becomes extremely important, allowing the selective display of the information by logically reorganizing the screens rather than physically moving monitors, and bringing the most relevant information within the ergonomic boundaries. This is a qualitative step in the direction of a clean observing environment, where information flows around the observer instead of vice versa. Also, in the case of LabView, new functionality allows displaying of graphical user interfaces on one screen even when generated by multiple applications running in different computers. This feature increases the attractiveness of remote observing tools based on this language and helps preventing graphic user interfaces from clogging as there is no need to try to show as much information as possible in just a few screens.

To face the increasing degree of complexity associated with the continuously growing demand for more functionality and consequent expansion of subsystems, it is imperative to use highly versatile, efficient tools, with self documenting features, and turn key subsystems whenever possible, paying attention to maintainability and serviceability issues well before starting to think about remote or even unmanned operations. More robotization implies more co-design as more pieces of hardware and software have to be combined together to achieve the desired functionality. But when something out of the ordinary happens to the equipment one still must be in control as much as possible, no matter if the telescope facility is unmanned or not. Budget constraints usually do not allow for voting computers systems and other similar solutions, but survival cells are a viable option as one could think about those like "encapsulated" parts of the control system that will allow initiating a local or remote diagnosis procedure and even to be able to perform a set of basic operations. Such cell should have its own uninterrupted power supply, like solar powered batteries, and should have access to external communications, like a phone line or low power wireless link. Since our programming tools allow for a very wide range of controllers, many of them manufactured by several vendors, a low power model can be picked. It should be able to establish a remote connection, respond to status commands and activate/deactivate other sub-systems. For this solution to work, simplicity and reliability are key issues, and for unmanned operations, lots of inputs and outputs are necessary for remote troubleshooting (circuit breaker status, access to contactor coils, internal status of major devices, measurement of electric current and other relevant parameters, remote startup of major components, etc.).

3.3. Maintenance aspects.

It is important to realize that a local or remote troubleshooting procedure implies a two stage implementation: the first takes place during the design phase of the telescope based on what we expect to happen as dictated by our expertise, but the second stage may only take place after the commissioning has been completed and some operations experience has been accumulated, when particulars about the behavior of the new systems and equipment are known and there is some historical data available. An example of this is vibration analysis, including acoustic, that may help predicting and preventing mechanical failures of the mount, dome and instrument drive mechanisms. A library of periodic recordings of vibration patterns should be kept in an electronic file to serve as reference or for further analysis. A simple FFT will reveal the spectral contribution of several distinct mechanical effects, and statistical analysis will show the change with time and indicate how those properties are drifting and how wear is affecting those mechanisms. Historical trends will expose if there is any abnormal situation long before it becomes critical. The same can be applied to dome temperatures to periodically check the efficiency of the cooling system and help fine tuning the environment control system.

The large diversity and quantity of sensors required in a modern telescope facility for properly measuring all the necessary quantities involved in the implementation of different control strategies and monitoring call for automated metrology and traceability techniques. No reading is complete without an indication of its accuracy and validity, and this task imposes some minor but very important bureaucracy, e.g. keeping calibration records and re-computing measurement error budgets after calibrations or replacement of any component of the data acquisition chain, or after a pre-established amount of time according to the manufacturer's specifications. This procedure has far reaching consequences as calibration standards and calibration equipment are both part of the same problem and should be periodically checked by independent metrology using means traceable to universally recognized standards. The cost of performing those activities may be substantial if some basic considerations are omitted, e.g. determining the accuracy really required for each type of measurement and for how long. High accuracy means more expensive equipment and calibration procedures, and the longer the calibration is valid the better, so the associated cost can be spread over an extended period of time, but equipment with long term stability also has a price. The right balance has to be found between living in a metrological illusion of doing it once and forever and the temptation of having always perfectly calibrated equipment to the highest accuracy. Initially we plan to approach those issues by numbering all parts using bar code labels and computer wands and keeping a simple spreadsheet for sensors, signal conditioners, calibration standards and meters, and from there computing the final measurement error for each type of reading. Narrowing the variety of sensors and standardizing some features of signal conditioners will prevent the replication of calibration standards and meters. Also suitable metrology shops will be sought to perform calibration of all standards and instrumentation.

3.4. Supervisory and passive controls.

While most of the active controls like the telescope mount [6] are provided by contractors as part of their systems, supervisory and passive controls are the principal task to be embraced by the DCT controls development team. This mainly comprises trajectory generation and position correction (based on calculations and lookup tables) safety interlocks, instrument interface and data handling. The only system that will have its loop closed over the Ethernet network is the environment control system (ECS) due to its very long reaction times, enough to recover from temporary loss of communication without jeopardizing the object under control. Closing a control loop over the Ethernet is quite different than sending corrected coordinates to the mount, dome or AOS (active optical system) [7] controllers as the real time response and determinism are limited by the available bandwidth and network switching times, even in the 10 gigabit era as the amount of information flowing through the control network has also grown along with the ever expanding functionality of the control system and programmable devices.

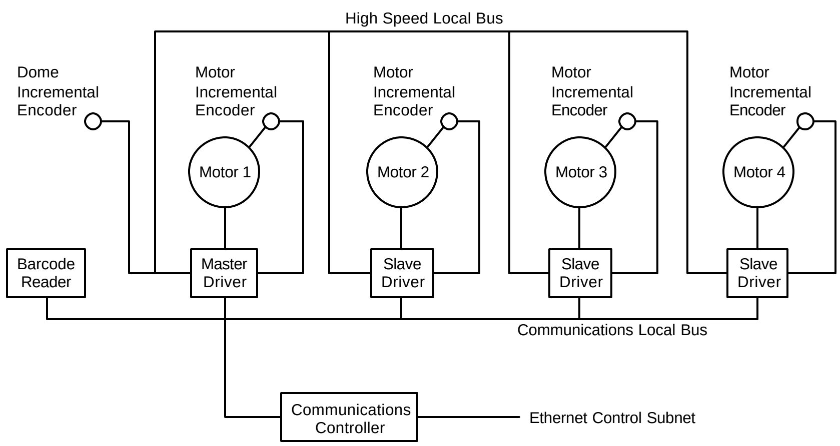

Fig. 5. Dome control system diagram.

To address real time aspects of the telescope control system there will be a GPS satellite receiver and time network server capable of generating IRIG-B and Ethernet time signals directly available to those few subsystems that really require it. The high level telescope control system rather works in a "prepare and execute" mode, where the new corrected coordinates are made available beforehand for the local controller to execute motion or other commands when the time arrives, and sticking to the strategy of running active control loops only locally for speed, accuracy and reliability issues.

A simple example of this approach is the dome control system shown in figure 5, which is composed of four azimuth drives working in torque sharing mode, each one with its own motor encoder for speed limit, and one of them configured as a master. The telescope control system sends position requests only to the master, and the master takes care of synchronizing all the drives and rotating the dome to the new position within the specified time. Eventually the telescope control system may find necessary to re-calibrate the master's local encoder by reading one of the barcode labels placed equally spaced around the ring beam, which indicate the absolute position of the dome, but it will never attempt to speed up or down any of the azimuth drives while moving to a new position. The dome controller, which in fact is a PC compatible computer executing a LabView application running under Linux or Windows, resides in the computer room and its only function is to generate the sequence of commands to move the dome to a new position in a particular time as instructed by the telescope control system. This characteristic makes the dome computer easily replaceable as utilizes the same hardware configuration as any other control computer, and without disturbing the operation of other major subsystems.

3.5. Electronically assisted balancing.

Balancing a telescope without the help of any tool other than releasing it and checking to what side the primary mirror cell starts moving is neither the most scientific nor efficient way to do it. Load cells have been around for a long time and represent a mature, reliable and inexpensive force or weight sensor. The strain gauge type is bidirectional, so besides indicating how much force is being applied, it is possible to know in what direction. To create a practical balancing tool it is necessary to build a wand with an embedded load cell and terminated with a mechanism that would allow locking the telescope while pointing to the horizon for maximum sensitivity. The reading of the resulting force links to the amount of weight to be added or removed. For very fine balancing it will be necessary to have two of those wands, one of them with a much more sensitive load cell, and repeat the process. This operation relates directly to the mount control system, which performs well even if the telescope is slightly unbalanced, but it is fine tuned to work with a perfectly balanced telescope, when many collateral effects get cancelled.

3.6. Hardware fabrication.

Of all major telescope subsystems: mount, dome, AOS, ECS and coating plant, only the mount and the AOS will be delivered as turn key solutions; all other subsystems controls will be partially or completely developed in house. The reason behind this decision is that in most cases the design is well known and significant part of the work is devoted to assemble custom specified control panels, sensors and actuators, which our supervision at the contractor facility implies as much work, time and travel expenses as doing it by ourselves. This also improves the quality of ownership the maintenance and operations crew will have over the telescope after having participated in the manufacturing process, easily mastering all technical aspects related to those systems and significantly shortening the operations crew learning curve.

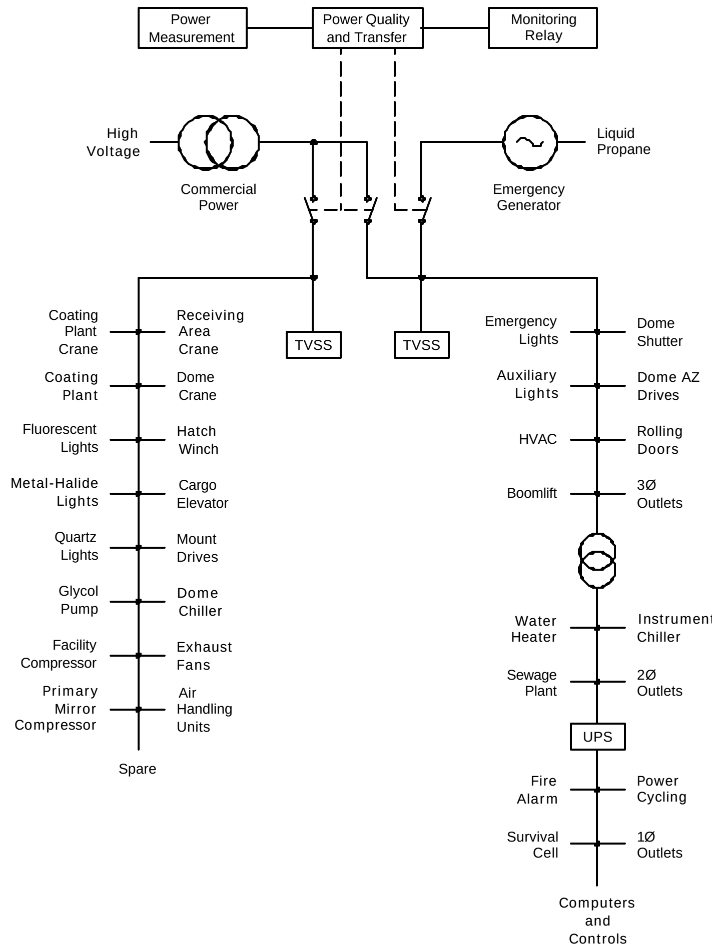

Fig. 6. DCT power distribution unifilar schematic.

One of the subsystems that always requires special attention is the power distribution system. After considering power outages occurrences at the telescope site and taking in account how the telescope is expected to perform, we decided that a full emergency power system is not necessary, but we still want to be able to control some of the loads in case commercial power fails, and this will require the addition of some extra electronics and the use of high current interconnection buses for distributing power inside electronically controlled electrical panels. Energy to the dome will be provided through a slip ring with two electrical circuits: three phase commercial power for the bridge crane and three phase commercial/generator power for the shutter, so in case of power outage it will still be possible to close the telescope. A hierarchical emergency stop system will enable only those loads permitted to run in each one of several potential scenarios, also taking in account safety interlocks and load limits.

CONCLUSIONS

Telescope control systems have reached a level of maturity so there are proven, cost efficient, successful, state of the art solutions that allow easy implementation on telescopes with different science missions just by introducing minor modifications. Hardware and software re-use represent an excellent alternative to long and expensive research programs, significantly shortening the duration of the development cycle and still leaving plenty of room for innovation. Modern graphic programming languages represent a further step towards productivity allowing focusing on the actual task rather than on lengthy coding and debugging. Functionality of those new tools permits integration on all levels of software applications, from science to auxiliary systems, and even remote observing. Simulation of telescope and instruments create new opportunities for getting the most out of every observation at lower cost. As telescope robotization moves forward, not only reliability but also maintainability and serviceability become more critical, and survival cells are an attempt to provide means to diagnose and keep some minimal degree of control over the facility even under the worst possible situations in unmanned modes of operation or harsh weather. This way, the most valuable resources can be dedicated to achieving mission goals as opposed to working on infrastructure. In house development and outsourcing should be carefully balanced as each one offers the best technical and economical alternative for specific subsystems.

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