

TECHNICAL INNOVATIONS

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Remote Control Astronomy Handbook

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ACKNOWLEDGMENTS and COMMENTS

We owe a debt to all our customers who have so willingly shared their experience and knowledge with us, so that we can share it with you. We particularly thank Dr. R. A. Greiner for his review and comments, and Bill Holliday for use of his photographs.

The names of manufacturers and products are included as illustrations only. No representation is made that any particular device or software is suitable or not for a particular need, and we accept no responsibility for such application.

The opinions herein are our own. We have tried to make practical judgments using our experience and understanding of existing products and technology. Because astronomy technology is changing rapidly, always check on current features before making design or purchase decisions. We welcome comments, suggestions, corrections of errors and other input for future editions of this handbook.

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1. Introduction

Background

This booklet will help you learn the practical side of operating a telescope and observatory by remote control. It is intended primarily for astronomers at the advanced amateur level and for professionals who need some orientation to the subject.

We will provide an orientation to computer controlled observing and discuss the decisions you will need to make as you plan your remote control observatory. We cannot give you detailed designs, but we do present the pros and cons of particular solutions, so that you can make the best choices.

This book is a companion volume to “At Home in a Dome” which discusses different types of observatories, how to choose among them, and how to construct and operate the one you design.

Our company is in the business of manufacturing domes and remote control systems. Not surprisingly, we use our systems as examples in our writing. We do not limit our discussion to these systems, but use them as a springboard to discuss the many competing observatory design interests and how they can be balanced. We emphasize the logic you will need to apply to succeed in your own situation.

We do put emphasis on the observatory structure and its control, as opposed to controlling the telescope and camera. This is partly our own bias but it is a justifiable one because the observatory is what protects the equipment. The observatory must have the highest reliability.

Also, we assume you already have some experience with computers, computer-controlled telescopes and cameras. We assume you do **not** have experience with a remote observatory or with thinking through how to make all the equipment work together.

You may be tempted to approach remote control as simply an exercise in remote software. We urge you to change your thinking immediately! In remote control astronomy, you will be operating machinery at a distance, not just computer software. This is a very different activity — and one that requires careful design attention.

Our examples of how to do things and descriptions of available technology are geared to astronomers with limited budgets and resources. We recognize that the professional observatory with a large research budget will approach the design problems differently.

But there are enough stars out there for all of us, so let’s get on with automating our observatories.

Organization of the Book

As an introduction to the art of remote operation, in Chapter 2 we present a “story” that briefly describes one astronomer’s remote observatory, an evening of operating it and some of the problems that arise and how they are solved.

In Chapter 3, we discuss general issues and considerations in remote observing. We present several different classes of remote installations as well as different goals they might serve. We pay particular attention to nomenclature here. Automated observing is so new, especially in the advanced amateur community, that there is not yet a standard set of terms to describe the different parts of a system. We hope our suggestions will help reduce confusion.

Chapter 4 focuses on computers and communication — the means for remote control.

In Chapters 5-7, we discuss each class of issues in more detail. Wherever appropriate, even if it is somewhat repetitive, we draw attention to the detailed tradeoffs among the design decisions.

Automated vs. On-Line Remote Control Issues

In this book, we assume that our reference remote observatory is being operated **on-line** (i.e., in real time) either Nearby or at a Long Distance (e.g., by phone line or Internet). That is, we have assumed that a human is directing the action and is (at least in theory) monitoring the behavior of the system. The system is designed to execute actions and report results to the operator. If properly designed, the observatory will automatically protect itself and its contents against a reasonably wide range of component or system failures.

An even more demanding application is a purely automated operation in which the observer prescribes a series of actions and the remote observatory then executes the actions totally without human oversight. In general, such an automated operation will include a system program that operates the equipment. The system would follow the observing program prescribed by the user. A typical concept would allow a user to access the system via the Internet and submit a more or less detailed statement (script) for the desired images. The operating system (which might include human review) would review the request and presumably proceed to execute it.

Such automated observing places very stringent reliability requirements on the system hardware and software, plus introducing additional the need for convenient software interface to the user. For example, often one of the goals in designing such a system is to minimize human oversight. That is, the usual goal is that the operating system must not only protect the equipment, but must also automatically conduct all the operations usually directed by the user. Thus, it is not sufficient simply to slew the scope/camera to the Orion Nebula and take a 10 minute exposure. Rather, one must also have the capability for the system to recognize that it is cloudy, that the nebula is not centered, detect and adjust the focus, take darks and flats, take the exposure, recognize when a result is reasonable (or not) and decide what to do. Such systems can be developed; however, it is not a trivial design or maintenance problem. For those who might wish to build such a system, it is surely a good first step to construct and operate an on-line remote control system. Once this is done, then automation can be introduced in a step-wise fashion with higher probability of success.

2. The Story

This brief story presents a typical remote observing session using a ROBO-DOME. This is a small (four feet high) observatory designed solely for remote control astronomy. We are at home. It is early twilight and Jupiter is high in the west. The kids have gone to bed, except for the oldest named Sally who wants to try taking a CCD image of the planet. Her father, Pop, is going to work with her through the steps.

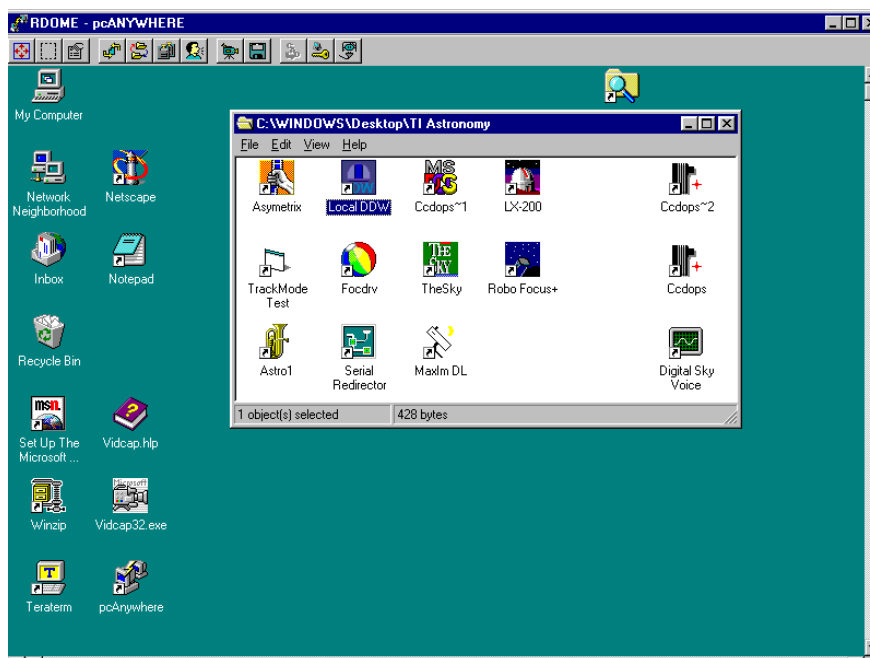
Pop has a “control room” in his house, where he keeps his “User PC”. On that computer he has installed TheSky® V.5 telescope control software and a communication program called PCAnywhere®. Pop’s observatory includes the following equipment:

- ROBO-DOME™, which is equipped with Digital Dome Works™ dome automation hardware, including a control box and various sensors
- An In-dome PC that is running the software called Digital Dome Works Control Program (DDWCP)
- A control room computer that has a matching version of PC Anywhere
- A 10 inch Meade LX200 Telescope
- ST-5 CCD camera by SBIG, using the third party software Maximdl

To place matters in context, Pop’s system is typical of a number of amateur observatories. Although the system would be the envy of many professional astronomers only a few decades ago, his total expenditure was only about \$7-10,000 — less than a motorboat!

The ROBO-DOME is 500 feet from the control room. The Dome PC communicates to the User PC via a local network connection. The computers and software are all running Windows 95®. The telescope and ROBO-DOME have already been aligned, and the system has been used recently. Pop method for controlling and communicating with the Dome PC is PCAnywhere (software that allows him to simulate being in the dome at the keyboard of the Dome PC while he is still seated at his own User PC).

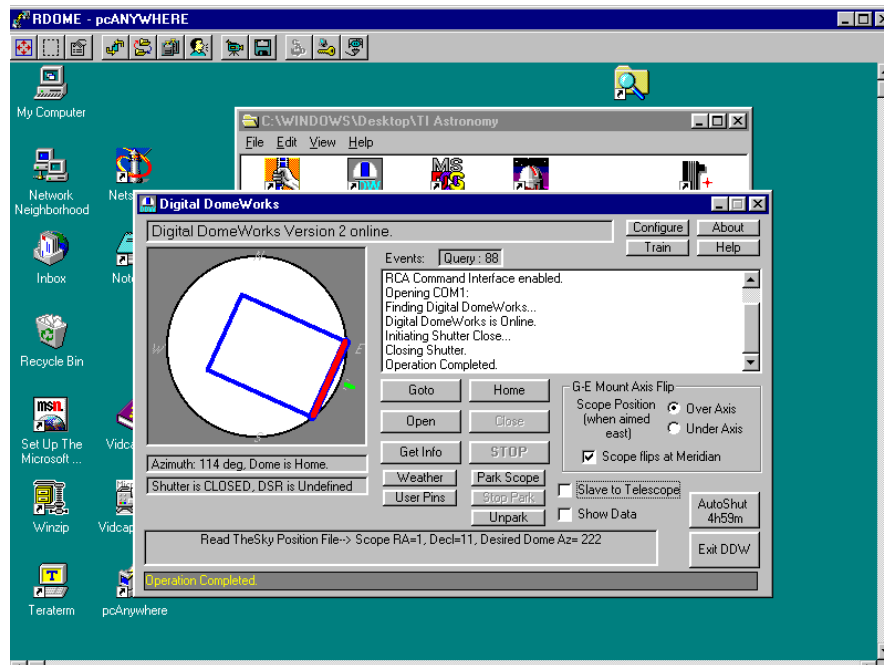
Pop turns on the control room computer and clicks on the icon for his Astronomy Group. He selects the PCAnywhere icon. PCAnywhere brings up a screen that shows the observatory as one of the host locations (Pop's computer network has three other computers on it). He clicks on Observatory. PCA starts and communicates over



the network with the Dome PC where its copy of PCA is waiting for a call (it was left in this condition when the system was last used, and thus will start up in this mode).

The Dome PC responds and the two copies of PCA now talk to each other. In a few seconds, Pop's computer screen blinks, then shows the Dome PC screen (note the PCAnywhere heading), with its desktop icons, just as if he were sitting in the ROBO-DOME instead of in the control room. What has happened is that Pop's control room screen is minimized and the PCAnywhere/Dome PC screen is maximized. The screen now shows the Astronomy Group.

Using his mouse, Pop again clicks on the Astronomy Group icon, then on the DDW icon. This starts the Digital Dome Works Control Program (DDWCP) on the Dome PC. DDWCP then connects to the DDW processor in the ROBO-DOME. In a few seconds, DDW responds — the Dome PC has established a connection with the processor in the DDW control box.



Pop's screen now shows the resulting data: the main DDWCP control screen. It tells him that the shutter is closed (as it should be) and that the dome is in the Home position (also as it should be).

Although Pop and Sally could look out the window to see the weather, they decide to check the weather system mounted on the dome. He clicks the "weather" button, which brings up a screen showing that the wind is only about 6 mph, temperature is 65°F and that it is apparently raining. (i.e., the wetness sensor shows activity.) Pop, of course, knows that there has been no rain. He decides that the birds have again done their thing, but that the wetness measurement interlock will prevent the dome from opening. He is ready to over-ride the sensor to open the dome, but Sally reminds him that the wetness may be the result of the water falling on the dome from the lawn sprinkler. Right she is! After Sally turns off the water, Pop decides it is safe to override the still wet sensor and open the dome.

Comment: The lawn sprinkler is a good example of a remote observing problem. Unexpected events will occur, and you need the ability to detect conditions that may affect operation. A good system will have protection built in. The user must be cautious in over riding protective interlocks.

The wetness sensor was doing the right thing: its job is to protect the contents of the observatory. It is vital that a truly defective interlock be

repaired as soon as possible, so that mistakes will not occur. Pop's decision to over-ride the sensor was valid (though he was a bit quick to do so!).

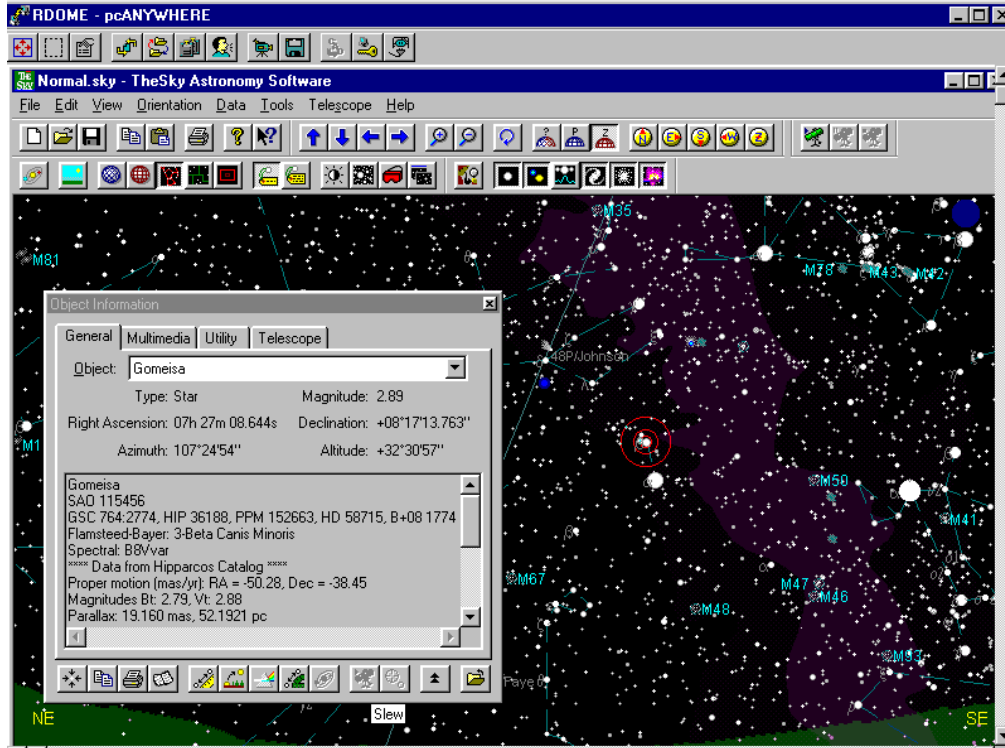
Pop now clicks on "OPEN". The screen shows that the dome shutter begins to open and about 10 seconds later, that the shutter is fully open.

Pop will be slaving the dome to the telescope, so he clicks on the "Slave" button. DDWCP will now obtain the telescope direction from TheSky® software and change the dome position to match.

Comment: TheSky and several other telescope control programs that direct the telescope around the sky will also write this direction to a file in the Dome PC. DDWCP reads that file every few seconds to find out where the telescope is pointed. DDWCP carries out several calculations to find the proper dome direction and commands DDW to move the dome accordingly.

An alternative slaving scheme (good with an LX200 only) is available. If DDW is connected directly to that scope, it will interrogate the telescope, get its direction immediately and then use this data to control the dome. This is particularly useful if your telescope control program does not support the data file or similar method of operation.

With the dome slave function turned on, Pop is ready to turn on the telescope. He remembers that the CCD camera is not running, and that it takes a while to cool down to be ready for operation. Pop has installed a remote relay device that allows him to turn items on or off in the dome by remote control. He selects the User I/O button on DDWCP and turns on Channel 1. This connects to a relay that turns on the 120VAC power supply for the CCD camera and the telescope.



Next he uses his mouse to click on TheSky icon, thus opening a copy of TheSky in the Dome PC. After a few seconds, TheSky planetarium screen shows on Pop's screen. He uses the menu to find Jupiter and, selecting it, he centers Jupiter on his screen in a red circle.

Now to run the telescope! He uses the menu to select Telescope/Connect. After a few seconds TheSky screen shifts direction, showing a white circle on some stars, indicating that the telescope is connected, and is pointed there.

Pop again selects and centers Jupiter in the red circle. He clicks on Jupiter, which brings up a small data and menu box. He selects "Slew To" and the telescope begins moving to point to Jupiter. A small screen shows that the telescope is slewing, and after about 20 seconds, the white circle creeps over Jupiter.

Comment. Note that Pop did things in the "wrong" order — he should have turned on the telescope, then selected Jupiter. This illustrates the desirability of planning your observation to save time and irritation. More importantly, you will want to plan a sequence of observations to minimize time wasted slewing back and forth. You may also need to plan the sequence so that the telescope and CCD cables do not become tangled or to avoid the telescope taking the "long way around" to get to an object. If you are nearby (as Pop is) fixing mistakes is usually easy. If you are 10 or 100 miles away, the solutions are more difficult!

We stated that Pop simply turned on his telescope. In fact, most remote telescopes including the LX200 cannot be simply turned off and on without additional steps to assure that they are pointed correctly. Handling parking and unparking will be discussed later in this book.

Meanwhile, as the scope is turning, so is the dome. Pop can see this on the DDWCP screen, which is up-dating the position of the shutter opening as the dome turns.

Pop now has the telescope and dome aimed at Jupiter. He is ready to operate the CCD camera. He clicks on MaximDL (the third party CCD program that Pop has chosen to use) which, after a few seconds, shows the MaximDL window on his computer. He uses the menu to begin CCD operation.

Sally promptly says, "You did it again, Pop. When you turned ON the CCD camera, you should have started MaximDL and started the camera cooling. If you had, the camera would be ready now!"

Pop groans, but turns on the camera cooling, aware that it will be five minutes before the camera is cold. "I was just testing you," he grins, glad that she is paying close attention.

Even though the camera is not cool, it can still be used. Pop selects his exposure setting and takes an image. In a few seconds, the magic of PCAnywhere brings an image onto his screen. Jupiter is not there! But wait, it looks to be just off the CCD chip, a little to one side. Pop selects the telescope motion controls in TheSky to move the scope slightly, then take a new picture. After several tries, there is Jupiter, almost at the center of the image.

Comment: CCD cameras are incredible, but the camera-telescope combination is not a "point and click" operation. The field of view is small, and skill and practice are necessary to get good results. The sky will still be there tomorrow and next year: astronomy requires and rewards patience.

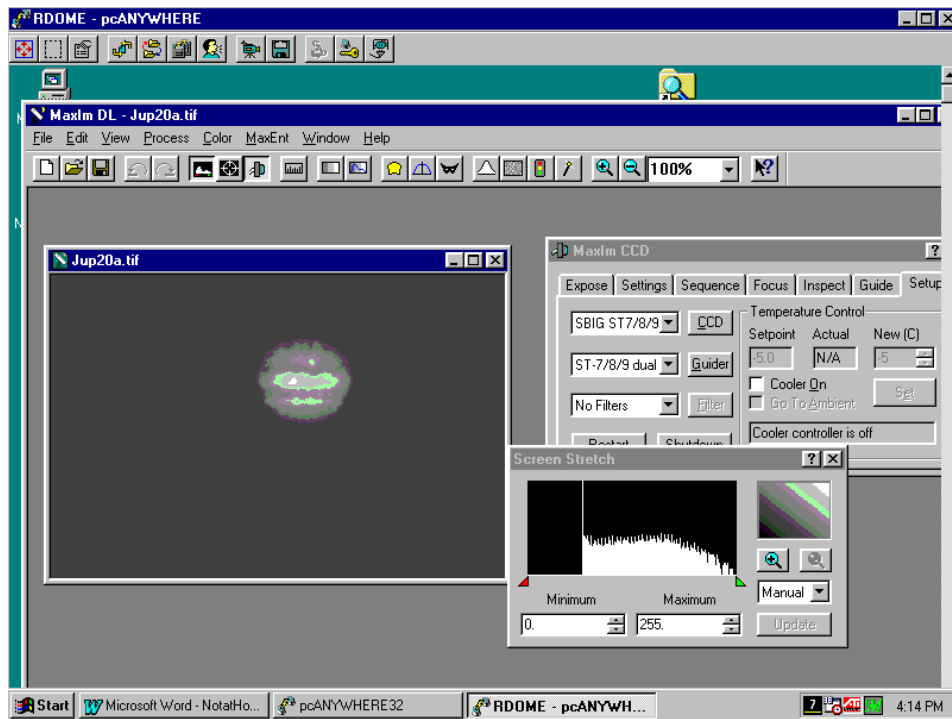
With Jupiter centered, Pop asks Sally why she thought the camera did not show it right away. She suggests that maybe the telescope is not set up right. Pop, who had finally read the entire instruction manual, points out that the telescope pointing accuracy is close, but that its software allows you constantly to refine its pointing. So, using the telescope controls on TheSky menu, he "synchronizes" the telescope to Jupiter.

Pop suggests that Sally take over now to get a good picture of Jupiter. She makes a shorter exposure of Jupiter but finds that the image is very fuzzy and is obviously out of focus. Sally selects the focus control, and begins nudging the focus (remotely on the telescope) to improve the image. After each focus adjustment, she takes a new image to see the result. After five minutes, her impatience growing; she sees the image improving until Jupiter becomes reasonably focussed. Her determination pays off.

Comment: Again, remote control is not point and click. Focusing is an activity that requires some experience to do quickly and well. The new digital remote controlled focusers would have made Sally's job much easier, but she should have moved the scope to a star and focused there, then moved back to Jupiter. This would be much easier—it is hard to focus on a planet.

This is an area where a little forethought can prevent most problems. Usually, focus will stay reasonably accurate from one night to the next. However, Pop made changes in the dome yesterday, switching to a different set of lenses. He did not refocus the system then, which led to Sally's frustration this evening.

It is most efficient to set up each of your most common optical trains and record the focus settings for each (e.g., 13 1/2 turns clockwise on the focus knob from full counter clockwise). This is not high tech, but it is effective! If you set the focus approximately correctly after changing lenses, final



focusing is very easy and quick.

Pop now helps Sally close the dome. She uses the DDW I/O control to activate a remote TV monitoring camera and light inside the dome so that they can see what is happening. Pop shows her how to start the video capture in the Dome PC and they now view images of the dome interior via PCAnywhere.

She goes back to the main screen and closes TheSky, thus terminating the connection to the telescope. Likewise, she turns off the camera cooling and closes MAXIMDL. She goes to the DDW screen and selects CLOSE. DDW directs the dome to turn to the HOME position, then closes the shutter (which they watch on a video monitor).

Pop shows Sally how to transfer her image files from the Dome PC to the control room PC and print them. Satisfied with their work, they go to the kitchen for ice cream.

Comment. When she closed TheSky, Sally did not first terminate the connection to the telescope. Although in this case it caused no problem, it is far safer to turn off programs in the reverse order than they were opened.

Pop and Sally used the video monitor to observe the closing of the dome. This is good practice: you should use all the information available to understand what is going on in a remotely operated facility.

But the worst mistake was that Sally neglected to turn off the drive (or the power) to the LX200 telescope. As a result, the telescope would continue to track Jupiter (its last target) until the wires are wrapped tightly around the telescope, and something breaks.

In this case, DDW saved them! Whenever the dome closes, if DDW is connected to the LX200 it will send a series of commands to the LX200 that will stop the drive (unless the feature is turned off). Thus, when Pop turns on the observatory again, the telescope will be parked, and ready for the next session.

After the ice cream, Pop (who is Prof. Von Poplin in his professional life) switches into his role as the professor in charge of the Anytown University remote observatory. The University observatory is a PD10 ten-foot dome, also running with Digital Dome Works, on a mountain 75 miles away and 5000 feet higher. Students use the observatory to patrol for supernovae. The observatory can be operated remotely in “real time” (as Pop and Sally did) but most of its work is done by an automated observing routine. This routine uses “scripting”, a simple method of programming a sequence of actions for different instruments to take.

Pop uses his computer to log onto the University network and through the high-speed link to the observatory. After providing his password, he checks the night’s activity files. He finds that even though the weather is fine, no pictures have been taken. With a little more research, he finds that someone left the interlock against windy operation in the observatory weather control set to 5 mph (even though the dome can operate easily to 30mph). With a wind of 10mph in violation of the interlock setting, the automated system would not open the dome. Pop resets the interlock to 25mph, restarts the automation script, and logs off. He’ll call back before he goes to bed to check again.

Comment. This example illustrates that amateur and professional astronomers can use the same equipment and software. New remote control products are available and used by both groups, blurring the line between the two. Opportunities for cooperative research are growing as a result.

But it also shows the importance of human checking — things can go wrong in any setting, and a human is usually needed to fix them.

Summary

This story illustrates that remote systems are fairly complex, involving a mixture of mechanical devices, electronics and multiple software programs operating simultaneously. A well-designed system will protect itself from damage. However, if the user is to have a highly successful experience, he must be able to

identify abnormal or faulty situations and be able to figure out ways to correct or work around a problem. This takes experience, knowledge of the system, and a positive sense of adventure and fun.

A question that frequently arises is how much training a person will need to put together and operate a remote controlled observatory. There is no simple answer. You cannot reasonably expect to take Hubble-type pictures by remote control with only a few hours of time invested. This equipment is not “plug and play”. On the other hand, most of us realize that learning complex activities takes patience, a willingness to master the practical details and many trials that succeed, as well as many that fail.

A person who wants to develop a remote controlled facility would do well first to put together and learn how to use all the instruments in a “hands-on” mode. You should consider getting your telescope, observatory, and CCD camera and computer to work well manually, building experience with each component. This way you gain the background knowledge needed to operate remotely with a high probability of success.

How long does all this take? We have customers who have “always wanted to do astronomy”, who jump in and in less than six months of intense activity develop the skills and knowledge to be very accomplished amateur astronomers and astro-photographers. Some of these customers work alone, and some work with other, more experienced people. Once having mastered the fundamentals, they build and use more complex observing and imaging systems, including full remote control observatories. On the other hand, we know of folks who proceed with much less intensity over a longer period (and just as much enjoyment), who also become proficient in the high tech side of astronomy.

It is not how fast you do it; but success will depend on thoroughly mastering the details.

3. Basic Goals, Issues, and Configurations of the Remote Control Observatory (RCO)

Introduction

In this chapter we discuss how to design your remote control observatory (RCO).

- What kinds of things do you need to worry about?
- What are the tradeoffs among the decisions?
- Why would you want to do remote observing anyway?

Here are some of the many reasons to establish and operate a remote controlled observatory:

- You want many users to have access to a single instrument
- Several users, in different locations, need to use the observing instruments
- The observatory must be automated for unattended operation in survey-type research
- The astronomer likes gadgets and high tech equipment
- You like the challenge of constructing complex systems
- You want to learn more about robotic systems
- You prefer to observe without being exposed to the wind and cold
- The observatory is located at a very remote site
- Sensitive observations require that there be no body heat from people
- The system is a teaching tool for robotics and/or astronomy
- The observatory with its telescope is too small to accommodate a human
- The observer is physically handicapped
- You want to be at the cutting edge of astronomy

Obviously, a given project may satisfy multiple goals. And, of course, the goals will have an impact on the type of system chosen. Yet, to a surprising degree, all systems will have many components in common. In practice, the goals will have more impact on questions such as “what quality telescope or mount must be installed” rather than the “architecture” of the system.

Sample Observatory Systems

To help you think about system design, we will describe several different types of remote observatory situations. Systems will differ in the **DISTANCE** between the user and the observatory and on the type of **CONTROL** system by which is used.

Distance:

- **Nearby** — A system in which the user can conveniently check the observatory if some problem occurs. This distance might be ten feet or hundreds of yards or farther.
- **Long Distance** — In this type of installation, the user is too far from the observatory to check or repair problems. A Long Distance system must be more reliable.

Communication and control system:

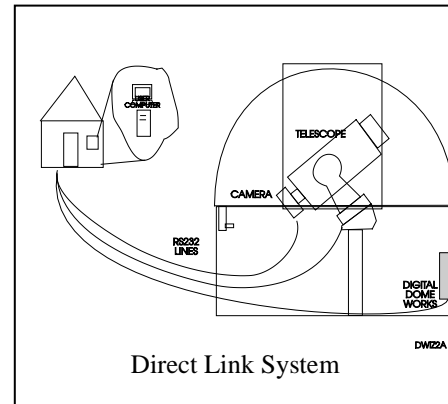
- **Direct Link** — A control system in which the User PC connects by individual cables directly to each of the major devices in the observatory. There is **one** communication link between the user and each device.
- **Multi-Link** — A control system in which the User PC connects by a single communication link to a Dome PC, which in turn connects to and controls each observatory component. Now there are **multiple** successive links between the user and each device. We will further break down the Multi-Link case depending on whether the actual device control programs are running in the Dome PC (“Host-Client Control”) or in the User PC (“Direct Control”).

Distance	Can use this Communication/control alternative	
	Direct Link	Multi-Link
Nearby	Yes	Yes
Long distance	No	Yes

Direct Link/Nearby RCO System

When the observatory and control room are reasonably close together, you can have multiple communication and control cables directly between the user computer and the observatory devices. Of course, this also includes the case of the user and his computer being IN the observatory. This direct link system is cost effective and allows convenient personal attention to problems in the observatory.

In the figure, we show an observatory containing a telescope, camera and remote control equipment. Each component is connected to the user's control room with a separate cable. The User PC in the control room runs the observatory components, moving the telescope, turning the dome and taking the pictures. A key distinction of this system is that the User PC contains and actually runs all the software. Note that even though there are multiple cables, there is only **one** communication link between the user and each instrument.



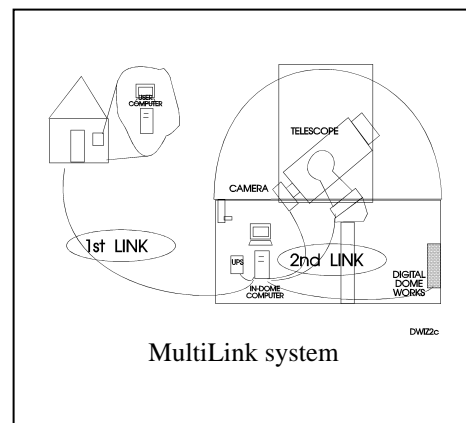
This system is particularly well suited when the user is in a room adjacent to the observatory, e.g., 10-20 feet away.

- An advantage of the system is that it uses only one computer and a simple communication system.
- A major disadvantage is the lack of a computer in the dome, which prevents in-dome operation or testing of the system.
- In addition, as the distance to the observatory increases, the cost and complexity of the cabling can increase very fast. Distances over a hundred feet or so are feasible, but offer rapidly decreasing benefit.
- An important implicit assumption is that the observatory components are relatively autonomous, i.e., sending occasional commands and receiving occasional data can operate them.
- In more complex installations, you may need to be connected to additional instruments and sensors. Then the number of wires rises, your computer needs more ports and these requirements will have an impact on system reliability and operation.

Multi-Link/Nearby or Long Distance RCO System

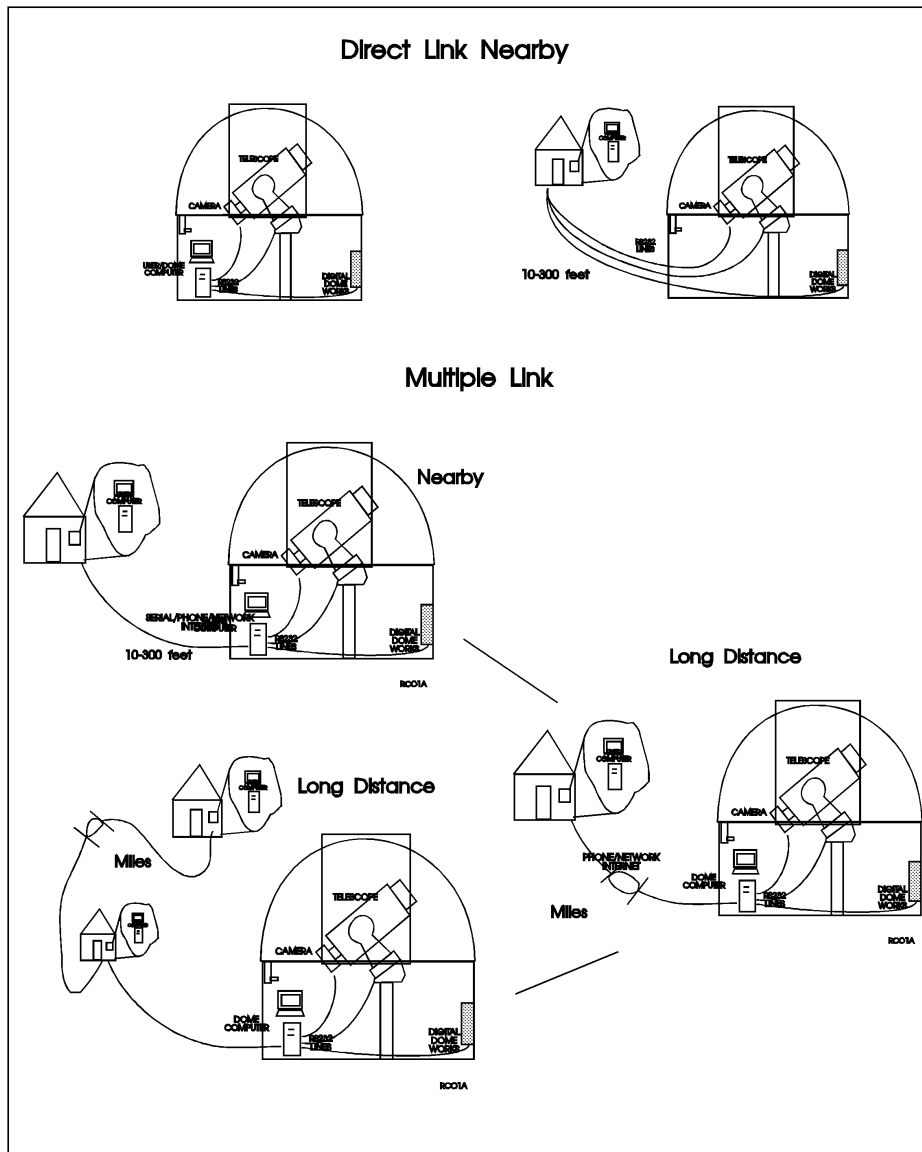
We tend to identify the Multi-link setup with Long Distance even though there is no inherent short or long distance limit between the user and the observatory. The distance between the user and the dome might be 20 feet, 100 feet, or 1000 miles. The real distinction from the Direct Link system is the method of communication and control to be used (which of course implies hardware and software differences).

In the Multi-Link figure, we show the same observatory (containing a telescope, camera and remote control



equipment) but now also containing a Dome PC. This installation has **Two** links in succession: one from the control room to the Dome PC, the second from the Dome PC to each instrument. The control room to Dome PC connection will usually be a Network, Internet, or phone connection. The Dome PC connects by individual cables to the observing equipment using short RS232 or parallel port links, as in the Direct Link system.

This setup is useful at any distance. The price for this flexibility of being able to use a single communication link (vs. many) is the cost of a second computer (Dome PC) and a more complex set of communication hardware and software. Because it offers flexible communication, this system is particularly suitable for access by multiple users (one at a time). Many people use this Multi-Link system even when near the observatory because it is extremely flexible for normal operations, maintenance, or checking equipment setup changes.



Control System Variations-Direct Link vs. Multi-Link

Communication and Control

As you can see, the DirectLink and MultiLink systems differ in Communication and Control. Let us look at how these control issues interact with the distance.

In the Nearby/Direct Link case, you are sitting at the computer running the programs that control each observatory component (telescope, camera and observatory control). In general, each type of equipment has its own software created by the manufacturer (or third party) which controls the component and provides feedback. Your computer sends commands to each component as necessary (e.g., tells the camera to take a 2 second exposure) and receives data back (e.g., the computer file of a picture that was taken.)

In the Multi-Link case, no matter whether it is Nearby (100 feet) or Long Distance (100 miles), you want to use the Dome PC to operate the observatory devices even though you are not in the observatory. How will you command that computer to move the telescope, for example, and to inform you when the movement is complete?

Question: Is the program controlling a device running in the User PC or is it running in the Dome PC?

Answer: Most installations install the standard control software in the Dome PC, and then use a remote computer operation program in the User PC to remotely control the dome PC. This is the configuration that we will use in our reference observatory system discussed in this book. However, other software and control arrangements are possible, and these are discussed in the next chapter.

Designing a Prototype Remote Control Observatory

To help make your thinking in the remainder of this book more concrete, let's design a Long Distance Remote Control observatory to use as a reference system in our later discussions. We choose the Long Distance case because it is the most difficult and will thus demonstrate the issues in the simpler cases. Because it is Long distance, we will have to make the system as reliable and as self-protective as feasible. This is not unrealistic. Many amateurs and institutions are already using similar systems.

We start with a brief description of each item in the system and its importance. The examples shown are commercially available products. In many cases, there are equally good alternatives available. In later chapters, we will discuss these items in more detail. This listing of the items and some of the issues is to give you an over view.

Here are the components of our observatory:

- Observatory dome (motorized)
- Digital Dome Works remote control system
- Communication/Control software
- Telescope on computer controllable mount
- Software to control this mount
- CCD camera
- Software to control this camera
- Dome PC
- Uninterruptible power supply (UPS)
- UPS management system
- Video monitor
- Remote power control system
- Remote focusing System

Observatory. We will assume a ten-foot diameter Pro-Dome observatory. Although a smaller or larger observatory could be used, the ten-foot size is large enough for you to be in the observatory with your equipment, which makes the job of setting up and testing much easier. The dome is equipped with motors to operate rotation and the shutter.

An alternative is a roll-off roof observatory or other design. These can also operate well. They are somewhat easier to automate than a dome. Still, reliable automation of a rolloff is not a trivial matter. Issues include quality of construction, reliability of motor systems, vandal and weather resistance, etc. There can be more subtle issues as well. Many roll-offs are constructed to minimize size and cost. With the resulting lower height walls and clearances, this may require that scopes be properly parked to allow clearance for the roof to move. If a telescope is not parked correctly, closing the roof (either by command or under an automatic closing process) may result in damage to a telescope. This is not an issue in dome observatory as they seldom have interference issues.

Digital Dome Works. This is set of the hardware and software that controls the movement of the shutter and rotation. Having its own processor (i.e., not dependent on the PC), DDW is a “smart” system. Thus, it can operate by hand without a computer, or remotely via computer, or autonomously by taking over dome closure and other actions even if the Dome PC fails or crashes. Features include its ability to handle unforeseen events, degree of feedback to user and flexibility in different applications.

Telescope, Focusing System, and Telescope Mount. The telescope is the optical tube (lenses and mirrors), including the focusing system. The telescope mount is the machinery that holds and points the telescope as desired under computer control. In some cases, the telescope and mount are combined, as in the Meade LX200 series telescopes. In other cases, you will get the optical tube from one vendor and install it on a computer-controlled mount from a different manufacturer. The focusing system may be manual (i.e., hands on), but increasingly, remote users require remotely operated focusers. Although many operate via commands sent through the telescope control system, dedicated digitally controlled focusers (e.g., RoboFocus) are now available as an important observatory component.

We will assume an Astrophysics Mount holding an LX200 16-inch S-C telescope. A RoboFocus remote focuser is installed on the telescope.

Issues abound in this area. For example, does the telescope mount support useful remote control commands, including the ability to recalibrate (realign) the telescope without a human going to the dome, is the pointing accuracy good enough, does it handle power failures well, can it handle telescope imbalance, etc. We will discuss these issues later.

Communication/Control Software. The user is controlling the Dome PC from the User PC, while the programs to control each device are running on the Dome PC. PCAnywhere is the remote computer control and communication software that we will plan to use.

Telescope Control Software. There are many brands of telescope control software. Some present you with a “planetarium” screen (star map) that allows you to point and click to go to a particular object. Some offer voice control (“go to Jupiter”), while others are text based (choose the object from a list). Many software packages handle only a limited range of telescope mounts, or offer only a subset of the needed scope commands. Some are slow in operation, some are quite expensive. Some may not provide important data to other programs, such as where the telescope is pointed (needed by the dome control system to allow dome slaving).

Let’s assume you are using TheSky®, a popular planetarium type program.

CCD Camera and software. The CCD camera choice depends on your budget and the type of images you will be taking. Cameras differ in size of image, quality of chips and ease of operation. They differ also in the type of connection to the control computer. Because the data rates are high when the camera downloads its image, most cameras require an “intimate” connection to the Dome PC such as a SCSI port,

parallel port, or USB connection. In addition, the control computer must process the image data and convert it to a file and/or monitor image.

Cameras are supplied with manufacturer software; however, third party software is increasingly available both to control the camera and to process the images. Third party software may offer operating or other advantages over the software provided with the product.

We will assume an SBIG ST7 CCD camera and MaximDL CCD camera control and image processing software.

Dome PC. In general, the Dome PC does not have to be a state-of-the-art machine. The control and data handling functions are fairly low level (unless this computer is to be used for extensive remote processing of images). The computer should have a large hard drive, as you will want to store many images. Environmental requirements are fairly easy: standard office machines will usually operate from below zero to above 100deg. F. The computer must obviously be fitted with the right number and type of ports, usually including at least three serial ports, a parallel port and network card connection. Other requirements may include a video card and other features. In general, laptops are not very desirable, as they are more expensive, have limited numbers of ports, and may not operate well over the range of temperatures at your site.

We will assume a standard PC, monitor and keyboard.

Uninterruptible Power Supply (UPS) and UPS Management System. For a long distance observatory, power backup is essential. A UPS prevents a minor power interruption from bringing the system down, and provides backup power so that the system can be shut down and dome closed if the power fails. A UPS will also help filter out power glitches that might disrupt the system. Obviously, the size of the UPS must be sufficient to operate the shutdown system and must be compatible with it.

Be aware that there is little standardization for data signals out of the UPS, so that compatibility with shutdown software and hardware is important.

Video Equipment to Monitor the Interior of Observatory. This is a very important tool for remote operation. A video camera is inexpensive. Its images will be sent directly to a monitor (if nearby) or via the Dome PC to the user. You use these images to verify movement of the telescope and dome components and detect aberrant behavior. For example, you might identify a snagged cable or stop the telescope before it wraps a cable. The camera is also very useful in re-calibrating a telescope. In general, a black and white camera is sufficient, and offers greater sensitivity than a color camera. Some method of turning illumination in the observatory on and off is also required (see below).

We assume a small wide-angle camera with built-in light.

Remote Power Control System. You often will want to be able to turn observatory components on and off from your control room. For example, you might want to turn off the mount or camera when it is not in use, or turn on a video camera and its light only when needed. The selected remote control system DDW offers two channels of control using an optional module.

As your equipment evolves in complexity, you may need to control larger numbers of items in the observatory and even adjust them to different levels (such as dew zappers). In the near future, there will likely be stand alone control systems (perhaps also controlling focus and other observatory functions).

We will assume use of the DDW remote power control device.

We now have discussed in general terms the physical elements of a prototype Long Distance remote control observatory. In later chapters, these components will be discussed in more detail, grouped into several categories:

- Computer, Communication, Control System

- Telescope and Control System
- Camera and Control System
- Observatory and Control System

We now turn to a different “filter” through which to design the observatory.

Design Goals for a Remote Observatory Program

There are two ways to “slice the design issues” of an observatory. These are

- The devices and components in the observatory (we just discussed these)
- The goals of the program which will be carried out.

Your program design goals may lead to conflicting design decisions. Lets look at a typical list of goals, and consider a few examples of how these goals may affect design decisions.

The purpose of the remote controlled observatory is to provide services to a user(s). We can classify the requirements in several different ways:

Astronomy Services

- Ability to take pictures at a particular field of view, optical speed, resolution, etc.
- Ability to modify optical system (focus, filters, field of view)
- Ability to view different parts of the sky
- Ability to provide access on a particular response (e.g., fast on-line to do gamma bursters or supernova)
- Ability to operate totally automated vs. on line

User Services

- Access for one or multiple users
- Suitable for use by experts and/or novices
- Image storage and image processing services

System Administrator Needs

- Assurance of minimal need for on-site maintenance (e.g., autonomous failure recovery)
- Self protection of equipment
- Internal documentation and logging
- Ability to operate on a schedule (e.g., allocate time)

At this level of detail, the design problem does not look so difficult. However, the devil is in the details as one tries to get from the objectives to the physical devices. It will be useful to discuss a few of these items and the kinds of issues that arise.

As an example, the desired optical goal may be that the equipment can reach a particular magnitude and resolution in a particular exposure time. This might drive the decision to get a 16-inch S-C telescope (such as the computer driven LX200 scope, which has its own mount) or a 16 inch Newtonian which is less expensive. Because Newtonians do not have built-in controllable mounts, one would have to be purchased. However, the Newtonian on its mount may require an observatory that is too large for the site. The smaller SCT would fit in a smaller dome, but you may want the ability to point the telescope to a precision higher than that provided in the LX200, thus driving you back to a separate high quality mount, with the possibility of still using the same optical tube.

Having tentatively chosen the telescope and mount, you will need to choose the telescope control software. The software will have to:

- Operate the mount remotely (not an issue if using Host-Client control)
- Allow remote focusing
- Be compatible with or support optical path changes (filters, reducers, etc.)
- Be easy to learn and use
- Protect the telescope and the camera (not aim at the sun, not hit the pier or wrap wires, etc.)

While some of these are not basic considerations that affect the images, they are very important for other reasons.

The remote equipment used in the optical train include focuser, filter changers, and possibly other devices (lens covers, auxiliary lenses such as reducers, etc.). At this time, only the focuser and filter changer are available as remote equipment. However, many models are somewhat unreliable, limited in range of operation, hard to use, and not well integrated into the rest of the observatory system. This is because most of them were designed as hands on (or nearby) device. A remote focuser that can't tell you its position may be very frustrating to use.

Viewing different parts of the sky and the speed of response needed may dictate the location and orientation of the observatory but will also help dictate the choice of telescope, mount, and even software.

Whether the RCO will be operated on-line (with a person remotely controlling it) or in an automated manner (where exposures are done autonomously by computer) has many implications in software and hardware choices. In general, the automated system will be the more complex. It will normally include the ability to operate on-line, but must also include additional features such as the ability to take in lists of desired images and schedule them for exposure, recognize and recover from all system errors (e.g., errors in image specs, positioning, clouds, equipment malfunction, etc.) A general-purpose automatic system is a major challenge to design, construct, and operate. Narrow purpose automated systems are much easier to design and create as the range of operations (and errors) are fewer in number.

4. Computers — Communication and Control

Introduction

In this chapter, we discuss designing and operating the computer system for a remote controlled observatory. There are two computers of interest, the Dome PC and the User PC.

As you read in Chapter 3, a “Direct link connection” is a remote control observatory in which there is just one computer, and all the observing equipment is directly connected to the ports of this one machine.

In a “multiple link connection”, the User PC and the Dome PC are separate machines. Therefore, they must be able to communicate with each other. The User PC is in the control room, while the Dome PC is in or next to the observatory, with its ports connected to the observing equipment.

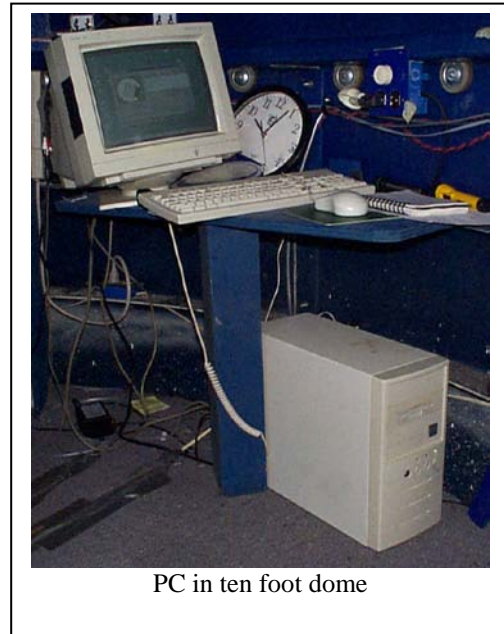
The Dome PC – Design Considerations

The “Dome PC” is usually a standard office machine PC. Although these computers are not designed specifically to handle the wide range of environmental conditions that exist in a typical observatory, most people find that they work very well. Industrial computers are available, but their cost is usually 2-5 times higher than a standard PC. Although the keyboard and monitor are not used in remote operation, you will need them for setup, changes and trouble shooting.

It is possible to use a laptop as the Dome PC. However, there are disadvantages:

- The display on a laptop may not operate at the low temperatures
- Laptops are more expensive than office machines
- It is difficult and/or expensive to add features (such as additional ports) to laptops

You can use MacIntosh or other machines, rather than a PC. However, the range of programs is smaller, and costs may be higher, especially as you add features.



PC in ten foot dome

What are some of the features you will want in your Dome PC?

- **Ports.** You will want three available serial ports (telescope, DDW, CCD), and preferably more. Because most machines only have two serial ports, you may need to add ports using an internal card or external expansion. You will also need at least one printer port — many CCDs use the printer port. If you also want to run a printer, you would need an additional printer port, or a switching device. Future instruments may require a USB port. Internal card or external USB four port expansion devices that share IRQs are available for \$125-250. Search the Internet for the best deal.
- **Video input.** If you want to use a video camera inside the dome at Long Distance, you will need a video card/frame grabber. Using this device, you can view the interior of the dome via PCAnywhere in the Host-Client mode. Some video cameras use USB inputs so this format will probably increase in popularity, and some cards allow use of more than one camera. If the installation is nearby, you can run a direct line from the video monitor camera to the display (bypass the computer).
- **Power On Control.** You should try to get a computer that will turn on without needing physically to push a button each time (see discussion on UPS systems below). One way to handle computer crashes and lockups is to remotely remove/reapply the power to the computer (“power off reboot”). Some

computers require a power button to be pushed after the power has been lost thus preventing you from being able to perform a power-off reboot remotely. Working around this problem is difficult, and may require custom wiring inside the computer. This is an issue primarily for long distance operations.

- **Speed and power.** The Dome PC does not have to be a high performance machine; however, it should have a large capacity hard drive (to store the many images). If you are using PCAnywhere or similar host-client communication control software, there is some speed advantage for machines working above about 500MHz.
- **Network.** The computer should include a modem and a network card as appropriate. See discussion on networks, below.
- **Monitor.** A separate computer monitor is desirable, especially during installation and trouble-shooting; the monitor would be turned off except when in use.
- **Keyboard.** A standard keyboard and mouse is probably best. Although touch sensitive keyboards (to eliminate a mouse) may be desirable to save valuable desk space, using one with gloves on is very difficult.
- **UPS.** You will normally want the protection of backup power for the computer.

Environmental Conditions for the Dome PC

Most Dome PCs are left on all the time. Thus the observatory is always remotely accessible. The heat generated helps keep the computer warm enough to operate in the winter and helps to prevent condensation from high humidity at other times. Cooling the computer is only needed if the ambient temperature rises above about 125° F. If the monitor is normally off, locating it above the computer will help prevent condensation in it. If you are in an extremely cold environment, a simple box to limit airflow through the computer will keep it warmer.

The User PC – Design Considerations

The User PC can be almost any PC. Because it will be communicating with the Dome PC over some communication system, it will need a modem and network card. It should have a large hard drive, as it will likely store many images.

Speed and power are important issues. You may do some preliminary processing of images in the Dome PC and but will usually download them to the User PC for later processing. Depending on the types of image taking and processing, you may place large requirements on the User PC. For example, it is common to manipulate dozens of images at once, requiring large amounts of RAM (preferably 128Meg or more). Some processing methods are very computationally intensive, thus benefiting from high speed processing. How fast a computer to have is very much a judgement call. Given the rapid development of new computers, if you are cash limited, you are probably better off allocating more money to the observatory equipment and less to the User PC.

Communication System (Hardware)

The communication system is the physical set of wires and attached devices that allow transmission of commands and data over one or more links between the user and the observatory. See Chapter 6 for more detailed discussions of this issue.

A **Direct-Link** connection means that the User sits at the Dome PC, which is connected to the observatory components using short RS232 (or parallel) connections (the Dome PC is either in the dome or nearby).

- If the cables are less than 50 feet or so, the type of cable is not very important. If the cables are longer and/or are outdoors, they should be in plastic or metal conduit (for protection).
- Runs of 100s of feet may require larger conductors to reduce voltage drop. In most cases, the practical limit for these cables is 300-400 feet (parallel port cables over 100 ft are problematic).

A **Multiple-Link** connection means there is a Dome PC in or close to the observatory with its direct wire connections to the observatory components. The User is at a second computer, which may be nearby (100 feet) or long distance (100 miles).

If **nearby**, the connection between the User PC and the Dome PC may be a dedicated line, such as a fast RS232 link. A local network connection between the two or more computers is more common. All use inexpensive cards in the PC, inexpensive cables (either twisted pair or coaxial cables) and offer high-speed service (e.g., 1 Megabyte per second). If you are not knowledgeable about these subjects, educate yourself using library books, how-to manuals, computer magazines, or Internet resources. Or find a mentor!

If **long distance**, the communication link will usually be some combination of the telephone system (via a modem), local network, Internet, or other public access system. In terms of physical wiring, all you need to do is make sure the desired links can reach the User and Dome PCs. However, be aware that once you connect to a public system such as the Internet, you will have to provide some measure of security for your system. Because the control software is so important, we discuss the special Internet issues below after the software discussion.

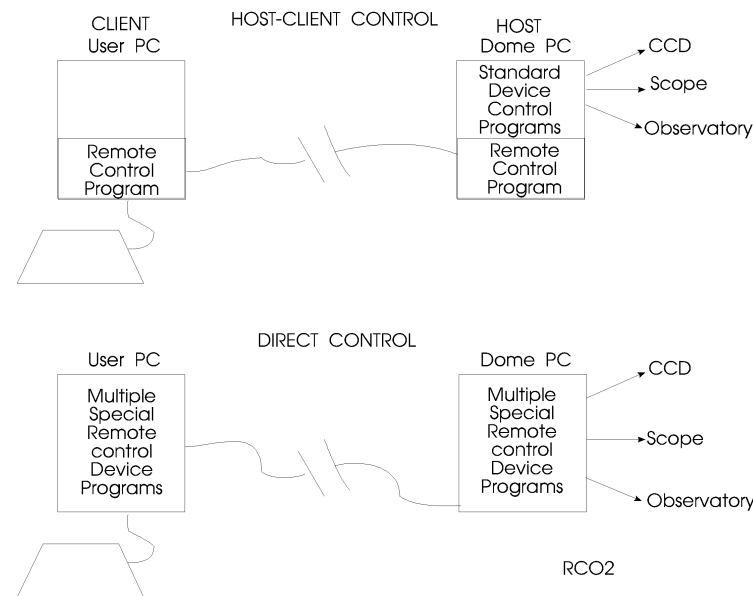
Control System (Software)

In our reference observatory example, we plan to run the device control programs in the Dome PC and the user sitting at the User PC; however, other arrangements are possible. Let us look at this issue in more detail.

The seemingly minor distinction of where the control programs are running carries major implications for program and system design and operation. As we shall see, this design choice can either expand or contract the types of hardware and software you can use. This control issue is one of the most subtle that you will face in your overall system design.

There are two ways of handling the control programs for the observatory devices:

- You can install the control software for each device into the **Dome PC**. You then use software on your control room User PC to “take over” and remotely control the Dome PC where the programs actually run. We call this **Host-Client Control** because the client user is indirectly controlling the programs via the host computer.
- Alternatively, you can install the control software (if designed for it) for each device into your **User PC**. Your programs then “simply” communicate through the Dome PC to each device. The Dome PC must contain special software to sort out which port (device) will be activated to execute each command. We call this **Direct Control** because the user is directly controlling the programs on the User PC



Note-Direct Control and Direct Link are not the same terms: Direct Control is a software term, Direct Link is a hardware term. Direct Control is used to describe the use of programs in the User PC to control the devices directly, via the Dome PC. Direct Link is used to describe direct wiring from the User PC to the devices. In a sense, Direct Link uses special programs in the User PC to act as though it were connected Directly to the observatory devices. In contrast, Host-Client control uses a standard remote control program in the User PC to control the Dome PC, which is connected directly to the observatory devices.

Host-Client Control is most widely used because it can be used with all existing hardware and software. Direct Control requires specially written programs. However, it may offer faster performance in some applications.

Before getting into this, be aware that there is an enormous confusion of terminology in this area. Unfortunately, similar terminology “Server-Client” is used to distinguish the role of computers in a network. The term “Host-Client” is, however, used by the vendors of remote control computer software. To make things more confusing, some persons use the term Server-Client for what we call the “Direct Control” case.

In the **Direct Control** mode, the instrument control programs run on the **User PC**. Commands and data are tagged with the component identifiers and sent over the communication channel into the Dome PC. There they are unsorted, and sent to each instrument in the dome (e.g., CCD camera). Returning data follows the reverse path. This system is sometimes called the “client-server” approach.

For many devices, this is fairly simple to design. These are devices that contain a fair amount of “intelligence”, and can operate autonomously with only simple, high level commands. Our dome control system is an example, as the control computer need only send simple commands (e.g., “OPEN”) and receive back short data packets.

Other devices, however, may require an intimate connection to the controlling computer — the typical CCD camera is a good example. Although commands might be relatively simple (“take a four second exposure”), the returning data (the image) may be a large and complex set of data. There may also be fairly close timing requirements between some of the commands and the data streams. Thus, the device may be affected adversely by transmission delays, especially over the Internet where delays may be a second or more. While it is possible to write software to handle this situation (usually involving splitting the program between the User PC and the Dome PC), there is little available at the present time. Such programs tend to be expensive, and may be limited in the range of hardware types they will support. Note that if you want to use a several different control programs, **all** the programs must support Direct Control—you cannot mix and match.

The alternative (and more common) method of control is to use **Host-Client**, which uses a commercial two-part Remote Control Program (RCP) to control the Dome PC and the device programs that are running in the Dome PC. To operate in this mode, one starts the RCP (client) on the User PC and connects to the Dome PC (via network, phone line, or Internet) where the RCP (Host) program is waiting for the call. Once connected, the user then can sit at his own keyboard and monitor and remotely operate the Dome PC. He would start and run any chosen programs, operate the telescope and camera, etc.

Note that the Dome PC must already be running the RCP program in a “waiting” mode so that the programs can connect. If for some reason the RCP program is not waiting (e.g., Dome PC crash or other computer or communication problem), then the connection cannot be made and nothing can be done. One of the issues in long distance remote control observing is how to increase the reliability of this process (discussed below).

The advantages of this Host-Client system are

- Flexibility — any mixture of programs can be run on the Dome PC
- It is easy to add new hardware with new software

- Network support services are available (see below)
- Inexpensive – only one copy of each of the many observatory component control program is needed for the Dome PC (plus one copy of the RCP for each user).

What is the downside? Operation may appear slow as the graphics (Windows) data are transmitted from the dome to the user. The actual time to transmit a graphic is not much different from Direct Control; however, all RCP programs seem to have lag time before any action starts after any mouse click. This lag occurs in the dome (host) computer and can be several seconds for each key click. In an experiment, we found that the lag time can be reduced with a fast computer as we saw lag times go from 3-4 sec at 150MHz to about 1 sec at 500MHz. Once the action starts, the time to transmit the screen update depends on the amount of data to be sent and the speed of the communication line. Speed is not very dependent on the user (client) computer. A more typical menu selection on a program might take an additional 5 seconds on a slow line, and one second on a fast network. A full screen image might take 10-20 seconds over a slow phone line and 5 seconds over a fast network. For persons accustomed to fast response systems, this will seem slow. However, in practice, most users find that it is not a major problem.

To gain faster operations, many users go to a minimal 256 colors, rather than other higher color settings. Color settings are present in the windows desktops in both computers, as well as in some of the RCPs (e.g., PCAnywhere has its own color settings in both the host and client). All of these settings must match, or you may get very poor video performance (ie., poor images transmission). It is also possible that some programs (especially those written in VB) may designate colors that are not in the 256 set. In this case, depending on which program window is selected on the desktop, you may get a variety of psychedelic colors. There is little to be done about this except to live with it or set the system for more colors (and slower operation).

You should also be aware that there are many conflicting claims that this or that RCP works well or doesn't work well. In practice, we find that for many persons, any of the programs work well. However, in some users' setups one program will work well while another may be incredibly slow or may crash often. The moral is that if you have problems that seem not to be solvable, try a different program. And don't be intimidated by those who claim that some program is impossible to use under some circumstance!

The RCP usually contains a variety of services that you will need, especially if the Dome PC is on a public communication system. These services should include:

- Security/Passwords. The program should provide several levels of password protection. Passwords should control where in the computer the user can go, what files can be looked at or moved and what operations can be carried out.
- Log Files. The program should be capable of recording who is connected, what programs they ran and other session information.
- Remote Configuration. The RCP should allow the administrator to configure the program for different purposes remotely.

An interesting characteristic of these programs is that you can actually run two at once on a network. For example, the Dome PC might communicate with one person using VNC while another uses PCRemote (an interesting experience as the two users can interact!).

Because a user may access several different observatories on the same night (or even at the same time!), avoiding confusion as to which one you are using is important. The easiest way to do this is for each of the Dome PCs to have very unique wallpaper, i.e., don't just name one OBS1 and the other OBS2!

Because this control issue is new for many people, we have tested several of the popular programs. The results are shown in the table.

What are the relative advantages and disadvantages of Host-Client vs. Direct control?

Host-Client control is probably the most widely used option at this time. One can choose among several general purpose, time tested remote control programs that offer quite high reliability, support a variety of

communication systems (phone, network, Internet), contain logging and password protection, etc. A major advantage of the Host-Client control is that you can use it to operate any software in the Dome PC. Many excellent instrument control software programs do not support Direct control, but Host-Client control allows you to use these programs without modification. No inter-program compatibility issues arise, as each program is running as designed (in a Windows environment). Another advantage is that each user in a multiple user system only needs to have one program, not the full set of device control programs.

One of the most frequently cited disadvantages of Host-Client control is the slow response time for the User PC. This objection arises with users who operate in a Windows environment and require transmission of a large amount of graphics data. Obviously, this problem reduces if the communication baud rate is high, as is increasingly the case.

Program	Pro	Con
PCAnywhere	This is a common program that has been around for many years and is in very widespread use. It has very good services (passwords, log file, file transfer, chat functions, etc.) and configurability. It is reasonably easy to use and as robust as any. It can operate on RS232, networks, the Internet or telephone systems	It is fairly expensive (about \$170). Transmission of full screen images is pretty fast, but it has about the same irritating lag time for even tiny screen changes as other programs.
PCRemote	Functionally, this program is a scaled down version of PCAnywhere with a reasonable amount of password, logging, and supervisor functions and is reasonably configurable.	The purchase price is about \$30. Speed is about the same as PCAnywhere.
Timbuku	This is a shareware program available at www.netopia.com/software/tb2/win/ . It "offers users a scaleable, multi-platform solution for user support, systems management, telecommuting and collaboration across a LAN, WAN, the Internet or dial-up connections It has file transfer, integration with Windows Network Neighborhood, intercom and chat capabilities and an Internet locator service.	The purchase price is \$129.95. This program seems to update the screen much more slowly than PCAnywhere or VNC.
VNC (Virtual Network Computing)	This is a freeware program available for download from www.uk.research.att.com/vnc/ . It runs on a wide variety of platforms and allows control of one platform from a viewer running on a different one. It's small (150K) and simple. It can be run from a floppy (instead of being installed like other remote control programs) and shareable (meaning one desktop can be viewed by several viewers at once.) It's free.	Its disadvantages are that it is a control program only, there is no file transfer capability included. It operates only on a network, does not include dialup and other services, and has no online help.

Direct control can offer faster response on slow communication lines because a higher level of data is being transmitted more of the time. Of course, once an image is taken, the time to send a copy of the file is about the same in both cases.

Disadvantages of Direct control include the need for all the device control programs to support the protocol. The programs may be hard to find, and tend to be expensive. For example, to provide direct

control for many CCD cameras, there must be a substantial program component in the Dome PC; i.e. the Dome PC is not simply a gateway for commands. This raises the complexity of the program and its maintenance. Nevertheless, more such programs will eventually become available and Direct control will become more feasible.

Internet and Network Operations

Many users have a vision of operating the remote control observatory over a local network or the Internet. There are many ways this can be implemented, and we will examine several (in order of complexity). The advantages of the Internet are sometimes oversold. For this type of use, the Internet simply offers an alternative communication link which may be cheaper (but not necessarily simple).

If the project is satisfied with non-realtime operation, the user simply submits a request to the observatory "site" for particular images to be made. This can be done using a simple form for submission of the request. The observatory staff would then take the request and conduct the operation and the resulting files could be sent to the requestor.

However, Real-time remote control operations are more complex. In general, the user wishes to operate the target computer (DomePC) from a remote location. This is not just a matter of logging onto a web site and downloading files. Rather, it requires actual operation of the target computer (either the DomePC itself or a computer that can establish a direct or Host-Client link to the DomePC). In general, this requires that the target computer must have a complete address and the user must know that address to be able to access the target computer (the address is a multidigit number that uniquely identifies the computer). A computer that hosts its own web site, or one that is on a network hosting a web site, will have such an address (you can get the address from the system administrator).

The target computer would normally be running the host side of the control software (e.g., PCAnywhere waiting). The remote user would use the client side of the control system (PCAnywhere calling). Using the target computer address, the call would be made whether over a local network and/or the Internet and the connection established, just as for a direct link or telephone connection. If the caller and observatory are both on the same local network, there is little operational complexity. If part of the link is over the Internet, the characteristics of the Internet itself will come into play, especially the variable transmission delays (one of the characteristics the control software must accommodate).

If the target DomePC computer is on a network hosting its own web site (or if the target is a web site), it will have a fixed address which the remote user can be told. However, if the DomePC is a web site or on a network served by a web site, the DomePC in theory might access the web via a dialup connection to an Internet service provider which will assign a temporary address each time the dialup connection is made. This setup will thus require an action by the DomePC to initiate the connection, and will require other Internet "tricks" to make a connection with a potential user (i.e., calling actions would be required at both ends of the links). For this reason, this does not appear to be a practical system—effective remote control requires the observatory to be associated with a particular web site. Note that it is only the target whose address must be known. The user can dial up over the Internet from anywhere and make connection to the observatory (assuming the correct control software, passwords, etc.).

Now let's look at alternative connection scenarios.

- The RCO might have its own modem and be connected to a telephone line. The users would call over the phone system, connect, and use the observatory. The system is simple, and easy to administer. The costs to the host depend on the phone service used, but would normally be no more than the phone line cost. The user will bear the connection costs for the session (several hours), and may be substantial.
- The RCO is on a network having its own domain name. The inside users would simply call over the network to the observatory, establish a connection, and operate. Outside users could call their ISP, connect to the Internet, contact the observatory DomePC, and operate (or the local network might have an outside inbound modem to allow outsiders into the local network). Inside users achieve fast, easy service, while outside users have only their local phone costs.

- The RCO is its own domain. Its connection to the Internet may be a continuous line (phone line, T1, etc) or it may be only on demand (when an inbound Internet call arrives at the service provider). This is highly flexible, but requires the most “overhead” in both administration and cost.

These alternatives involve various tradeoffs of cost and flexibility. However, in all cases, once you expose the observatory system to the whole world, you will want to be sure to have extensive password and other protection. Some remote control software such as PCAnywhere does contain these features; however, other software does not. If you are using a direct control system (i.e., integrated remote control software), you will also need to protect the system from intruders. Be aware that some of these systems may not have extensive protection, or the writers may not have much experience with it.

These approaches are all ways of using the “normal” remote control methods to operate over the Internet for at least part of the communication link. More ambitious is the idea of allowing a user to employ a browser (e.g., Netscape) to access a site and operate the observatory, i.e., without having to employ PCAnywhere or an integrated astronomy program. The advantage, of course, is that users of such a site do not have to have specific software to use the observatory. While such a site that allows operation with only a browser can be developed, this would be a very large effort, especially if it is to be able to operate a wide variety of observatory equipment. Never the less, various persons are attempting to develop such systems, and they will surely meet with at least some success.

Computer System Reliability

In the case of a nearby observatory, a problem in the communication or control system is easily handled: the user simply goes to the observatory and fixes it. However, at long distance, a failure of the system means there is nothing the user can do until someone or something fixes the problem. To accomplish a reliable long distance RCO, the designer must consider and eliminate as many sources of failure as is feasible.

Techniques to increase the physical reliability of the system are discussed in detail in Chapter 7, The Observatory and Control System.

Computer software reliability issues are the most common problems you will encounter. Even though the Dome PC may be electrically sound, the operating system or programs may not be crashproof. Windows programs are well known to crash or hang up in normal operation. However, in a remote operation, we demand that the software run flawlessly for weeks, and be always ready to make a connection with a remote control program. Many users find that the probability of some type of software failure will approach 1-3% per day. For a nearby set-up, this is not a big problem because you can simply go to the observatory and reboot the machine. However, a long distance remote site requires a system to detect and correct all types of software failures.

You may experience software failures during connection or while a program is running. Thus, even when on line, the system or program may crash or hang in such a way that you can do nothing.

We have seen the case when the Dome PC programs locked up. However, PCAnywhere on both ends was still running so that the user could reboot the Dome PC by remote control. Unfortunately, when the user rebooted the Dome PC, Windows closed the PCAnywhere program in the Dome PC first, but the next program to close as part of the rebooting process brought up a message requiring that the user acknowledge it. Because the PCAnywhere had already closed, the remote user could not even see the message and system rebooting stopped. Even though the communication link was still running, the user had no control, and had to go to the dome to hit the Enter key. (Incidentally, the dome still would have closed automatically as a result of protections within DDW!)

In sum, Windows running on a PC was not designed for this type of service and has potential problems in it. On the other hand, there is an incredible variety of inexpensive hardware and software that is designed for Windows. Some persons may wish to go to different operating systems or machines to gain more

reliability. However, even if it is better (and there are always new bugs!), most users will not have that option and will instead set up a Windows system that can handle these types of faults.

The best solution for this problem appears to be to provide for a rebooting system that will activate when any part of the Dome PC system fails. This will be a Power Off Reboot, as any lesser Reboot may not be effective and PCs do not provide for an external reboot connection. Because the types of faults are varied, such a system must be carefully designed.

In the case of the DDW dome control system, we have a RoboReboot system available as an option. Briefly, it uses several tests to determine when to cutoff power to the Dome PC to perform the PowerOff Reboot. One test is a type of watchdog: if the DDWCP inquiry fails to arrive within 8 min. the dome will close and the DDW RoboReboot will reboot the computer. Note that the Dome PC must be a type that restarts when power is applied. Some computers require that a “Power” button be pushed every time power is applied. In this case, the computer may require a modification to allow the RoboReboot to start the machine.

Custom Software and Scripting

The designer of the system may evaluate available software and conclude that none of it has quite the features he wants. Or he may want to have two pieces of software work together that were not designed to do so. Developing custom software control can be as simple as writing a several line script to get data from one program to another, or it may require a major investment in program writing. In this section, we will explore a few of the alternatives.

Most commercial software is “closed”; i.e. the user cannot get at the source code to make additions or changes. This is not true of all software — some manufacturers make their source code available. In addition, there is a fairly large freeware market where much of the software is “open source”.

An increasing number of software developers are becoming aware that their users want to be able to customize applications. Here are four different approaches in today’s marketplace.

1. **Include Everything.** Some of the commercial software companies deal with this desire by attempting to include every option that everyone wants in their software. Such software is highly integrated and will meet the needs of many users. However, it tends to be expensive, large, and complex. If it does not offer some feature you want, you may not be able to operate all of your hardware.
2. **Joint Development.** Another approach is for a supplier to identify potential benefits from working with software from other developers. This can lead to joint projects between manufacturers. An example of this is that several telescope control software developers have incorporated simple changes to export the telescope direction information so that the dome can be slaved to the telescope movements.
3. **Interprogram Data Transfer.** Other software developers provide a means of receiving and sending data and commands. For example, a telescope control program might provide a means for accepting telescope movement commands, while responding to external queries for telescope position data.

One simple method for doing this is for the program to support reading and writing simple text files. Thus, an external program might write a text file that includes the command “OPEN”. The dome control program might check this file every few seconds for new entries, would then open the dome and write data to a similar text file for external programs to read. This method is simple and easy to implement, but it is not real time, and cannot offer tight control and interaction.

4. **Scripting.** A more complex, but powerful interactive method is to use a form of “scripting”. The most common is a highly structured but fairly simple to use system supported by Windows called ActiveX. Using ActiveX with programs supporting the system, the user can write scripts that will command different programs to execute commands or provide data. The system can allow the user to develop his own

complex processes that might operate more quickly and accurately than “manual” program operations. Obviously, it is also feasible to use scripting for automated operations (see Chapter Seven for more on this).

ActiveX has a steep learning curve for the writer and it requires that the programs support the desired actions. In 1999, a coalition of astronomy vendors developed a standard called “ASCOM” (Astronomy Common Object Model) to make scripting more widely available to astronomers. ASCOM is discussed in a Sky & Telescope article (May 2000). ASCOM also has a web site <http://ascom.dc3.com>, which includes substantial discussion of the standard and a growing “library” of scripts.

Summary

Both Nearby and Long Distance remotely controlled observatories are entirely feasible. In general, the user will probably have a Dome PC, a communication link and a User PC. Remote control software allows very flexible choices for operating programs that control equipment in the observatory. A PC Windows based Long Distance installation must provide for detection and correction of failures of the software system to achieve reasonable levels of reliability.

5. The Telescope and Its Control System

Introduction

In this chapter, we describe how to control the telescope in a remote observatory and what some of the problems and solutions might be. We will assume the Long Distance reference system that uses a computer-controlled mount on a pier, CCD camera and software running in the Dome PC. The user controls the system using the Remote Control Program (RCP).

This section is NOT a tutorial on using computer-controlled telescopes. We assume that you are familiar with such instruments, how to setup and align the mount, how to balance the system, how to arrange cables so as not to snag, how to establish computer link with the telescope, etc. Our focus is on the special problems of operating such a telescope remotely, especially at long distance.

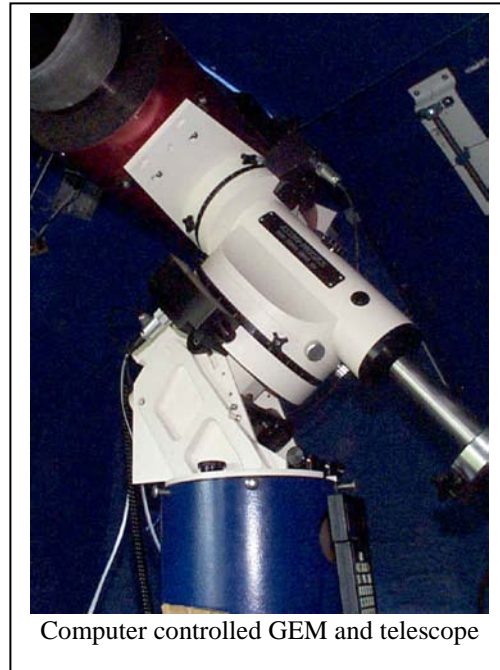
As part of our discussion, we note the features and shortcomings in computer controlled telescope systems now on the market. They are not yet as convenient as they could be for remote use. To help the user select a system (or at least, to know ahead of time its limitations), we include a table of functions that are desirable in telescope hardware and software.

General Mount Considerations

In this section, we will discuss telescope mounts in remote control astronomy. The telescope and mount may be manufactured as a unit or they may be separate items. For example, the popular LX200 series of S-C telescopes include the yoke mount as part of the instrument, while the telescope and German Equatorial mount (GEM) for our reference system are manufactured by different companies.

The most basic requirement is that the mount be capable of computer controlled movement so that it can be remotely controlled. Nearly all the available mounts use control commands that are similar to the LX200 set for which there is a fairly large amount of control software.

You should know whether your mount uses servo (small DC) motors for their drives, or stepping motors. Stepping motors tend to be less expensive; however, they do not have as wide a range of speeds as a servomotor. At high speeds, their torque decreases significantly. Thus, stepping motor driven mounts tend to have low slew rates (1-3 deg per second), while servo controlled mounts can move at about 10 deg per second.



Computer controlled GEM and telescope

The higher speed is an advantage in imaging a large number of objects around the sky. High speed tends to go along with greater power, which allows the mount to carry more weight or a higher moment of inertia telescope. A mount with a stronger drive can handle a greater imbalance in a telescope setup without drive slippage. It can be difficult to balance a telescope in all directions and it is a real pain to have to rebalance a telescope even for small changes in the optical setup.

Issues related to the type of drive include the precision of the position readout, how accurately the telescope can be pointed around the sky, and how accurately the mount will track a celestial object once it is found. Although remote control vs. hands-on use does not impose any unusual requirements in these areas, it is especially desirable in remote operation to have accurate pointing to minimize the recalibration problems.

Ironically, in many installations, the inherent pointing accuracy of the mount is likely to be better than the quality of the alignment operations carried out by the user. With very good setup, one can typically achieve a pointing accuracy of several arc minutes around the sky (a few do better, but many installations do much worse than this).

At the risk of alienating partisans of particular mounts, here is a list of the currently available mounts with some level of remote control. These are relatively low priced units — professional level mounts are available from other suppliers at higher cost.

Mount	Description	Comment
Combined S-C telescope and Yoke Mounts		
Celestron Ultima	8" S-C telescope on yoke mount. About \$2-3K.	May have problems carrying large camera. One model very suitable in wide-angle CCD use.
Meade LX200	8-16 inch SCT on yoke mounts. About \$2-16k	Most popular telescope, widely considered a good value.
Meade ETX Series	3-5 inch SCT on yoke mount. \$500-1000.	Not generally suitable as it will not carry large CCD camera.
Separately available German Equatorial Mounts		
AstroPhysics 400-1200	Four sizes. High quality, telescope size to 16 inch. \$3-9K	
Bisque Paramount	Current model uses stepper motors. High quality, telescope size to about 11 inch. \$9K	Recently improved with servomotors and other changes. Mount requires PC to access major functions
Vixen Polaris	Medium quality, handles smaller telescopes \$1-2K	
Meade 750	Medium quality, handles small to medium telescopes \$2-3K	
Takahashi	High quality.	
Parallax	Various sizes, uses AstroPhysics control system on Parallax mount	

Pier

Your mount will sit on a pier or a tripod. While a tripod takes up more floor space than is usually desirable, this matters less in remote operations where the human is not in the observatory. Again, remote control does not impose any particular requirement on the pier design. Because no one is in the dome when observing, the pier can in principle be less solidly mounted than in hands-on installations. On the other hand, in a long distance installation, if the pier shifts its alignment (misaligning the telescope), it will usually require a personal visit to the site to restore proper alignment. In general, a solid, stable installation is highly desirable.

Mount Physical Alignment

All computer-controlled telescopes provide for re-calibration (sometimes called resynchronization), which is often needed when a telescope is powered up or unparked at the beginning of a session, and sometimes during the session. **Re-calibration** is distinct from the basic mechanical **alignment** process by which the polar axis is aligned along the earth's axis using on-site adjustments. This is done as part of the initial installation of the mount. Many computer-controlled mounts include a hardwired capability to help this

mechanical alignment process, while others provide such assistance via software. Of course, one can also align a mount without any computer assistance but the process takes much longer. Once the mount is aligned, it should remain well aligned for long periods, assuming the pier and footings are stable.

Note that some software allows the telescope to be accurately pointed even though the mount is misaligned to the polar axis. T-Point from Software Bisque, for example, “calibrates” on several dozen stars. The software then measures the error in the mount alignment and corrects for that error when sent to a particular object. This solves the alignment problem but does not prevent the residual alignment error from contributing to field rotation during long time exposures.

The degree of tolerable alignment error depends on how you are using the equipment. Many amateurs successfully operate with alignments off by more than a degree. However, for long time exposures and for accurate remote pointing, alignment to a few minutes of arc is usually necessary. This degree of alignment precision is completely feasible, but requires care to attain and a stable system to keep.

Even if the mount axis is properly aligned to the earth, the optical axis of the telescope may be misaligned with respect to the mount axis. This may arise from a mechanical misalignment or from the optical axis being shifted relative to the physical axis of the telescope. A misalignment of only .010 inches on a 24-inch long mounting plate is 1.5 arc-min, and will introduce a 1.5 arc-min error in pointing. It is easy to have 10X this error, especially in any telescope including adjustable mirrors.

This is not usually a serious problem in commercial S-C telescopes on fork mounts, as the mount and telescope are aligned at the factory. However, it can be a serious problem (called “orthogonality”) for a telescope mounted on a German Equatorial mount. Rotation of the telescope 180° (necessary as a GEM moves from one side to the other) will introduce a serious pointing error if the telescope optical axis is not perfectly aligned with the mechanical axis. The solution involves performing aligning steps with the telescope flipped in both directions, and adjusting the optical parts or inserting shims to align the optical axis properly. Failure to do this accurately is a major source of pointing error in GEM systems.

Starting the Telescope : Parking/Unparking

In a typical observing session, you will begin by connecting to the Dome PC, start the dome control program, and open the dome. You will turn on the telescope mount, then start the telescope control program in the Dome PC. However, before you can move the telescope, you will need to Unpark it from whatever position it had been parked. To understand Unparking, we need to understand how Parking is done.

Before we do *that*, you should be aware that different manufacturers apply the term Park/Unpark differently. We will use it here in the broadest sense — the actions used to allow the telescope to be left for a long period of time, but ready for reuse.

Remember that most computer-controlled telescopes and mounts were NOT designed for remote operation and so do not contain the protections or services that a RCO needs. For example, in most computer-controlled telescopes and mounts, the drive runs continuously in the sidereal tracking mode. That is, if left alone, the telescope will rotate until something stops it (e.g., mount hitting the pier, wires wrapping around the mount, short circuit that burns out the motors, etc.). Simply turning off the telescope is not an option, because this will cause most scopes to lose their calibration (knowledge of where they are pointing). However, if the scope control software can record the position before the power is removed, then when re-powered, the telescope control program can properly recalibrate the telescope. Some software products have these features, and scopes and mounts are also beginning to incorporate these features.

There is an alternative to “simply turning off the power”. Most mounts do have a computer command that allows you to partially “park” the scope by at least turning off the tracking (usually by commanding a sidereal rate move to the east). Unfortunately, not all telescope software (or even hand controllers) will support this command. Worse news is that even for the scopes having this function (such as the LX200), if the power is interrupted and then returns, the telescope will probably again start tracking and will then wrap

its cables and may damage itself. This event can be prevented by deliberately (remotely) turning off power to the scope after parking it.

As you can see, parking is not a simple process. To build a reliable system, the user will probably want to assure the following:

- the scope can be directed to a particular park position. This may be one of several standard positions or it may be in any direction.
- movement (tracking) can be stopped
- power can be turned off and on remotely

To unpark the telescope, the power would be turned back on (e.g., via the remote power option in the DDW). Once turned on, the telescope will usually need initial calibration information so that the telescope would now know where it is. These data may be supplied from the scope control program, auxiliary program, or parking control hardware. In some cases, the mounts will have stored the parking information so unparking is simple.

These actions can in principle be carried out either using software (using the scope control program or an auxiliary program) or in hardware (a controller that is dedicated to assuring parking under all conditions). Each has its advantages and disadvantages.

Let's look a little closer at **where** the telescope should be when you park it. In general, most users want the telescope parked horizontally to minimize dust on the objective. Some directions may be more convenient than others. For example, a German Equatorial aimed East has its counterweight straight down (out of the way), but if aimed south, the counterweight arm is horizontal (more likely to be in the way). Finally, there are some operations (e.g., taking flats) in which the user may want to park the telescope in non-standard positions. Although at the moment, parking is not well provided for in software, this situation is changing rapidly.

Software Parking. Software parking/unparking options are few. Only a few scope control programs support commands related to parking/unparking, and none support all the commands for more than a single scope. Even if they support the commands, the programs are not configured for convenient parking and unparking, especially to allow the power to be turned off. It is feasible to write an auxiliary program to provide parking and unparking, but these are not generally available.

Hardware Parking. Another Parking/Unparking option that will soon be available is a hardware based system called RoboPark. Using this system, the parking action would be triggered by either a software command from the scope control software or by another action (such as the dome closing). The RoboPark unit directs the scope to a known park position, and shuts off the tracking. Power can then be turned off. When the power is turned on, RoboPark automatically unparks the scope.

A software solution would likely be less expensive than a hardware solution, but would not likely offer the same capabilities to provide power off parking, automatic parking in event of computer crash, etc. These functions, of course, are very important in a remote operation.

Re-calibration

In any case, once unparked, you can then use the telescope software to direct the telescope to a known object (the moon, planet, or a star), and use the CCD imager to verify that the telescope is aimed properly. However, you may find that the telescope calibration is incorrect, thus causing the object not to show up when you take the image. The telescope is not pointing where you think it is and you are 20 miles away. What do you do now?

Unless you have planned ahead, there are only two choices:

- You can visit the site and re-aim the telescope (a 20 mile trip?)
- You can attempt to search for a known object. You might be lucky; however, a systematic one degree search using a typical scope/camera could take over 200 exposures (good luck!)

However, a better solution is to recalibrate remotely. This is feasible, but requires advance planning and some experience.

The problem is that even if the mount itself is properly aligned mechanically, the pointing electronics may still be confused as to where the telescope is aimed in RA and Dec, i.e., its “calibration”. When the telescope calibration is wrong, the telescope “thinks” it is looking at a particular RA and DEC, when in reality it is looking somewhere else. Thus, when the user directs the telescope to an object and takes an image, the object will not be at the center of the CCD camera and may even be completely off the camera!

Calibration (pointing) errors of 10 arc-min or more can be caused by orthogonality errors (mechanical optical misalignments). Nonmechanical calibration error sources include bugs in the design of the parking, power off, power up or un-parking routines, while computer clock or telescope mount clock errors (changes in clock errors from previous sessions) will cause calibration errors when restarting. Calibration errors may even be as much as 90 degrees or more, particularly if a cable snags during a slew motion.

Switching a mount to “lunar” or “solar” or other non-sidereal rate during a session can cause a mount to lose calibration during a session by a degree or more (this is rarely documented in the instruction books). If such a mount is then parked without having been recalibrated, when the mount is unparked its calibration will be wrong.

To correct a calibration error, you must be able to aim at a known recognizable object (e.g., bright star or planet) at a known position in the sky. You then use the telescope control software to order the telescope to “change its mind” to accept the new (known correct) pointing direction: this is the calibration or “synchronization” process. The operational problem is to find that known object. If your only tool is the CCD on the scope, its field of view is small and so you will find it virtually impossible to find the object even using systematic search methods.

Let’s look at some of the strategies for solving this problem by remote control.

A very small calibration error is easy to fix:

- You command the telescope to a particular star, which appears somewhere on the CCD image (but not at the center where it should be)
- Command the telescope to move slightly to put the object in the center of the image
- Calibrate on the new correct position (i.e., you command the telescope software to send the known star coordinates to the telescope and tell it “calibrate on this”). Some software, such as TheSky, calls this “resynchronization”.
- Go to a second object to check that you calibrated on the star you thought you had!

Often the calibration error is the result of clock errors or some tracking error that result in the scope being aimed West of where it thinks it is. If this is likely the case, you can slew the scope to what should be a bright star. You start your CCD in continuous image taking, then start the scope moving slowly eastward so that you will see the star pass through the field of view. When this happens, you reverse direction, get the star, and recalibrate. If the scheme does not work and you have not recalibrated, you can still slew back to your starting point.

If the object is completely outside the field of view but you think it is fairly close (say, within half a degree or so) you might point the telescope to something “big” like the moon or Andromeda or Orion Nebula. You could then take an image that will show some part of the object, figure out where you are, then roughly center the object by moving the telescope. Using the known position of the object, you then proceed as described above. Having achieved at least a rough calibration, you would then go to a star or planet, precisely center it, then recalibrate exactly.

If you think you are close but do not know which direction to move, you might want to conduct a spiral search pattern. Doing this easily is just wishful thinking at this time — virtually no software has this feature, so you would have to conduct this search manually.

The best and most flexible process to recalibrate for moderate pointing errors we have seen is to use a small wide angle viewfinder equipped with a simple video camera that you can use remotely. Options include:

- Video camera mounted on a wide-angle telescope or viewfinder to gain a larger field of view than the CCD on the main scope. This will usually give a field of only about 1-2 deg, not sufficient if the scope is far out of calibration.
- You can make (or buy) a simple video viewfinder containing a 2-3 inch fl objective. This will give a field of view of 6-8 deg or so, a very good compromise.
- You can also mount a video camera on the outside of the telescope tube. This will give a wide field of view (50-90 deg.), but this is so wide that you will have difficulty aiming the scope accurately enough for the main camera.

Thus, if the calibration error is less than the field of view (e.g., 5-7 deg.) you would use the video viewfinder to center the telescope on a bright object (star or planet) and perform a rough calibration. You would then refine the calibration using the main telescope/CCD. Used with a frame grabber card, a video viewfinder allows remote recalibration at low expense. However, this approach does involve the addition of cables, brackets, etc. onto the moving telescope. If you don't deal with this in a long distance operation, you can easily lose nights of operation due to the need to visit the site to recalibrate.

In theory, another method of discovering where the telescope is pointed is to use star field identification. Using the CCD camera, you could take a picture sufficient to show a number of stars (say, 20 or more). Computer programs exist that can compare the CCD star pattern to computer star maps (a program called PinPoint is one of these), and thus identify the sky location (the direction of the scope). However, for successful operation these programs rely on knowing at least the approximated direction of the telescope, or a very large scale (covering many degrees of sky). If you cannot satisfy these conditions (and you usually cannot in a radically miscalibrated scope), the computer time necessary for the analysis can be so long (many, many hours) that it is not feasible.

What if none of these imaging methods show results, indicating that the telescope is seriously out of calibration (e.g., more than 5-7 degrees away from correct)? Because you are "flying blind", you have no way of knowing whether you are a little off, or whether the scope is 90 deg off! Because you don't know where the telescope is pointed, you may even damage something by unknowingly slewing the telescope into bad positions.

The simplest method to obtain a rough calibration while protecting equipment is to have a video camera in the dome (this is discussed in detail in Ch. 7). Using this camera, you can look directly at the telescope and see very roughly where it is pointed. Watching the video image, you can then direct the telescope to a known direction (e.g., due east) which is accurate enough for the video viewfinder to take over.

Because of the limited resolution of the video picture, unless you take other steps, you will not be able to aim the telescope to better than about 20 degrees, still not enough even for a 5-8 deg. video viewfinder. However, there are simple steps that will achieve 3-7 deg pointing using the In-dome camera (thus close enough for a video viewfinder to take over). Possible steps include:

- Install a mirror or other target on the telescope so that the video camera will show alignment along the center line of the video camera. This is hard to set up and is subject to being bumped out of calibration. It is also difficult to know which way to move the scope to achieve proper aim.
- Install a small laser on the telescope which will place a bright dot on the observatory wall in a known position that can be seen by the video camera. This is fairly good alternative. The laser can be powered from the video viewfinder.
- On each axis, install a magnetic or mercury switch that would activate a small light to be seen by the video camera. The light could be battery powered (thus, no wires), and the switch would be placed so that the light rarely operates (easier said than done).
- Develop two easily recognizable lines at right angles to one another that can be recognized in the video viewfinder. These could be reflective tape on the inside of the dome, or they could be the roof and chimney of a nearby building. If the lines extend at least 10 deg or so, they can be tracked (even if too

close and out of focus) using the video viewfinder, and the intersection will show calibration to within several degrees.

- Low Tech/ Good Results: apply highly visible pointers or tape markers on the axes of the scope that are visible by the dome camera. These markers will indicate when the scope is at a known alt-az position(not necessarily the normal home parked position). In most setups, you can easily achieve better than 5 deg accuracy of pointing. This method is easy, and not subject to error.

Thus our recommended remote recalibration system includes

- Use of an in dome video surveillance camera that will show the approximate pointing of the scope
- A video viewfinder on the scope with about 5-7 deg or field, and the ability to locate the scope alignment to within 10 a-min.
- A scope control program will let you make relative movements in the sky, e.g., 5 deg E or N. If your program does not support such movements, you will have to point and click on the screen relative to where the scope thinks it is.

Let's sum up the process: Assume for example that the reference position to be due East at the horizon.

Recalibration would be as follows:

- Use the dome video camera to monitor moving the scope to its the its normal park position as accurately as the pointers on the mount (or other means) will support.
- At this point you know within 5 deg where the scope is pointing. Use your scope program to recalibrate the scope to this position. For example, in TheSky, this means clicking to the reference alt-az point (East on the horizon) and resynchronizing (recalibrating) the scope.
- Now, at night, slew the scope to the brightest object convenient (or use a daytime calibrated object). Use the video viewfinder to center the object (you may have to do a little searching). This should now be accurate to within 10 a-min, close enough to show on the main scope CCD. Recalibrate the scope again.
- Finally, use the main CCD to center the scope precisely, and recalibrate.

Yet another approach to recalibration is to find the Alt-Az of the telescope. If you know the alt-az, you can use most scope software to recalibrate the scope. For example, using TheSky, you can locate a spot on the screen that has the alt-az of the scope (this information is provided on the screen) and then recalibrate at that point on the corresponding RA and Dec.

One way to get the alt-az of the scope is to observe (using the CCD or video viewfinder) an object visible through the open observatory (a house, streetlight, etc.) If you have previously determined the alt-az of the object, you can then recalibrate. Of course, unless the target is illuminated, this trick will only work in the daytime. Many telescopes will be too far out of focus and have too narrow a FOV for this method to work well.

A completely different approach is to have electrical switches or even mechanical stops at a known position on the mount (this is a fancier version of the third alternative above). Some telescopes (e.g., the 16-inch LX200) have such "home" or reference switches. While this can offer a reasonably precise calibration, it is at the cost of installing devices and wiring onto the moving parts of the mount and usually requires compatible software to read the resulting data. The video camera is still very desirable so you can see what is happening!

In summary, telescope re-calibration must be a part of your system design. In a nearby application, simple re-calibration techniques may be sufficient. However, in a long distance observatory, faulty calibration is a serious potential trouble source, and your strategy to correct the problems that must be carefully designed and tested. Most such systems rely on a video camera to allow a view of the telescope and/or through an auxiliary telescope. **If** properly prepared, even large-scale re-calibration of the mount is easy in a Long Distance RCO.

Focusing

When operating the observatory remotely, how do you focus the camera? Or do you simply focus when you set up, then leave it alone?

In nearly all astronomical imaging, the focus must be at least very good. To get the best results, focus should be as good as you can get it! Many setups will show image degradation if the focusing is off by even a thousandth of an inch. Focusing is critical. It is almost never sufficient to focus the telescope and camera, then leave them alone indefinitely. In fact, many installations require focus adjustments every few hours. Shifts of focus result from mechanical looseness anywhere in the system: mirrors shift, eyepiece tubes bend, etc. and will often show up as the telescope changes its orientation. Temperature changes are a notorious cause of focus shifts, particularly with S-C telescopes.

Although there exist several motor-driven focusers that can be operated remotely, they are expensive, limited in travel motion, and are not “system designed” to operate easily at Long Distance. Some will not carry the physical loads needed from heavy or asymmetric camera systems with heavy cables. Many are very difficult to retrofit to existing focusers, especially on refractors that require long focus lengths. Others will slip when power is removed (not a good idea on a vertical telescope when the power goes off!) Finally, only a few have digital readout and position control, which is almost essential in remote, controlled astronomy. S-C scopes such as the LX200 can have simple motors added to the focus knob. However, these motors provide no remote readout, and are subject to backlash and other remote operating problems.

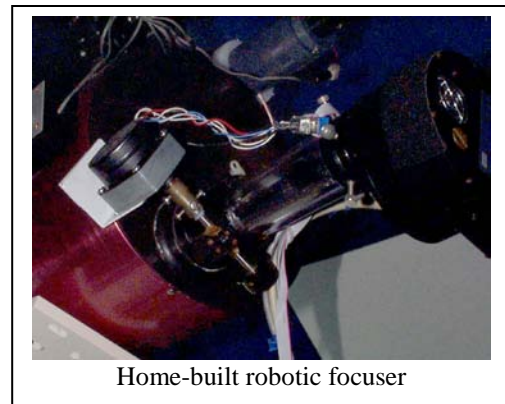
Before getting into the remote focusing process, remember that you will set up the telescope and camera (and other optical equipment) in a hands-on session. That is, you will install a desired mixture of lenses, filters, etc., and will then make sure the system is working (by operating the system with the Dome PC). You will perform at least coarse focusing. In many systems, this is hard to do in the daytime, for objects even a mile away may have very different focus points from those at astronomical distances.

Some telescopes will have both a rough and a fine focus adjustment. For example, if your SCT is equipped with a motor driven focuser on the eyepiece, the rough focusing can be done with the regular focus knob, while the motor driven focuser can be used for fine focus.

The remote focussing problem results partly from the time needed to complete a CCD image before you can see the result of a focus action. Focusing is more difficult if you focus on a non-point object (stars are easy), or use software that does not provide a good measure of focus (max pixel or FWHM). Focusing with a video camera is easier because it gives instant feedback.

In general, you want the best possible focus. This requires taking a succession of images, comparing them, and determining the best focus position, returning to it, and verifying the result. In practice, this process is difficult because most remote focusers do not have calibrated movements, or if a focuser has them, they may have substantial errors (especially depending on the direction of travel). Some remote focusers will not move slowly enough to allow 0.001-inch movements.

Part of the problem is in the hardware, but software can also make the process difficult. You will normally have two different programs running — the CCD program for imaging and the telescope program that usually contains the remote focusing control. Some CCD programs are clumsy in doing the many quick images desired during a focusing operation. The program may not allow multiple images to be retained on the screen, thus preventing image comparisons. The telescope focusing software may provide little or low quality feedback



Home-built robotic focuser

to the user of the focuser position (some use the time of motor operation as a surrogate for position). You will have to develop a strategy that suits your particular system.

Indeed, as this is being written, our company has released a digital focusing system (RoboFocus) that can be attached to almost any existing focuser. The system allows remote digital operation, and includes automatic backlash correction. Use of RoboFocus or a similar device will revolutionize how remote focusing is done.

In fact, it is easy to imagine a system in which the focusing program remotely directs the CCD to take successive pictures as the focuser changes the focus under computer control. The program analyzes the pictures for sharpness and sets the focuser to the best position. This product may be available before you read this!

Telescope Parking and Storage

When the observing session is finished, you should park the telescope in a standard location and turn off the power, if feasible. Different mounts and software provide for different parking arrangements, as described above. Within those constraints, there are several issues.

Some mounts provide no parking; some prescribe particular telescope positions, while others allow parking at the user's discretion. Choose the parking position after considering the various alternatives:

- Horizontal telescope and/or dec axis parking allows one to use a spirit level to do a rough re-calibration.
- Horizontal telescope parking tends to reduce dust settling on the objective
- Parking at one angle vs. another may reduce the chance of water dripping from the observatory roof from striking the telescope (we know of a telescope in a competitor's dome whose CCD camera became encased in ice as a result of a leaking shutter gasket).
- Some parking positions allow you easier use of space in the dome during visits to the observatory

This is a good point to discuss telescope storage. One consequence of remote observation is that it is not usually feasible to provide covering against dust for the telescope when not in use. With a reasonable dust free observatory and good parking geometry, this is not usually a problem with a closed tube telescope. Every six months or so, the dust should be cleaned off the objective (or corrector for the SCT). Removing dust is important, as it can combine with water (dew) and damage the glass or coating. If you have an open tube telescope (e.g., Newtonian), you will likely have more of a dust problem.

Another concern is the action of humidity or dew on the finish of the telescope, internal parts, or optics. Dew can form on any surface when the surface temperature drops below the dew point (when the humidity of the adjacent air increases to 100%). Humidity by itself causes few problems — it is the formation of dew (liquid water) that causes problems. In fact, most telescopes are quite resistant to damage from dew. Dewing is less of a problem inside an observatory than outside. In extremely humid climates, some users will place a dehumidifier in the dome to reduce dew. Others will turn on a light bulb (50w) or similar heater near and under the telescope to heat the telescope a few degrees. Usually, this is all that is necessary to prevent dew formation. Using a remote power control, you can turn off the heater when you observe.

You might think about remotely operated dust covers. These are not generally available, and would certainly add more complication and potential failure. In the end, most users find that a telescope in a dome, consistently parked in a safe position and reasonably cared for, is not seriously affected by the lack of a cover.

Summary

Although most computer-controlled telescopes are capable of extremely good results in remote service, most were not designed with remote control in mind. You should be aware that most telescopes and their associated programs do not contain extensive interlocks, error detection, and error or fault correction

routines. Telescope system failures often show up only when you attempt to take a picture and find the object is not there.

We have mentioned that most telescopes, once started tracking, will track forever. In a related problem, virtually no telescope or telescope software includes adjustable motion limits. That is, you cannot program how vertical or how horizontal the telescope can move in the various directions. At most, some mounts limit the movement close to vertical or limit movement to above the horizon. Often these limits are unreliable; they may only limit slew (fast) motions, while tracking is not limited. The limits may not be defeatable, so that if you need to “violate” the limit, you cannot do so. Nevertheless, limits on motion are such an obvious need (and easy to build into telescope control software) that they will surely soon be developed.

The German Equatorial Mount and the Yoke Mount each have their advantages and disadvantages. However, both mounts have motions or settings that are rarely properly identified. For example, as the telescope on a German Equatorial moves across the meridian, it will usually be flipped end for end (either manually or automatically). The telescope on a yoke mount has an analogous action, which is to pass through the forks or “go around the long way” to aim at a particular point in the sky. The control software usually does not make it obvious to the user when this event happens (hence one of the reasons for a video monitoring camera in the dome).

With either mount, there may be times when you want the telescope either to do or to avoid certain sequences of motions as it moves to some part of the sky. No present software provides for this function. However, with care (and often with the help of a video camera), you can deliberately take several slewing steps to move from one part of the sky to another, thus forcing a particular path to be taken.

In summary, at this time we are somewhat handicapped by hardware and software that does not effectively address remote control issues. This situation will surely change quickly, as more people demand these functions. Nevertheless, with reasonable care, you can conduct telescope operations with confidence and reliability.

Remote Operations Telescope Control Software Features

Control Feature	Description
Export telescope direction	Provides data to external programs to allow the dome to slave to the telescope
Alt-Az movement limits	Adjustable limits to control extremes of movement in both slewing and tracking modes. Should be easily bypassed.
Wire wrap prevention	Limits on rotation so that wires do not wrap even if telescope is left running
Park Functions	Most desirable is for user to park in any position, leaving power off or on
Tracking shutoff	Should be easy to stop and restart tracking
Alt-Az coordinates	Should be able to readout the Alt-Az coordinates of telescope
Alt-Az direction	Should be able to direct telescope to a given Alt-Az
Alt-Az recal	Should be able to recalibrate the telescope from a known Alt-Az position
Programmed move	Should be able to direct movement a programmed amount in given direction
Search	Should have convenient facility to do a spiral search
Power Failure	The telescope should tolerate and be able to recover from sudden power failure
External control	Should include ability to send commands to program and receive data in return
Show Data	Should have the ability for you to type in a command (which may not be supported by the software) and to view the response from the telescope (very useful for troubleshooting or for custom installations)
Ger Eq flip	Should support GE flip mode for the mount being used. Should tell user status of flip
Remote focus	Provide remote focus and position readout
Ephemeris	Should include the ability to insert orbit constants for comets or asteroids, and to insert them into the object database
Object movement updates	Should include the ability to send repeated GOTOs to the telescope to track objects such as comets that move relative to the stars
Low earth satellites	Should include the ability to drive the telescope to track low earth satellites. Most telescope mounts will not track fast enough, but some will.

6. Telescope Cameras and Their Control Systems

Introduction

Obtaining images from the camera is the “nitty-gritty” of observing from a remote site. In this section, we discuss aspects of camera design and operation that may affect remote controlled operation.

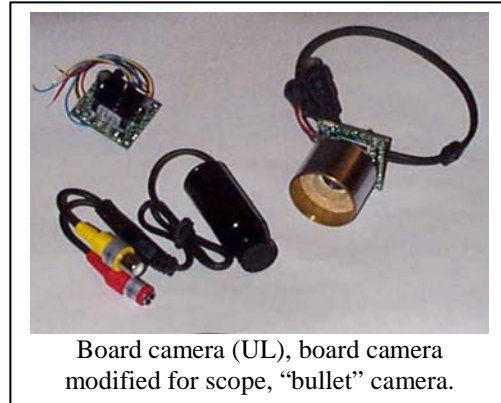
Types of Cameras and System Architectures

We identify several types of camera systems:

- Video Camera
- CCD camera
- Hybrid camera

A video camera can be placed in your eyepiece holder to produce real time, continuous images. In most cases, images are in standard television format, monochrome or color, and typically operate at 30 frames per second. The cameras we discuss here are standalone cameras (not combined video camera tape records), and range from a small \$50 general-purpose “board camera” used (usually without the lens) directly as a sensor (shown in picture), to a video camera designed for astronomical application. The

latter are in the \$500 range, and feature manual brightness control, lower noise levels, and wider dynamic range as compared to the board camera. Because the standard video camera operates at 30 frames per second and is uncooled, you are limited in how faint an object may be detected. In a typical setup, however, you can easily get excellent images of the planets and brighter stars and, of course, the moon.



Board camera (UL), board camera modified for scope, “bullet” camera.

The output of nearly all the video cameras is a standard video feed that can be sent up to about 200 feet. Many television sets can accept the feed directly, or the user might employ a RF modulator to allow the signal to feed into the antenna wires of a TV set. In any case, the TV will then show a live image, which can be observed, used to focus the telescope in real time, or recorded on any video camera or video recorder.

Images recorded on tape can be selected later one by one for analysis or for image processing. In this manner, it is easy to take thousands of images (say, of the moon) and then pick the 10 best for processing. The recorded images can be used as teaching tools as well. We recently met members of an astronomy club in Massachusetts who got funding to visit nursing homes, rehabilitation hospitals, etc. with just such a system, showing the telescopic skies to those who are physically unable to see them any other way. A very creative project!

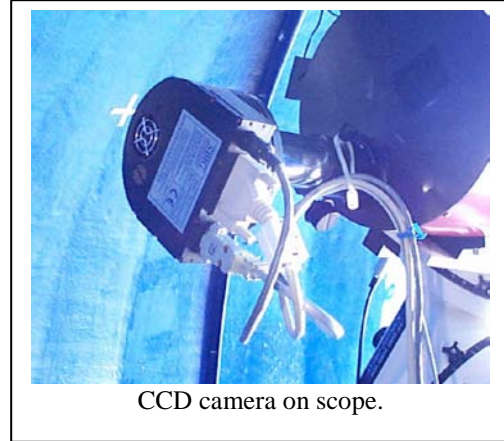
Instead of feeding to a TV set, the signals can be fed into a special board called a “frame grabber” (around \$50-150) in the Dome PC. This board will extract one video “frame” at a time and, with the proper software, will display it on your User PC computer monitor. Depending on the size of the image, you may obtain 1-2 pictures per second or as low as about 10 seconds per frame. The major limitation in remote operations is the limited rate of frames that may be sent over a computer used in the Host-Client mode.

In summary, the video camera used in astronomy is inexpensive and useful in a variety of applications.

- If used with a VCR, it can take thousands of images per hour for later analysis (e.g., to cull the instants of best seeing more effectively than a CCD camera)
- It can give live feed that is useful for centering objects or calibrating the alignment of the telescope
- It can provide “visual” information in installations where a person cannot observe (e.g., in a very small robotic observatory)

The second type of camera is the astronomical CCD camera (this is a misnomer, because the video camera also contains a CCD!) This camera is optimized for astronomical work in that it contains a cooling system to reduce noise and a shutter mechanism to allow long exposures on the imaging chip. It may contain additional guiding chips to allow frequent (every few seconds) readout so that star images can be used to guide the telescope. Most cameras are monochrome, and require multiple exposures with color filters to provide color images, but some cameras can take color images directly.

Nearly all CCD cameras require a computer to be connected, usually within a few feet (though some will operate 100 feet away). The computer software sends commands to the camera electronics and accepts the downloaded image data. The CCD camera tends to be fairly bulky and heavy (3-7 lb.) and may have several fairly large electrical cables connecting it to the computer (thus, smaller telescope mounts may not be rigid enough to carry the camera). CCD cameras also tend to be expensive, ranging from \$1-8,000.



Most CCD cameras can operate remotely without much difficulty if the connected Dome PC is close by. If the operation is Long Distance, then the user will probably operate the CCD control program in the Dome PC using remote control software such as PC Anywhere. At the User PC, the user will observe the various images and menu controls as in Nearby operation. Long Distance operation will be slower than Nearby, as large detailed images can take many seconds to transfer to the User PC. CCD files themselves can be quite large, so that actual file transfer can take several minutes if sent over standard telephone lines. Other than this slower operation, remote CCD operation presents no particular problem.

Software for CCD control and image processing is usually provided as part of the camera package. You also have a growing selection of third party software. It may be expensive but can offer substantial operating benefits (easier operations, faster operations, better graphics, more file type flexibility, etc.) In general, software that works better when on-site will also be more satisfactory at Long Distance.

The third camera type we have referred to as the “hybrid camera”. This new camera type has a design that combines many of the features of the video and CCD. The only example of this at the present time is the STV camera (SBIG). The STV with its own display (or a TV) and control box can be run as a standalone camera (i.e., without a computer) with real time or long exposure capability. It can also be used to guide a telescope using some other camera for imaging. The STV can be run remotely using the same techniques used with other cameras.

CCD Imaging Issues

We assume you have a reasonable knowledge of using a CCD camera in a hands-on environment, but there are issues that arise when taking images under remote control.

Color Imaging. If your goal is to take color images, you should know that most CCD cameras require using multiple images taken through different color filters. The images are then combined using computer-imaging software.

Even if you are doing hands-on imaging, it is not practical to take the camera off the telescope, change the filter, and then return the camera to the telescope for the next image. Aside from the awkwardness of the process, there is a great risk that the telescope will be moved accidentally. Even worse, when the camera is reinstalled, it is very difficult not to change the orientation of the camera, thus resulting in images that are more difficult to align (though some software does this very well).

Most people who do color CCD imaging use some sort of filter holder system. While some of these systems are manual, most use some type of automatic filter changers. In most cases, you will choose a filter changer that is compatible with the CCD camera software, so that the software will change the filters automatically as it takes the successive images. Such filter changers are reasonably reliable, but as usual, any Long Distance observer should make every effort to obtain the most reliable equipment available. Pay particular attention to self-diagnostics: if the filter changer becomes confused, can you regain control remotely.

File Handling. We mentioned above that CCD files might be large. There will be many of them. It is not unusual to produce several dozen 500K files in an evening of observing. Obviously, the Dome PC must have sufficient storage capacity. It is your job to consider how to store the files — decide your naming and dating conventions in advance, use multiple folders, etc. You must also have a strategy for winnowing the storage to get rid of old images!

In Long Distance operation, depending on the size and number of the files, and the speed of the communication link, the time to transmit all the files from the DomePC to the User PC may be substantial. There are several different strategies

- **PreProcess in DomePC.** You may choose to perform a substantial amount of processing in the Dome PC. For example, images can easily be dark corrected and flat fielded in the Dome PC.. If you do not have to inspect each image, you might also combine images (e.g., combine a succession of short exposures into one longer one), and then download only the result.
- **Later Download.** You may choose to batch download the files after the operating session. You can then process the images at the User PC at your convenience.
- **Download During Session.** When taking a sequence of images, you may be able to configure the software to save each image directly to the User PC, i.e., download each image as it is taken. At the User PC, you could then examine each image in detail, as well as perform preliminary processing. In unattended operation, communication failure may cause loss of images due to a lock up of the imaging program in the User PC.

Flat Fields. One of the processing steps in many CCD images is taking a flat field image (i.e., imaging a uniformly illuminated surface) for the purpose of correcting any CCD image flaws. There is a continuing debate about the best flat fielding methods, with partisans of “sky flats” (evening overcast), “dome flats” (uniform surface on the observatory) and other techniques. In Long Distance remote operation, these two methods will work. A problem with the sky flat is that the Long Distance user does not necessarily know the sky conditions very well enough.

The dome flat is probably the best alternative. Typically, this is a white Styrofoam board fastened to the inner wall of the observatory. The board is illuminated in a shadow free manner. The telescope/CCD camera is aimed at the board, and suitable images taken for later use.

In remote operation, there are two considerations. First, the dome flat must be illuminated. It is normally most desirable to maintain the inside of the observatory at a low light level (to avoid adverse effects of any light leaks or reflections in the optical system). Therefore, you normally want the dome flat to be illuminated only when in use, thus requiring a remotely operated light source. If you installed a remotely operated video monitor camera and light in the observatory, its light can be used to illuminate the dome flat, or you may have a separate light operating off the same remote control. (Note that DDW observatory control has such remote control



Interior of dome showing 24inch flat.

service available). Regardless of how the illumination is done, it must be uniform and without shadows on the surface.

The second consideration is that the telescope must be aimed at the dome flat. The flat might be several feet across, so the aiming requirement is not severe. However, in the case of our reference observatory design, the flat would be on the inside of the rotating dome, so its location changes as the dome turns. In practice, you want to take the dome flat with the dome and lighting in a particular orientation (e.g., the dome in the HOME position) where you know the Alt-Az coordinates of the flat. The problem then is to direct the telescope to that Alt-Az coordinate. How easy this is depends on the telescope (mount) and the features of the software. Some telescope software may not allow you to send the telescope to a given Alt-Az position. In other cases, such as planetarium software, you can direct the telescope by selecting stars in the “right direction”, verifying the Alt-Az, and then refining the pointing if needed. In our own observatory, the flat is at the horizon (relative to the scope), due SouthEast. It is easy to direct the scope to this direction.

Note that after being sent to the location desired, most telescopes will continue to sidereal track. If you plan to stay for long on the flat, you should stop the tracking or redirect the telescope back to the proper direction. Again, this action may or may not be easy to perform in your particular telescope software.

Finally, the dome flat may be located below the horizon of the telescope. If your telescope mount or software blocks slew movements below the horizon, this will prevent your using the flat. In some cases, this interlock can be turned off, in other cases not. Another placement consideration is that if you place the flat very low, the telescope will be in an unaccustomed downward direction. You need to be careful that there are no potential problems with snagging cables or other interference as the telescope moves to this direction.

If you have a video monitor in the observatory, you will be able to observe that the telescope is properly aimed.

Focusing. Focusing is always an important action when taking high quality CCD images. We have discussed focusing in the chapter on Telescope Control because at this time, remote focusing is usually a part of the telescope control program. In the future, it is possible that focusing will be increasingly integrated with the imaging process. Several users are actively working to integrate certain CCD imaging software with the digital RoboFocus system to provide automated focusing.

Physical Security. The CCD cameras and filter changers can be heavy and may have several stiff cables connected to them. Many cameras are not symmetric; that is, they are not cylindrical and will thus present rotational forces on the eyepiece holder. You must be sure that for all scope movements (i.e., not only the various directions, but also the paths to get there) the cables loop easily, do not twist and do not snag on anything. This will usually require a series of cable ties to various parts of the telescope and mount.

The twisting forces may cause the camera to loosen on the holder. The catastrophe, of course, is that the camera can fall off the telescope, but a safety chain or rope can prevent this (but only if you install and use it!) A more likely scenario is that as the camera loosens or rotates on its axis and the focus changes. To prevent this, consider installing additional clamping screws (three on each stage of the optical train are none too many) and check carefully that all camera set screws, nose extensions, etc. are tight.

Summary

Remote operation of CCD camera and/or video cameras with their software presents very few difficult problems. Reasonable attention to detail will prevent or address the problems.

7. The Observatory and Its Control System

Introduction

In this chapter, we discuss observatory control, including the features to look for in the control system. What operational problems arise when controlling the observatory remotely, and how will you handle them?

The reference system that we cited assumes a dome observatory controlled by our own Digital Dome Works (DDW) system. While this is our basic orientation, we note that most of the issues discussed here apply to controlling other observatory building designs, including roll off roofs.

We are not attempting to write a guide to observatory design and choice. Rather, we are focusing on those aspects of design that affect remote control.

Our philosophy for designing dome control recognizes that all other parts of the remote observing system can fail — the telescope can slip, the CCD camera can refuse to operate and/or the computer can go down. In any case, the observatory must **always** close to protect the contents. If for some reason the observatory does not close properly, it is essential that the user be aware of the fact. There is a burden on the observatory designer that is much less forgiving than for any other part of the system!

Observatory Building Design Considerations

The purpose of the observatory structure is to protect the equipment inside from the adverse effects of weather, while providing a suitable observing environment when the telescope is in use. In our reference case, we assume that the dome has a remotely operable shutter and rotation system (in the case of a roll off roof, the roof must be remotely operable). The electrical and mechanical systems must be robust so that there are minimal problems in operation. The observatory control system must itself be as robust as possible and must be able to identify failures of the other systems.

For a Nearby remote application, you have more flexibility in what parts of the dome operation will be under remote control. For example, you may only need the ability remotely to rotate the dome. In this case, a system can be as simple as a set of remotely operated relays. If you can see the dome, that may be sufficient to tell you the dome azimuth position. Other options are a simple external video monitor or electronic device for measuring the dome position.

An obvious refinement is to have the dome slave to the telescope. There are a variety of ways to do this:

- One can use a non-computer system such as our DomeTrak that can use infrared to sense whether the telescope is aligned with the slit and move the dome accordingly
- One can interrogate the LX200 to obtain its azimuth position, and operate relays to move the dome accordingly (DDW has this built in as an alternative function)
- One can obtain the telescope direction from the telescope computer control program and move the dome accordingly (this is the usual method used by DDW and other observatory control systems). Before you purchase a telescope control program, check to be sure that it will support this function.

Note that if the telescope is not located at the center of the dome or, if it is mounted on a German Equatorial mount, a set of mathematical transformations must be done to convert telescope RA/DEC into the correct dome azimuth. The telescope azimuth and the dome azimuth may be very different, so this is not a minor matter (the DDW control program normally handles this function).

Even a simple slaving system requires more than a series of relays. Rather, it requires at least some computing capability, either by a dedicated microprocessor or by connecting the relays to a computer that can operate them. Such a system as this presents reliability and operational issues. For example, if the

dome drive system stalls or fails, what is to prevent the rotation motors from being damaged? If the system fails, how will it notify the user?

A Long Distance operation places the even greater demands on reliability and robustness of design. In spite of careful design, components will fail on occasion. A major design challenge for the observatory control system is to be able to identify failure conditions, signal them to the user and then correct or work around the failure, either by built-in processes or with the assistance of someone on site.

Observatory Wiring Issues

Although this is not a treatise on general observatory installation issues, remote operation does require more attention to electrical installation questions. The most common question we get is “what wires should I install?” The answer is, of course, “It depends!” Nevertheless, a large fraction of installations can be served fairly well by the following advice based on our experience and that of many customers.

Safety. Be sure to follow local electric codes. Many areas provide for do-it-yourself installations (at least of the signal cables), but in all cases safety is an issue. Installation of the 120VAC system is particularly important to get right. A long extension cord is NOT an acceptable system for observatory power.

Burial. Most installations will require cables to be buried. We use direct burial of both power and signal cables if the run is long, conduits (usually plastic pipe) if it is short. If using conduits, make them big (2 to 3-inch diameter) and leave a pull string so you can add more cables later. If the power and signal wires are in the same trench, dig a deep trench, put in the power wires, then 12 inches of dirt, then the signal wires.



Typical conduit and wiring installation
(in 15 ft dome on wood wall)

120VAC Service. We usually recommend providing at least one 15A (120VAC) service, and preferably two (wire is cheap). Each circuit should have its own circuit breaker, both in the main box and in the observatory. You should have a main disconnect in the observatory. Grounding MUST be correct for both safety and lightning (transient) protection. See discussion below.

Signal Cables. The kind of signal and communication cabling to use is a more complex issue because the cable choice depend on what kinds of activity you are likely to do and the distance to the observatory (long runs over 100 ft. may require larger size or shielded cable).

If you are using a Direct Link system (direct RS232 control of each instrument), you will need a set of suitable cables. You can use ordinary telephone wire for runs less than 100 ft, but you may want larger conductors for longer runs. RS232 uses only two conductors plus a ground, so you can use shielded twisted pair cables. You may also need a parallel port cable for your camera, which can easily cost \$1per foot or more.

If you are using a Multilink system, instead of multiple RS232 lines, you will need a cable to connect the User PC to the Dome PC in a local network. Depending on your type of network, you may use coaxial cable or special twisted wires (usually what is called Category 5 cable). You may need to talk with your computer advisor to decide this issue. Runs up to 300-400 ft are possible with “standard” cables in most network systems.

In addition to the above cable, you will probably want other signal/control cables. These might include a coaxial cable for a short run video monitor, a run of #14 w/ground for general purposes and some twisted pair cables for controlling relays. You may also want to run wires for a telephone, an alarm system, or other purposes.

Finally, although it sounds simple, label both ends of all cables, both in the long runs, and inside the observatory itself. This is important for signal cables, but it is vital for the many power cables that connect to the various devices in the observatory. It is possible to destroy a CCD camera by plugging in a wrong polarity power lead!

Lightning. Another issue is often a concern about lightning. In most cases, it is not realistic to prevent nearby lightning strikes (this would usually require nearby, high, lightning rods). Instead, we usually act to prevent damage to the electrical systems. Nearby lightning strikes can induce very high voltages in wiring in the observatory or in the underground wires going to it.

The first line of defense against damage is to assure a good grounding system. This usually requires one or more long rods pounded into the ground close to the observatory at the ends of the cable run at the control room and at the observatory (better than the rod(s) is a large area wire grid buried underground). The rods are normally connected to the ground (neutral) power connection at the observatory power distribution panel. In addition, the ground would have a separate heavy wire connected to the telescope pier and to other major metallic items in the observatory, including the case of the computer (or even better, the network card itself). All grounds should be as short as possible, and made with heavy cable (#4 or larger) or braided wire.

Even with good grounding, voltages sufficient to damage or disrupt electronics either via the power or the signal wires may be present in event of a nearby lightning strike. Use a variety of means to reduce the likelihood of damage:

- Full service transient protection at the observatory switch box
- UPS for 120VAC service inside the dome
- Surge protectors on multiple outlet strips
- Lightning/transient protectors on RS232 and network connections

To give a sense of how severe the problem is, let us take a typical UNPROTECTED observatory including a remotely operated networked computer that is subject to a couple of moderately severe lightning storms a year. Such a system will likely sustain damage to some component every year or so in an area of average storm frequency in the Eastern US. The typical damage might be a network card (\$50 plus time to replace) or even the scope electronics (\$300 typically). A recent bad hit near (not on) a poorly protected observatory damaged/destroyed the mother boards and network cards in two computers, the CCD camera, and the telescope mount. Based on general experience, had the installation been reasonably thoroughly protected (grounds, protective devices, etc), damage in this case might well have been minor. On the other hand, one cannot perfectly protect—a low probability severe hit can overwhelm almost any protection.

In general, transient protection is desirable on all cables that inter-connect equipment. Thus, protection should be placed on connections that enter the computer (or other instruments) from the control room, as well as between components inside the dome (e.g., Dome PC to Telescope connection). Many instruments have NO lightning protection built in, so these are always at risk of damage. Contact the manufacturer to ask about lightning protection for your equipment.

The problem of protecting RS232 and network connections is rather frustrating to deal with. As noted, much of the equipment has no built in protection (DDW does have it so the PC-DDW connection is protected). The problem then reduces to finding adequate devices that can be inserted into the signal path that will prevent damaging voltages from passing through into the electronics. Such devices are not widely available, but they do exist. All devices, to be effective, must require you to attach a wire as short as possible to a good ground—if the device does not require that (or if it requires it, but you do not install it), it is not able to give much protection.

In summary, be aware that you can greatly reduce but not eliminate the risk of lightning damage by using good design and installation. If your installation is not covered by insurance, you need to be prepared to handle the cost of repair. If you want to learn more about the details of lightning protection, call us for advice. You can also link to www.lightning-protection.com which has downloadable files of technical papers (see especially application note TAN1007).

Uninterruptible Power Supply (UPS)

Most observatories should use a UPS, especially if a remote computer control system is in use. In the event that the AC line power fails, the UPS automatically transfers the power to an internal battery which powers the connected system. During this time, the UPS can provide power to

- Close the dome if working inside
- Enable systematic shutdown of equipment
- Enable systematic shutdown of computer programs

In addition, the UPS will provide at least some measure of transient (lightning) protection.

To maximize the duration of the backup power, one should connect only the essential items to the UPS. This will generally include the computer, telescope, DDW, CCD camera, and an emergency light, if needed. If one is working remotely one might choose not put the computer monitor on the UPS. However, if the UPS has sufficient peak capacity to handle the monitor, we normally recommend that the monitor be connected to the UPS. When working remotely, the monitor should be off and will not drain the battery, but when working on site, the monitor will be available to assist in a manual shutdown.

The UPS issues for the user are (1) to choose rationally what UPS to purchase, and (2) to provide automatic shutdown of the hardware and software.

UPS Specifications. The major specification is the power load that the UPS will support. This is usually given in Volt-Amps and/or Watts. The second major spec is the duration of operation. This is a much “fuzzier” number, and is usually given in minutes of operation at some fraction of the rated load. In general, the higher the power rating, the longer the UPS will support a given power load. Here are typical loads in an observatory.

Item	Watts	Notes
PC Monitor	100w	Would be off unless in active use
PC computer	100w	
Motor Drives (TI DC motors)	100w	Operate only during rotation, closure
CCD	50w	
Telescope	25w	
DDW	25w	

For remote operations, the third concern is how to make the observatory shutdown properly when the UPS detects a power failure. Most UPSs present a contact closure when the UPS switches to battery operation due to a power failure. This contact closure can be used directly with DDW to force a dome closure, thus protecting the astronomy equipment. In many installation, DDW can also park the telescope during this process. The power failure signal can also sent to the PC where, with the proper programs, it can initiate a controlled shutdown of the astronomy programs and of the PC itself.

One problem with choosing a UPS is that although most UPSs provide the power failure signal, each one uses different connectors or pins for the function. Some UPSs even require that you physically push a button to return the unit to service after the power returns. Obviously, this is a major problem in a remote application!

Recommendation. We recommend the APC line of UPSs. These are moderate priced units that meet the needs of observatory applications.

- For a typical small to medium dome up to ten feet diameter, we recommend a capacity of about 300watts (e.g., APC Model 500VA).
- For a fifteen-foot dome, we recommend 450 watts (model 650VA) as the larger dome has more and larger motors that run longer.

You can use larger units than these but the added capacity is not really needed, and the unit will take up more space (an issue in the RoboDome). For most UPSs, the model number reflects the V-A rating (the wattage rating is about 2/3 of the V-A rating).

We ran a series of tests with the Model 500 in a ten foot dome, fully equipped, with everything turned on except as noted below. In each test, we the UPS had charged for at least 24 hours and the temperature was 70-80deg F. After tripping the power, we operated the shutter open and closed, then continued timing how long the UPS provided power under different loads. The results were as follows:



Test	PC Monitor	PC Computer	Duration(minutes)
1	ON	ON	7:30
2	ON	ON	7:43
3	OFF	ON	15:10

Our conclusion is that this UPS provided sufficient power and duration even with the monitor on (normally it would be off). Seven minutes is sufficient, but 15 minutes is even better and provides a reserve against lowered capacity at low temperatures.

Hints: UPSs are normally shipped with the internal battery disconnected. If your UPS won't work, check the battery connections (usually underneath the unit). Also, most UPSs have several outlets, but at least one may be a pass through (not backed up). Be careful which outlets you use!

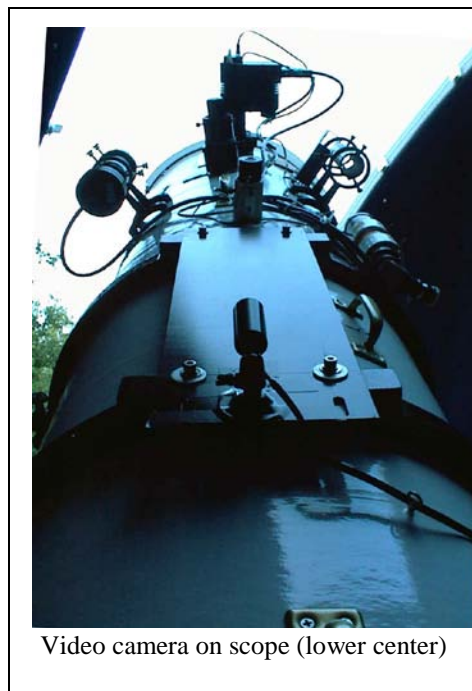
In-Dome Video Camera(s)

We have made many references to using an In-Dome video surveillance camera for monitoring movements of the dome or telescope. Such a camera is always very useful in remote operations. It is virtually a necessity for Long Distance applications. The camera allows the user easily to see what is happening in the dome, to verify correct operations, and to detect problems early.

The camera(s) should be capable of operating over a wide range of light levels (the more sensitive the better). Sensitivity ratings are in LUX and 0.1 LUX is a good sensitivity for this purpose (monochrome cameras are more sensitive than color cameras). Resolution is fairly important, so the camera should have about 400 lines of resolution.

The camera should have a wide field of view so that it can see most of the interior of the dome and still be in focus (i.e., have a large depth of field). For example, in most applications, the so-called pin hole or wide angle cameras can view the telescope mount, most of the telescope and the inside of the shutter area all at the same time. An alternative is to install several cameras aimed at different parts of the observatory. Another alternative to the wide angle is to use a remotely aimed and focused camera. This is feasible, but more costly, and usually not worth the trouble. The camera needs to be mounted on a conveniently adjustable, but stable mount. It should be out of the way so it does not get bumped.

In general, a camera will require additional light to operate at night inside the dome. Most video cameras are sensitive to



infrared, making it possible to use infrared instead of visible light. However, most infrared illuminators are of fairly low intensity and none are suitable if a color camera is to be used, or if you want to be able to see color distinctions properly in a monochrome camera. If white light is used, it can be either an ordinary incandescent light or a small halogen light. In any case, will want to be able to turn the illumination on and off by remote control so that there is no excess light in the dome. If properly arranged, the video light might serve to illuminate the flat field target as well.

The camera may have a standard video plug output (RCA plug) or may be a USB compatible system. The standard video signal can be run up to a hundred feet or so, and can connect directly to television sets having a video input, or to any TV antenna terminals using a RF modulator, or to a video (non-computer) monitor. If you are at a substantial distance, it is necessary to send the video signal through the computer link. As we discussed earlier, you can feed the video signal into a frame grabber card installed in the Dome PC. When activated by the software that is included with the card, the frame grabber seizes a frame every second or so, and feeds it to the computer monitor for display. Some cards can support up to three cameras, with any one or all three shown at once. If the camera is USB compatible, you may need a USB port adapter to use the computer link.

Although we have emphasized the use of a video camera mounted on the interior wall of the observatory, many users will also place additional cameras in the dome. We show a picture of one installation in which the astronomer has a wall camera, plus a second camera mounted on the telescope tube, plus a third camera on a viewfinder telescope.

If you want to use multiple video cameras, you may be able to use a remote controlled switch to select the desired camera. If you are running the camera to a nearby monitor or TV set, you may also use a four way split screen device so that you can view all the pictures at the same time. However, an even easier way to use several cameras one at a time is simply to place their video outputs in parallel using inexpensive Y-or T-connectors. The output can then be fed into a frame grabber for long distance remote use. If you provide for turning each camera off and on remotely (e.g., using a remote power control module), you can then easily select the camera to operate.

The cameras themselves are not expensive, ranging from about \$50-200, but very few are available that include white light illuminators. We do offer a combined system that includes a camera/light/mount and frame grabber that is suitable for use in the observatory. Frame grabber cards cost about \$50-150, and normally come with software.

You might see ads for inexpensive video conferencing cameras. These may work in the dome, depending on their light sensitivity and field of view. You will still need to arrange some sort of lighting system for them.

Remote Power Control

You will often want to turn the power for some device on or off remotely. For example, you will turn off the CCD and telescope when they are not in use but, at the same time, but you might want to turn on a small heater on the telescope/pier (to prevent condensation). You may want to use the In-Dome video camera and its illumination periodically during an observing session.

The observatory control system should allow basic remote power control. DDW includes four control lines that allow you remotely to control four power outlets or other devices via the dome control software. Comprehensive remote control power systems can become very complex and there are few systems on the market. One can imagine an integrated design that handles several peripheral controls in the observatory. For example, our own remote focussing unit also includes four channels of remote power control (which could be used in addition to those controlled by the DDW).

You might also consider purchasing a card for a computer that includes a group of relays that can be wired to control equipment in the observatory. However, you should be cautious; it is easy to create very unsafe systems if you are "cobbling together" 120V control relays and outlets.

Control System Architecture for a Remote Controlled Observatory

The Long distance observatory requires that its control system provide these functions:

- Rotation control and feedback, manual and slaving
- Shutter operation and feedback
- Automatic closure in event of system failures
- Feedback to user of system status (including weather data)
- Configuration settings
- System Log
- Safe and convenient manual operations

While the basic rotation and shutter operations may appear obvious, they are more complex than you might expect. For example, the system should include protections against failure of drive systems (if motors slip, they should shut down automatically). The systems must include good feedback, so that you know what is happening in the observatory. The system should include means for calibrating the azimuth and shutter sensors, both at zero or end points, and for calibrating the range of motion.

Automatic closure operations should include the ability to respond to problems such as inadvertently leaving the dome open (a very common problem), power failure, adverse weather conditions, computer failures and loss of on-line control. The system should even include a function to attempt repeat closures if the initial closure effort fails for some reason.

Feedback to the user should include constant information as to the status of the observatory. A dome control program should be designed to display dome position, shutter position, motor current, interlocks, etc. It is vital that this information be complete so that fault conditions can be identified. It is just as important that the system allow the user to bypass interlocks and otherwise attempt to work around any problem that is identified. A long distance system should include weather instruments (including wind, wind direction, temperature, presence of rainfall or snow, etc.) so that the user will know whether it is safe to open the dome.

The system will require some degree of customization, usually done through configuration file settings. These will include telling the program the locations and size of the dome, type and location of the mount in the dome and numerous other factors required for proper operation. Weather settings should be permitted, and when there is considerable distance between the control room and the observatory, these should operate as interlocks, shutting down the dome if limits are exceeded.

The system should include some process to log activities of the observatory. This log provides a record of commands issued and how the system responded that will help you identify the cause of events when a problem occurs.

Safe manual operations are also needed. A person inside the observatory may suddenly find that the dome begins to rotate or the shutter to close. This can be startling and may even present a threat to safety. The system should have audible alarms and convenient emergency stop switches or buttons to permit a person to stop movement of the observatory.

Convenient manual operations are another issue. Many control systems require a Dome PC to operate the motors, sensors, etc. in either remote or manual mode. This means that a failure of the Dome PC not only causes the remote operations to fail but also means that manual operation is impossible unless the



Computer is brought back on line. In practice, it is frequently necessary to operate the dome when the Dome PC is not on line. A dome control system designed with its own “smart” microprocessor is more convenient and reliable. This is not done in many observatory control systems because designers find it is easier and cheaper to use the PC.

There are several different phases in operating an observatory:

- Awaiting a session
- Opening the observatory
- Operating the observatory
- Closing the observatory

The operational problems that might occur at each phase are discussed next.

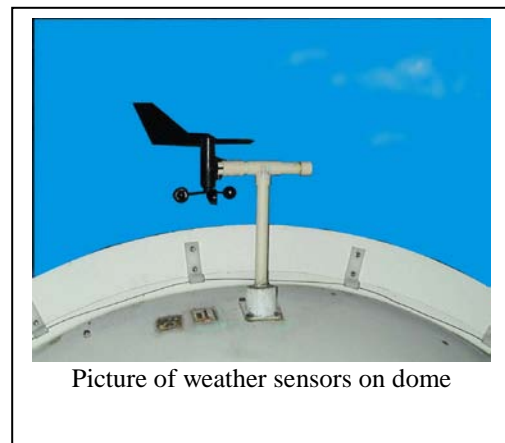
Awaiting a Session

The observatory may remain in a closed condition for hours or weeks, but must be ready for use.

Obviously, during the waiting period, the observatory must provide the safe environment for the components inside. Because the observatory is unattended, it may be desirable to maintain some interior checking. An internal video monitor camera can fill this need, as we recommended earlier. Some people also install an alarm system.

Another concern is a very unpleasant one: protection against vandalism and theft. The observatory should have at least a reasonable degree of protection against illegal entry. We usually define this as a requirement that an intruder must be willing to use tools in a destructive manner to force an entry. Raising this bar requires increasingly complex and costly design and installation measures (alarm systems, fences, etc.) Some protective measures, such as installing the observatory on a relatively inaccessible roof, may carry substantial disadvantages with respect to the astronomy to be done (vibration, adverse seeing effects). The level of protection needed and, ultimately, the level of financial insurance coverage that is desirable, are matters of individual judgement. Although we have all heard “horror stories”, our customers’ experience is that the actual risk of vandalism and theft is often much less than expected.

In a Long Distance application, you begin an observing session by accessing the Dome PC. PCs are a potential weak link because they can crash, their software programs can hang and they are not designed to be self-diagnosing or correcting. If one of these events occurs, you will not be able to make connection with the observatory system, and cannot run an observing session. In most cases, the only sure cure for a computer software problem is to perform a Power Off reboot of the computer. Unless you provide a way to do this remotely, someone will have to visit the observatory to reboot. A computer crash can happen any time before or during an observing session, so this is a critical issue to resolve (this was discussed in the chapter on Control systems).



Picture of weather sensors on dome

Opening the Observatory

Opening a dome shutter (or moving a roll off roof) is a major mechanical movement. A properly designed shutter has a low risk of failure and the control system should identify most failures. However, as no system is perfect, it is very desirable for you to be able to observe the shutter opening (and later, the shutter closing) using an in-dome video camera. In this manner, any unusual event can be identified, and perhaps corrected.

Weather. Before opening the observatory, you need to verify that it is safe to do so. This is true especially for the Long Distance system. The major issue is weather: Is the dome covered with snow? (Some domes are safe to open with snow on them but others are not.) Is it raining? Is the wind too strong? The system should both inform you about these conditions and prevent unsafe operations, but also allow you to override the limits as needed.

It is usually not necessary to have highly accurate or detailed weather information at the observatory. For example, it is easy to design super-sensitive rain sensors. However, it is more difficult to design sensors that operate for years without maintenance, do not corrode, do not provide false positives or negatives, and that are resistant to dirt, mold, algae growth, hygroscopic dust, etc. Similarly, it is not necessary to record the total rainfall that has occurred. Rather, the question is whether it is raining now! A pragmatic, practical approach is far better than attempting to provide overly sophisticated instrumentation.

Even if the weather is safe, the sky may not be clear enough to observe. Humidity detectors in the weather sensing system can detect heavy fog or mist. High clouds or other high phenomena would prevent most astronomical observations from being successful, but there is no straightforward way to detect them. This is an issue for Long Distance operation, where the user may not know the weather at the observing site.

Various people have proposed or developed special sky clearness sensors. Some concepts use the differential cooling rate for a Peltier plate exposed to a clear sky on one side and the ground on the other side. However, these are susceptible to dirt, snow or other surface coverings, and will not inform very well on many cloud conditions. Another alternative is to fire a laser light pulse upward, then watch for the reflections from clouds. This is expensive and potentially an interference to other observers.

Simple but effective measures are these:

- Use an external, sensitive video camera that can be aimed at the sky. Wide-angle, inexpensive cameras that can see the bright stars are barely sensitive enough for this application. Image intensifiers would make this a simple task, but they are expensive.
- Use your computer on the Internet to get a real time mapping of clouds and weather activity at the observing site. This is a surprisingly powerful method, as the maps are usually less than an hour old and available 24 hours a day.
- Direct the telescope to several known targets (e.g., stars) in the sky to measure brightness and hence atmospheric clarity. This, of course, is the final test of the observing conditions!

In any case, when operating at Long Distance, you must have some means to evaluate both the general weather conditions and the quality of the viewing. The former is handled by the weather station, but the latter is dependent on knowing your requirements and developing a strategy to provide the necessary information.

Operating the Observatory

During an observing session, the dome control system should have little to do. It will provide for rotating the dome (manually or slaved to the telescope) and will detect fault conditions, etc. It should continue to monitor weather conditions and warn you (and/or close the dome) if pre-set limits are exceeded. System services, such as remote power control to operate the in-dome video monitor camera, should be convenient to use.

Although a dome control program may be running on the Dome PC, it should take a minimum of computer power so as not to slow down the other programs that are running. This is one of the reasons to use an observatory control system containing a “smart” processor. In general, the observatory control system should “stay out of the way” of the other operations going on.

Closing the Observatory

At the end of the observing session, you will normally turn off instruments in a particular order to prevent damage and to make turn-on at the next session much easier. Thus, the CCD cooler will be turned off, then

CCD power removed (via remote control), then telescope will be parked, then power removed, and so on. At some point, the observatory dome will be returned to its Home position, and the shutter will be closed. As when opening, it is very desirable to verify proper closing by watching the shutter movement as seen by the in-dome video camera.

Finally, when all instruments are in their resting state, you will terminate the communication link to the Dome PC. At this point the Dome PC will revert to a waiting state, ready for the next session.

Glossary

ADC	Analog to Digital Converter. Device used to measure an analog voltage and give a digital reading. E.g. 8-bit (256 values) ADC
AZ	Azimuth. Measure of direction or angle in the horizontal plane. North is zero, and azimuth increases to 360 deg. clockwise. Note: LX200 telescopes measure AZ CW from South.
CCD	Charge Coupled Device-digital camera used in astronomy
Comm Port	Serial port on PC, usually a 9-pin male connector on PC
CW/CCW	Clockwise/Counterclockwise
DDWCP	Digital Dome Works Control Program. Program provided with DDW that runs in a PC and allows user to control DDW hardware and software remotely.
DIP (switch)	Dual Inline Pin. A DIP switch is a small device containing 4-8 switches used to set configurations.
Direct/Host-client Control	Direct: Installation in which the control programs run in the User PC which sends commands to a Dome PC which sorts them and sends them to the observatory components. Under In Direct control the programs run in the Dome PC under control of the User PC using a Remote Control Program.
Dome PC	Computer in or very close to the dome that has direct wires to control the various observatory instruments
Dome PC	The computer in or near the dome that is wired directly to the observatory components. In a Nearby RCO, the user may sit at this computer, or may use it via an RCP
DomeTop	Dome Top. Refers to the top, rotating portion of observatory.
DomeWall	Dome Wall. Refers to the wall, non-rotating section of the observatory.
DSR	Dome Support Ring-a part of many Home-Dome/Pro-Dome observatories
Firmware	The program in the main DDW processor is called firmware because it is loaded once into the processor as a permanent program.
I/L	Interlock. A sensor that registers a particular condition and that is used to prevent some activity. E.g., a wind speed interlock that prevents operation of the observatory.
LED	Light Emitting Diode. Small light emitting devices used as indicators for power, interlock status
Long Distance Remote	Installation in which the observatory is far from the observer
LX200	Common Schmidt-Cassegrain telescope on a computer controlled yoke mount manufactured by Meade Telescopes
MODEM	Part of computer that transmits digital data over the telephone lines.
Nearby Remote	Installation in which the observatory is within direct wiring distance of the user (e.g., less than 100 yards)
Observatory Component	Major components in observatory: telescope, camera, observatory control system
PCAnywhere	Remote Control Program from Symmantic that allows a user to control a distant computer
PIC	Programmable Interface Controller. This is a small microprocessor with a permanent stored program that controls peripheral devices. Synonymous with CPU.
RCO	Remote Control Observatory
RCP	Remote Control Program. Allows the user to operate the Dome PC via a communication link
RS232	A particular convention for the voltages and timing for serial communication. RS232 uses +12v for a logic zero, and -12v for a logic one. Non-RS232 serial communication between digital devices use +5 for logic zero and 0v for logic one; however, the timing of the data pulses is the same.
SBIG	Santa Barbara Instrument Group, manufacturer of popular CCD cameras.
Serial	Serial data is the term for digital data that occurs on one wire, with pulses in a sequence representing the data. Data are sent at a particular Baud Rate, usually 9600/sec, which is about 1000 char/sec
Signal/Power	"Power" wires are those that carry electrical energy for the operation of a component such as a motor or Control Unit. These usually have relatively large conductors to reduce voltage drop. "Signal" wires or cables are used to transmit varying voltages that carry information, as in a sensor output. All signal wires in DDW installations are 6-conductor cables.
TheSky	Program from Software Bisque Co. that represents the sky, and provides for telescope control. V5 provides interface data suitable for DDW
UPS	Uninterruptible Power Supply. This is a battery powered 120VAC power supply that takes over when the power line is down. The UPS will power the Dome PC and DDW (and dome motors) for about 15 minutes.
User PC	PC at the user location
Video Camera Monitor	Video camera used to monitor the interior of the observatory. Readout may be direct wired to a nearby display monitor, or using a frame grabber in the DomePC, sent over the communication system via the computer links

