An Observatory for Education and Public Outreach controlled through the World Wide Web

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ABSTRACT

For the last two and a half years the Department of Physics and Astronomy at Louisiana State University (LSU) has been engaged in a collaborative effort with the Recreation and Park Commission for the Parish of East Baton Rouge (BREC) and the Baton Rouge Astronomical Society (BRAS) to develop a observatory that can be used for astronomy education from primary school through graduate studies as well as for recreation and public outreach. The observatory includes a 2,300 square feet facility, a 20" diameter Ritchey - Chretien telescope, a back - thinned CCD camera, a computer control system and an internet T1 link. The on site public outreach and education program has been fully active since Fall, 1997 and we are currently in the process of developing a platform-independent system for remotely controlling the observatory over the internet. The initial version of the Java / World Wide Web (WWW) based software is currently functioning and provides interactive control of the observatory via any Java compatible web browser. The main principles of the remote control system are presented in this paper, along with a discussion of the education and outreach goals of the observatory, details of the facility and hardware, initial measurements of system performance, and a discussion of our future development plans.

Keywords: Internet, WWW, Java, control, education, observatory

1. INTRODUCTION

The Highland Road Park Observatory project was originally conceived during Fall, 1995 as a collaborative effort between the Louisiana State University (LSU) Department of Physics and Astronomy, the Recreation and Park Commission for the Parish of East Baton Rouge (BREC) and the Baton Rouge Astronomical Society (BRAS). This unique partnership between state, parish and community organizations was established to design, develop and maintain the observatory and to provide a program that supports astronomy education at LSU as well as throughout the community. During 1995, in response to a growing amateur astronomer market, a number of commercial firms were developing high quality computer controlled telescope systems at relatively low cost and the cost of CCD imaging cameras was rapidly decreasing. The Hanna City Robotic Telescope project provides a good example of assembling a robotic observatory from inexpensive components that are widely available on the amateur astronomy market[1]. Further, the development of remote controlled observatories at Iowa[2,3], Bradford[4], and Mt. Wilson[5] demonstrated the potential of locating an observatory under dark skies while still allowing full control of the system from a home institution. In fact, a few commercial firms had expressed their intention to include internet control capability in their "planetarium" display / telescope control software. It was, therefore, conceivable that a fully remotely controllable observatory could be constructed from commercially available components at a reasonable cost (< $100,000) with little or no custom development. While locating such a system near Baton Rouge would not be competitive for scientific research it would serve very well for state-of-the-art astronomy education[6,7].

The cost of developing the observatory was shared between BREC and LSU, with BRAS assisting in the design and public interaction. The BREC responsibility lay with constructing the facility and maintaining the grounds, building, and utilities as well as providing a startup staff. The telescope, CCD camera, computer control system and other support equipment was purchased by LSU with a grant from the Louisiana Board of Regents. In addition, LSU is responsible for maintaining the telescope equipment, providing a dedicated graduate student teaching assistant and bringing scientific expertise to the public program. Building construction began in October, 1996, was completed by June, 1997 and the major telescope components were installed in November, 1997. Currently there is a very active and successful public outreach program established at the observatory with a broad range of events scheduled throughout every weekend.

On site computer control of the telescope, dome and CCD camera is fully functional, but as of this date there is no commercially available software package that provides internet control of the telescope let alone of all the other, related observatory functions. Thus, we have been required to develop our own custom remote control software. Given our limited man-power, however, it has been necessary to develop a solution which minimizes the development effort. To solve this problem we have turned to the World Wide Web (WWW) and, in particular, Java client / server applications. With this approach a majority of this "custom" interface is relatively easy to develop, is highly portable and platform independent and can be adapted to include future needs. In this paper, we describe the project goals, provide an overview of the observatory facility and equipment, discuss the remote control system and summarize the current status and performance of the facility.

2. OBSERVATORY GOALS AND DESIGN

The primary goals of the Highland Road Park Observatory are to: 1) Significantly improve the effectiveness of teaching university level Astronomy courses at LSU, 2) Develop a science center which can support K-12 education throughout the area, 3) Provide LSU with a mechanism for community outreach, 4) Establish a new form of science-oriented recreation for the parish, 5) Seek to increase / include participation of under-represented students and groups in all of these areas, and 6) Support the local amateur astronomy community. To meet these goals the observatory must address the needs and requirements of a broad audience located throughout the region, from K-12 students and teachers, to university undergraduate and graduate students, to amateur astronomers and to the general public.

The most important aspect of the observatory for LSU is the need to provide the equipment and infrastructure necessary for students to gain experience in the operation of modern astronomical instrumentation. Modern observatories are fully computer controlled and the usual eyepiece has been replaced by electronic focal plane instruments which require digital processing techniques for data analysis. The Physics and Astronomy building on the LSU campus includes a vintage 11" f/11 Alvan Clark refractor which was installed in 1939. This venerable instrument has been used for decades to support astronomy classes at LSU, but is currently capable of only visual observation and is not easily adapted for computer control. To refurbish this instrument and outfit it with modern instrumentation would cost as much or more than completely replacing the old telescope. Further, light glare from other nearby campus buildings provides other problems that would have to be overcome. Locating a new facility in a relatively nearby dark location would address a number of these issues, but with over a thousand students each semester attending classes that would potentially use the new facility it is impractical to anticipate shuttling students between the facility and campus for laboratory classes multiple times each week.

To solve these problems we designed an observatory with remote control capability that can be accessed over the internet. A T1 network link connects the observatory to campus, and an Astronomy Teaching Laboratory (ATL) consisting of 6 to 10 desktop computer will be established in the Physics and Astronomy building. The ATL will allow groups of students on campus to investigate astronomy fundamentals using interactive software and to perform specific experiments using optical data from the telescope at the remote facility. LSU is now in the processes of developing a series of laboratory exercises for the ATL to complement our existing course offerings and provide broad training in astronomy and modern observational techniques. As has been pointed out by Lockman[8] good science training in observational astronomy ultimately requires direct contact with the telescope hardware and such contact is very elusive over a remote interface. Thus, for our undergraduate majors and graduate students the ATL exercises will be supplemented with practical experience at the observatory.

In addition to the university level classes, it is equally important for the observatory to support K-12 education. Children are very receptive to "space" presentations and an astronomy theme can be used across the disciplines to enhance education. The observatory already has an active on site program of classroom interaction and with observatory access over the internet, it is conceivable that this interaction can be expanded to include telescope observations from the K-12 classroom itself. In this case, however, the interface would need to be very user friendly and should not require the school system to purchase commercial software. In addition, as school classes are held during the daytime, the observatory control software will need to support a batch mode through which observational requests are submitted and scheduled for overnight processing.

For remote control applications it is also necessary for the facility to have the capability to "safe" itself. It is relatively easy for an on site operator to determine if it is raining outside, but without such personnel, it is more difficult to determine if a remote user should be allowed to open the dome shutters. To handle this problem the facility includes a full weather station and power to critical systems is provided through an uninterruptable power supply (UPS). Software on the observatory control computers monitor the weather and UPS data and provide "alarm" states that prevent remote usage when conditions warrant.

The observatory supports an active public outreach program including public "stargazing" nights. The use of the facility for these public viewings establishes additional constraints on the observatory system. In particular, the public will be most satisfied if they can view astronomical objects (e.g. Saturn's rings) with their own eyes, yet remote use of the telescope requires that the CCD camera be in place. Physically alternating between an eyepiece and the camera is potentially problematic and could lead to numerous trips between campus and the observatory to correct problems. Our solution is to attach an instrument selector onto the telescope so that the eyepieces can be mounted par-focal with the CCD camera and such that neither device needs to be physically removed. This arrangement also assists with "crowd control" at the observatory where the latest CCD images can be displayed on monitors in a public lecture area while smaller groups view the object directly through the eyepiece.

3. THE OBSERVATORY FACILITY

The facility constructed by BREC to house the new telescope is shown in Figure 1. The building site is located on the southeast side of Baton Rouge approximately 10 miles east southeast of the LSU campus. Several sites were considered across East Baton Rouge Parish. The present site represents the best compromise between relatively dark southern views, ease of access by the general public and LSU students, space for future expansion, and pleasant surroundings. The facility is centered in a roughly 300 feet diameter clearing and is surrounded by trees. While these trees obscure the sky within about 15^o of the horizon, they also shield the site from the glare of neighborhood lights and from the headlights of passing cars.

Figure 1: The Observatory building

The buildings itself is octagonal in shape with 22 feet long sides and provides more than 2,300 square feet of floor area on two levels. Included in the design are lavatories and two office / storage areas where portable equipment can be secured. The main floor has been left open, except for a few support structures, to provide maximum flexibility for utilizing the space for exhibits, displays and lectures. The second floor, with somewhat more than 300 square feet of floor area, is dedicated to the telescope and control systems. A set of built-in cabinets with desktops and shelves provides more than adequate space for the telescope accessories and control computers. The telescope is mounted on a three foot diameter, poured concrete pier that extends from the telescope deck to 16 feet below ground level. This pier is physically isolated from both the telescope deck and the building foundation to minimize transmission of mechanical vibrations to the telescope.

The entire building is air conditioned with the telescope deck including humidity control as well to protect the telescope and equipment, when not in use, from our high humidity environment. Both floors are in separate heating / cooling zones and a doorway allows the second floor to be sealed allowing the telescope area to quickly come to equilibrium with the outside temperature when the shutter is opened. The 22.5 feet diameter dome is from Ash Manufacturing Company, Inc. and includes full motorized rotation as well as upper shutter and hydraulically operated lower shutter motion. When open, the shutter provides an aperture from the horizon to 15^o beyond zenith which is 71 inches wide. The metal roof surrounding the dome is painted white and heavily insulated to minimize thermal mass and allow the roof to rapidly cool after sunset.

The f/8.1 telescope, shown in Figure 2, was purchased from Optical Guidance Systems (OGS) of Huntingdon Valley, PA and uses a Ritchey-Chretien (RC) optics design with a 20 inch diameter primary mirror and a 7.25 inch diameter secondary. The RC design utilizes hyperbolic primary and secondary mirrors to correct coma and provide a flat, high quality image across a wide field of view. Further, the RC design contains no refractive elements and only two air to glass surfaces providing less light loss and a greater spectral range than a Schmidt-Cassegrain. The mirrors for the telescope were fabricated from low expansion ceramic and are figured to a final wave front error of 1/30 RMS. The mirror coating has been optimized to maximize reflectivity (> 90%) over a broad spectral range (~400 nm to 750 nm) and yet be resistant to abrasion and humidity. The secondary mirror mount can be positioned by a stepper motor to provide electronic focus control over a back focus range of 10.5 inches. Both mirrors are mounted to allow for the differential coefficients of expansion between the mirror and mount while providing boresight stability regardless of telescope orientation.

The equatorial fork mount, also from OGS, was purposely oversized for the 20 inch RC to provide as stable a platform as possible and allow for a future upgrade of the telescope. The axes of the mount have an orthogonal alignment of better than one arcminute and both axle drives include Byers gears with an 18 inch gear on the Right Ascension axis. The telescope optical axes are aligned with the mount axes to within 1 arcminute and the combined system is capable of tracking objects with an accuracy of less than 3 arcseconds periodic error without the need for computer software corrections. Computer compensation for such mechanical misalignments enables the positioning accuracy of the telescope to be increased to ±30 arcseconds RMS error over the entire sky and the tracking error to be reduced to 1 arcsecond over twenty minutes of time. This precision assures that commands from a remote, off-site location will position the telescope on target and that active guiding will not be needed for most exposures.

The CCD camera used with the telescope is the model AP7 purchased from Apogee Instruments, Inc. of Tucson, Arizona. This remarkable camera costs less than $10,000 and contains a back-thinned SITe SIA502AB CCD chip. The chip is a 512 by 512 array of 24 micron square pixels with a large dynamic range (well depth >350,000 e^-) and relatively low noise (dark current is 50 pA/cm^2 at 20^{o}C). Further, the camera is equipped with a thermoelectric cooler which is capable of reducing the chip temperature to more than 50^o C below ambient, minimizing the dark current noise. The camera electronics provide a read noise of about 15 e^-, 16 bit digitization and a readout rate of 50 kHz (a full frame can be read in about 5 seconds). Coupled with the f/8.1 telescope this camera has an image scale of 1.2 arcseconds per pixel and a field of view of more than 10 arcminutes. These characteristics offer a good compromise between the Baton Rouge "seeing" conditions and the ability to capture a large object in a single frame.

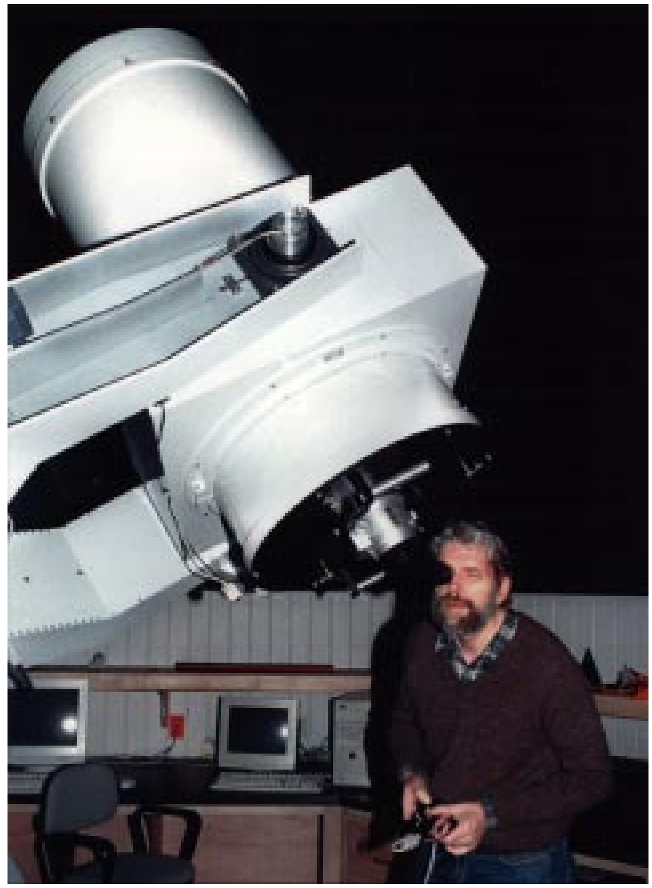

Figure 2: The 20" f/8.1 RC telescope and control computers located on the 2nd floor of the facility.

The thinned, back-illuminated CCD offers a significant performance advantage over standard front-illuminated chips. In particular the quantum efficiency or QE (a measure of how well photons are converted into electronic charge) is greater than 80% over the wavelength range 550 nm to 770 nm or more than double that of the standard chip[9]. Further, this high QE continues into the blue region (~70% at 450 nm) where it is almost an order of magnitude more sensitive than a front-illuminated CCD. This relatively flat response provides a distinct advantage for photometry where all "colors" can have roughly the same exposure time. The high QE also allows shorter exposure times reducing the accumulated dark count in the image. Typically, this camera is able to produce a recognizable image of "faint" objects with exposure times as short as a couple of seconds. This high sensitivity camera will allow remote control object location and focusing to be performed effectively and provide high throughput for most of the images associated with the observatory education and outreach goals.

Other components are also needed to provide the observatory with full remote control capability. For example, Astronomical Consultants & Equipment, Inc. (ACE) of Tucson, Arizona supplied a contactor box and relay controller box to interface between the dome rotation and shutter motors and the control computer. The contactor box includes a copper bus slip plate to conduct shutter motor power and limit switch signals when the dome is in the "home" position. The relay controller provides push button control of all dome functions as well as the computer interface. Also purchased from ACE is the instrument selector. This device attaches to the telescope base plate and includes a stepper-motor-controlled diagonal mirror that can be rotated to direct the light path to one of four output ports. The port selection can be controlled by computer and allows us to select between the eyepiece port, the CCD camera or one of two other instruments. The CCD camera will also be equipped with an ACE filter wheel where filter position can be selected by computer. This filter wheel will accommodate up to eight 50 mm square filters, where the size and shape were chosen to conform with filters used at national astronomical observatories. A GPS receiver is included in the observatory equipment and can be read out by the control computers to synchronize their clocks with UTC to better than 0.05 seconds. Communication between the observatory and campus is provided by a dedicated T1 network link which is maintained by the LSU Office of Telecommunications. The observatory network is currently thin coax 10Base2 and can accommodate approximately 30 on site nodes. Through the campus connection, the observatory is linked to the internet providing world wide access. In the event of a power failure, all critical observatory systems (e.g. telescope, dome motors, control computers, network link) are connected to a high capacity Uninterruptable Power Supply (UPS). This UPS provides approximately 30 minutes of power to smoothly shutdown observatory functions. Finally, the observatory site includes a full weather station that continuously monitors indoor and outdoor temperature / humidity, wind speed / direction, rainfall amount, and sky brightness. These sensors allow us to compute the dew point as an early rainfall indicator and we are developing a rain sensor which will trigger on the first raindrops. The integration of the many hardware components described above into the observatory control system is discussed in the next section.

4. THE OBSERVATORY CONTROL SYSTEM

The observatory control system provides complete computer control of all observatory functions for an on site operator. This system is schematically illustrated in Figure 3 and consists of two Pentium class CPU computers, the Telescope Control Computer (TCC) and the Observatory Control Computer (OCC), plus the hardware interfaces. The TCC runs the DOS operating system and is dedicated to telescope and dome operations using the PC-TCS software from Comsoft of Tucson, Arizona. The OCC runs Windows NT to support the multiple processes necessary to handle off site internet communications, camera and filter wheel control, weather data collection and monitoring, other support functions and communication with PC-TCS over a serial interface. This system minimizes our costs and software development by enabling us to use inexpensive computer hardware and to take advantage of low cost commercial software that has been developed for Windows and DOS systems for the amateur astronomy market.

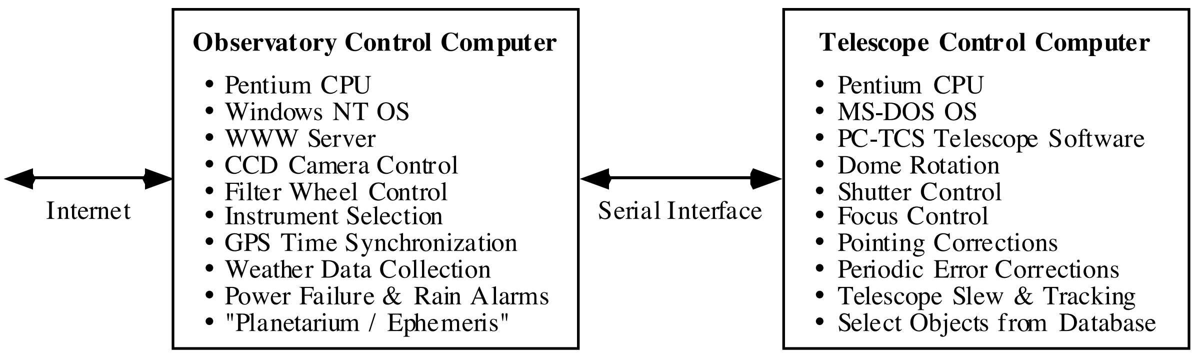

Figure 3: Schematic of observatory control system and high level functions.

PC-TCS is a personal computer based telescope control system designed for use with moderate to large professional astronomical telescopes. Fundamentally, PC-TCS provides a link between the hardware that monitors and controls the dome, shutter, and telescope and a high level user interface that allows a user to literally operate the telescope with a few keystrokes. PC-TCS also implements an observatory control script language that can be executed from both batch files and over a serial link. This feature accomplishes a crucial first step towards automation.

PC-TCS interfaces with the telescope axes and focus control stepper motors through a CR-10 ISA Bus card connected to a CTR-10 interface module. The TCC also interfaces to the ACE dome controller which enables PC-TCS to rotate the dome, sense the state of the upper and lower shutters (i.e. opened or closed) and operate these shutters. An encoder connected to the dome allows PC-TCS to determine the relative angle between the shutter aperture and telescope azimuth. This enables PC-TCS to automatically rotate the dome to always keep the telescope pointing through the clear aperture.

Included in PC-TCS is the ability to correct for various errors which can affect the pointing and tracking accuracy of the telescope. PC-TCS can automatically make pointing corrections for proper motion, precession, nutation, annual aberration, atmospheric refraction and repeatable mechanical flexure. PC-TCS can also correct tracking rates for differential refraction, flexure, periodic error in the right ascension gear and declination gear backlash. The site specific corrections for flexure, which include other terms such as misalignment of the mount and non-perpendicularly of the right ascension and declination axes are generated by the TPOINT package from data collected with a semi-automated calibration routine within PC-TCS.

The Apogee AP7 camera is handled through a dedicated controller which resides on the OCC ISA bus. This controller is a single width board that supplies the camera with power, regulates the thermoelectric cooler and controls the camera functions including transfer of the digitized image. Both 16-bit and 32-bit APIs have been written for the controller and over the last year a number of camera control packages have become available. These include Maxim DL from Cyanogen Productions, Inc., PMIS from GKR Computer Consulting, CCDSoft from Software Bisque, and Image Pro Plus from Media Cybernetics. While each of these packages provides basic camera control, they provide different levels of functionality and are optimized for different applications. For example, Maxim DL and CCDSoft are optimized for astronomy applications and include capabilities such as blink compare, photometric analysis, and maximum entropy deconvolution. However, only PMIS includes a script control feature which is useful for remote control applications. Thus, two or more of these packages would likely be needed to cover the full range of requirements associated with our application. This is, in fact, a cost effective option, since the price of Windows software is low (e.g. CCDSoft costs less than $250) in comparison to the personnel cost that would be necessary to develop a custom camera control application.

The OCC also includes an ISA bus interface for the ACE Instrument selector and camera filter wheel stepper motors. The stepper motors rotate the optical components to the proper position and a positive mechanical detent system consistently locks the position to high accuracy. Further, at detent position the stepper motor is powered off to minimize thermal effects. Both devices are controlled through a Windows NT compatible user interface which includes menus that allow the user to easily select a particular filter or switch between instruments. The source code for this program has also been provided by ACE and will be modified at LSU to include a remote control interface.

Weather data are collected automatically by the PC208W Datalogger Support Software running on the OCC. The observatory weather station instruments are controlled by a CR10X Datalogger from Campbell Scientific which operates independently of the OCC. The data logger is read out over a serial interface every 10 seconds and the data are processed to generate averages or computed quantities such as indoor / outdoor dew point. These data are then stored on the OCC disk for later retrieval. The disk file can be copied over the internet, displayed on the OCC to review weather conditions at the observatory, or processed by other routines on the OCC to generate "rain alarms".

Another ISA bus slot in the OCC is taken up with a GPS receiver which provides a highly accurate time standard for both the OCC and the TCC. The internal clock of a PC can have a high rate of drift and, in fact, the OCC clock has been measured to loose more than 8 seconds every day. If left uncorrected, this would correspond to an error in pointing the telescope which would increase roughly 2 arcminutes every day. Thus, we have developed a simple program that runs on the OCC to continuously read the GPS receiver time and periodically update the system time on the OCC along with sending a SETTIME command to PC-TCS on the TCC over the serial link. By automatically updating these times every eight minutes we can maintain synchronization with UT to better than 0.05 seconds.

Finally, the on site operator can use the OCC to access astronomical information and images such as the Digitized Sky Survey from the Space Telescope Science Institute (STScI) over the internet or to run planetarium / ephemeris software directly. For the latter, programs such as Megastar Sky Atlas cost less than $130 yet provide accurate interactive sky charts generated directly from the NGC, GSC and other catalogs. Megastar can display Hubble Guide Star Catalog stars down to magnitude 15.5 and includes over 110,000 deep space objects. A mouse click on any of these objects accesses the database and displays a full set of information including, for example, object coordinates, magnitude, and apparent size. Programs such as Megastar also have the capability to compute and display charts for any time of the day, for any day of the year well into the future or past, and can calculate planet and/or asteroid positions, the positions of the Jovian moons and even the apparent tilt of Saturn's rings. This kind of capability makes it very easy to plan an observing session, days, weeks or even months ahead of time. Further, many such programs have the ability to communicate with amateur telescopes such as the Meade LX200. With a compatible telescope properly aligned the display shows the current telescope pointing direction on the sky chart and selecting a different object on the chart causes the telescope to slew to the new object. This provides a very user-friendly interface to telescope control and it is conceivable that we can adapt Megastar to provide a similar interface for the PC-TCS controlled telescope.

5. THE REMOTE CONTROL SYSTEM

While the systems at the observatory provide an on site operator with complete control over the telescope and camera, a remote control interface is also necessary to support real-time or near real-time use of the observatory during classes at LSU or in K-12 classrooms. Due to the limited amount of man-power at LSU which can be dedicated to this project, it is highly desirable to minimize the amount of custom software development and to purchase the required capability from commercial software vendors whenever possible. The initial design of the observatory, two and a half years ago, called for telescope control software that could be accessed remotely over the internet to be available within about a year after project start. This appeared to be a reasonable assumption given the success of the University of Iowa Automated Telescope Facility[2,3] (ATF), the Bradford Robotic Telescope[4], the development of dial-up modem access to Mt. Wilson[5] and our discussions with particular vendors. However, internet capable telescope control software has yet to appear in the commercial market and this has required us to reevaluate our approach.

By the time it became clear, about one year ago, that commercial software would not be able to provide the internet communication capability, the project was well underway and, due to the long lead time, we had already committed to a particular telescope and control system. Retrofitting this system with something like the ATF software was not an option due to the limited available budget and the large amount of expert man-power such a custom retrofit would require. The powerful "remote command" capability of PC-TCS, however, provided us with the flexibility necessary to devise a solution.

In particular, all that is really required is to develop an application for the OCC which receives data (e.g. object coordinates, focus position, desired dome shutter state, etc.) from the remote user, constructs appropriate PC-TCS commands from these data, and sends these commands to the TCC over the serial link. Command construction and serial communication are both well defined and simple to implement, leaving the internet communications as the outstanding issue. By taking advantage of recent developments in WWW tools, in particular the Java language, a significant amount of time consuming, TCP/IP socket level programming necessary for two way communication can be hidden, greatly simplifying the task. This approach also provides advantages in portability, platform independence, ease in adapting different telescope control systems, and eliminates the need to purchase multiple licenses of a software product for remote telescope users. In fact, with the concept described in the following sections, remote internet control can be quickly and easily added to any telescope system which already includes a "scripting" capability.

An interactive user interface for observatory control is not an appropriate means for meeting all our goals. In particular, we require an observation queuing system that allows students in a classroom for example to submit observing requests that will be executed later that evening. The implementation of this batch observing interface is straightforward and requires only CGI programming while the actual batch observing software consists largely of elements that have already been developed for the interactive interface. Observatories such as Bradford have already developed successful queued observation systems and we will draw from experiences such as theirs. Further, significant advances have been made over the past decade in scheduling observations in an efficient and flexible manner[10]. For this paper, we will concentrate on describing our method for providing remote real-time access to the observatory.

5.1 The WWW Server and Java

For our webserver, we use the WebSite Pro v 1.0 package from O'Reilly software[11]. WebSite provides an intuitive user interface for incorporating and managing content and controlling access to our web. In addition, WebSite is shipped with high quality documentation that has helped us to focus our efforts on more pressing matters. For web pages with limited interaction, WebSite includes support for a variety of languages that are useful for CGI programming, including the Perl 5 language that we use.

To provide a real-time interface to the observatory we have chosen to write our own client/server software in Java. Java is an object oriented language that is made compelling not so much by the features of the language itself but by the way the language is implemented. In principle, Java allows one to write software once and run it on any computer that implements the Java Virtual Machine. Machine independence is accomplished by first compiling the Java program into an intermediate form called byte code. Byte code can then be executed as an interpreted language on any computer through the Java Virtual Machine[12].

A particular use of Java that relies on its platform independent nature is Java applets. Applets are Java programs that can be downloaded over the Internet and executed by the user's web browser under certain restrictions. One important restriction is that applets are only allowed to make network connections back to the computer from which the applet was downloaded. This restriction does not represent a problem for our purposes currently but if we need to distribute the work load among different computers at a future time we can use proxy servers to reroute the applet requests as necessary.

Java provides several high level constructs that make writing the graphical user interface (GUI) client and the server relatively easy. First, the Socket and Server Socket objects make network communication almost as easy as performing I/O with stdin and stdout in C[13]. In addition, the Java language provides adequate high level GUI elements in the Abstract Windowing Toolkit and also provides objects for multi-tasking through threads and protecting critical sections with synchronization.

5.2 The Observatory Internet Control Software

The Internet control software running on the OCC server is currently designed to handle three different interfaces: 1) To an auxiliary controller over a serial link, 2) To a device running concurrently on the server, and 3) To receive "interrupts" from monitor applications also running concurrently on the server. The algorithms necessary to provide remote access to essentially all observatory functions can be described by one of these interfaces. Thus, we will limit our discussion here to three examples which illustrate each of the three interfaces.

Common to all the interfaces are the processes necessary to prepare the remote user for observing and to establish the client / server connection as illustrated in the top half of Figure 4. To initiate remote observatory control, the user retrieves the observatory web page from the OCC WWW server. At this point the remote user has access to a number of static pages including user guides, observatory documents, archived images and weather data summaries. The observatory home page also contains a link to the observatory control interface, but access to this link is secured with a password authorization.

Upon successful login, the observatory control applet is uploaded from the client system and begins to run under the Java Virtual Machine associated with the user's web browser. The Java client first initiates a socket connection with the Java server running on the OCC. The socket connection provides two way communication between the server and client. To prevent deadlock or run conditions the client must ensure that it is the only active interface to the observatory. Thus, the client queries the server to determine if there is another active remote connection and if so the second client is locked out.

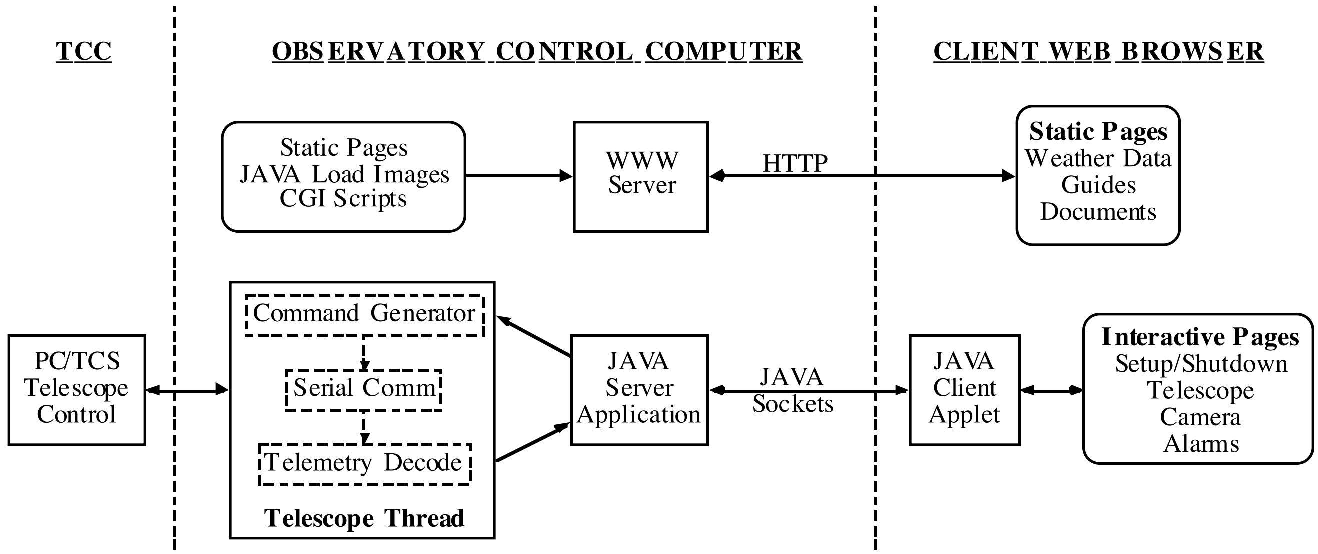

Figure 4: Remote telescope control processes and data flow schematic.

When the client is allowed access to the observatory the client applet pops up a series of GUI windows which display current information and allows the user to control the telescope, CCD camera and other aspects of the observatory. For example, from the GUI windows the user is able to move the telescope to a specified coordinate pair or to an object from one of several common catalogs, set the CCD temperature, take flat and dark frames, rotate a specific filter into the optical path and execute several other functions.

The elements which comprise the telescope remote control interface in particular are shown in the lower half of Figure 4. The GUI client both displays status information from the telescope and provides abstract controls that allow the user to execute commands on the TCC. To update the current status of the telescope a separate thread running in the applet requests the telemetry service from the Java server. The server then collects the telemetry data broadcast from PC-TCS over the serial connection, parses the telemetry data structure and sends this information back to the client. The client applet displays the information it has just received and waits for the next update time.

To execute PC-TCS commands the user enters command arguments (if necessary) and selects the corresponding abstract command from the GUI. For example, the user enters a right ascension and declination coordinate pair, and chooses the control for moving the telescope to the new desired direction. The client then starts a thread that requests a command execution service from the Java server, transmits a command code and command arguments (e.g. *right_ascension*, *declination*) and then waits for acknowledgment from the server that the command executed. The telescope command service consists of a command generator that constructs the appropriate sequence of PC-TCS commands and an external (native) routine that reads and writes data to the serial port connected to the TCC. For this particular example, the server would transmit the following three commands to the TCC: NEXTRA *right_ascension*, NEXTDEC *declination*, MOVNEXT. The server checks on the status of the commands it sends to PC-TCS by reading the telemetry stream and notifies the client when the abstract command has been completed. The client then kills the thread it started to execute the command and waits for further input from the user. Multiple command requests from the client are queued by the server until shared resources such as the serial port on the OCC are available for use.

The remote camera control, illustrated in Figure 5, is similar to the telescope control interface except now communication is between the client and a device controller running concurrently on the OCC with the Java server. The communication between the server and the Camera Control Software is accomplished through a Dynamic Data Exchange (DDE) interface. The

DDE provides access to the Camera Software through a series of callable functions, without the need to directly link the server software and device control software. Several CCD control packages provide this capability including IDL from Research Systems, Inc. and PMIS from GKR Computer Consulting. Currently the camera interface is being developed for PMIS.

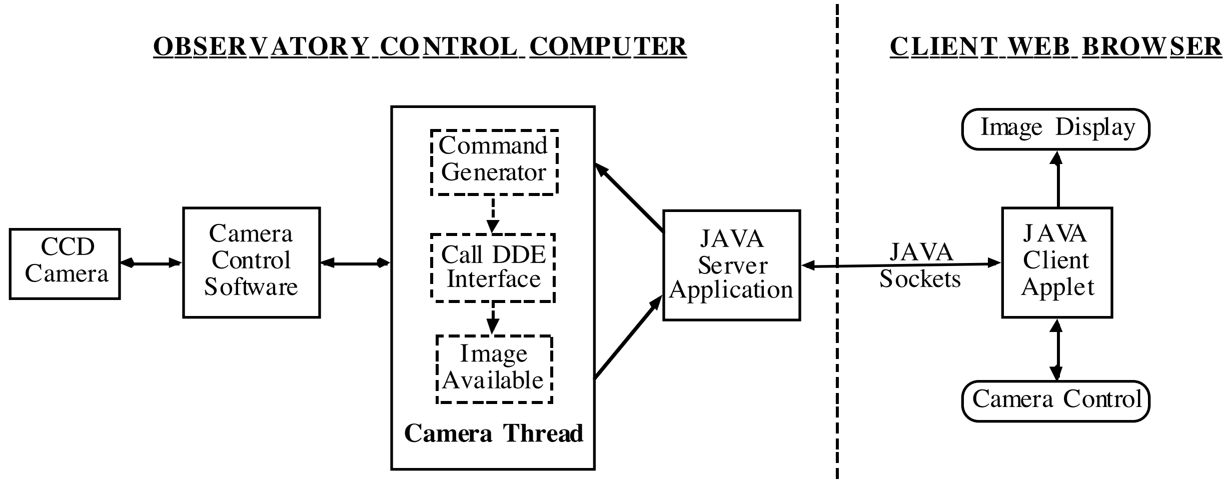

Figure 5: Remote camera control diagram of the processes and data flow.

Communication between the client and server again takes place through Java socket objects. The client displays information about the camera status gathered by the telemetry service described above and sends camera commands to a camera command service running on the OCC. The camera command service generates commands for PMIS and executes them directly. A successful return from the DDE interface provides an automatic command verification mechanism. If as a result of a command an image is generated, this image is available in memory and can be directly accessed by the server and passed to the client.

The remaining example interface is illustrated in Figure 6 for the alarm system. To operate the observatory without an operator on site, requires that precautions be taken to assure that a remote user cannot operate the observatory during conditions that would damage the equipment or would be otherwise unsafe. Such conditions include rain at the observatory or a power failure. As mentioned previously, the observatory includes a weather station with a rain sensor and a UPS which is activated when line power fails. The weather station data are constantly monitored by the datalogger and archived on disk by auxiliary software running on the OCC. Operating under an event timer, the Alarm Thread periodically wakes and reviews the latest weather data and line power signal. Currently the conditions being tested include indoor or outdoor dew point within a degree (C) of the ambient temperature, a positive rain sensor signal, an accumulation of rain and a positive line power failure signal. If none of these conditions are met, then the event timer is reset and the Alarm Thread is suspended.

If an unsafe condition is detected, however, the Alarm Thread assumes priority over the system, interrupts any other activities being processed by the server application and sends a warning message to the remote client that a system shutdown will immediately occur. If there is no active client at the time the warning is generated then the server locks out remote logins until the alarm is removed. The Alarm Thread then proceeds to "safe" the observatory including as the highest priority

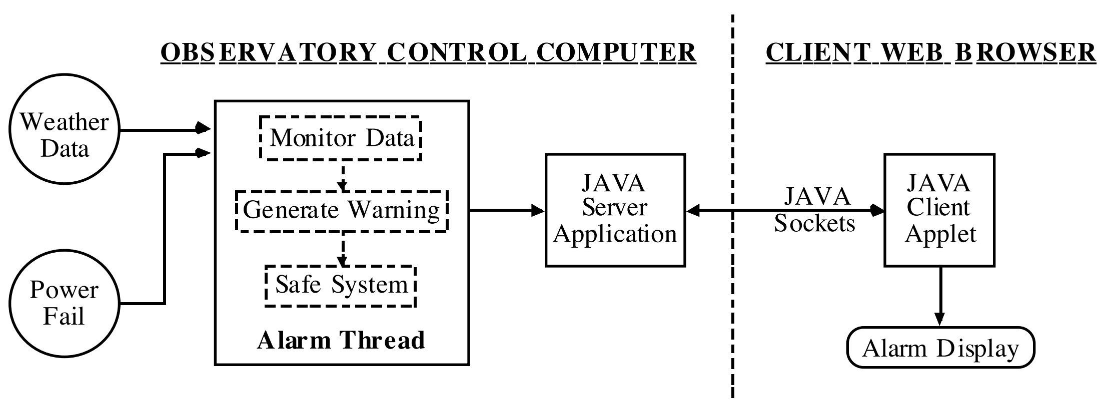

Figure 6: Alarm monitoring processes and data flow.

shutting the dome shutters, warming the CCD camera, resetting the telescope to a known state and locking out remote logins. Once "safeing" has been accomplished, the Alarm Thread returns to monitoring the environment data and will notify the server to release the remote login lock once conditions permit.

5.3 Possible Extensions for the Future

A powerful feature of the Java client / server approach we have taken is that it can be readily adapted to other kinds of telescope systems or other related applications. The main concept behind developing the telescope, camera services and alarm thread is that device dependent specifics are hidden from the main server application and client applet. As the application and applet communicate only at a high level using "generic" information (e.g. point telescope, object coordinates, camera exposure setting, etc.) there is no need to modify this code or the GUI interface if a different telescope control system or camera is used. In fact, much of the server code is reusable as well and only modules such as the Command Generator and Telemetry Decode would need to be altered. Further, since the Java language is standardized across a wide variety of platforms, the lower level code is written in ANSI C and system calls are minimized, code maintenance and portability across platforms is enhanced.

Extensions to this system are already being planned. In particular, we currently have no remote control capability over the ACE Instrument Selector or Camera Filter Wheel. We expect these devices to be delivered in March, 1998 along with their driver software. Since ACE will supply the software source code it should be relatively easy to adapt these routines to a DDE interface and incorporate the appropriate calls in the Camera Service code. We have also purchased a calibrated screen that will be mounted on the inside of the dome to one side of the shutter and used to take flat field exposures. In this case, we will need to include an extension which moves the telescope outside the shutter aperture to point at the flat field screen prior to taking a CCD exposure.

It may also be possible to adapt the system to use particular sky chart software, such as Megastar, on the client as a visual telescope interface. Megastar and several other similar programs include control of popular amateur telescopes, such as the Meade LX200, through a serial port on the host computer. Despite Java's device independent nature it is possible for both Java applications and Java applets to access (read from and write to) serial ports. Thus, it is conceivable that we could modify the client applet to communicate with a program like Megastar. In this configuration a version of Megastar would need to be running on a client which has two serial ports that are connected together. Megastar would be attached to one serial port and the client applet would attach to the other. This modified applet would also have to translate to and from the LX200 telescope control language. Now, in addition, to the normal remote telescope control GUI a sky chart would be available to visually show the pointing direction of the telescope and new objects to observe could be selected directly from the chart.

Other extensions may also be needed or desired as the observatory facility matures. However, with the flexibility discussed here designed into the software system from the start, the cost associated with some future evolutionary path should be minimized.

6. CURRENT STATUS AND PERFORMANCE

The observatory system has already exceeded our expectations both in its ability to observe faint objects and as a facility for public education and outreach. Even before facility construction began the project announcement generated articles in seven newspapers across the state and, to date, close to twenty different articles about the observatory have been published in Louisiana newspapers. The observatory has also been featured on local television several different times and one station has committed to providing a 5 minute segment on astronomy and observatory activities every other month. Since the facility building opened in June, 1997 public attendance of observatory activities has steadily increased. During June / July, 1997 BREC increased its extensive summer camp program to include a "Stargazers" astronomy summer camp at the new facility. This summer camp was highly successful and will be expanded during 1998. During mid-October 1997 we began a program of activities designed to provide the public with a regular schedule of events that can be enjoyed at the observatory each weekend. Of these regular events our most popular is the Friday Night Campfire, where speakers lead a very informal talk on astronomy or an astronomy related topic around a blazing campfire. On clear nights the campfire discussion is followed by sky observing using the facility telescope augmented by BRAS personnel with their portable telescopes. A typical Friday Night Campfire draws a crowd of about 100 people.

The observatory has also provided a focus for K-12 classroom space science / astronomy activities. In a typical month 4 to 5 group field trips are scheduled for the observatory and we try to sponsor at least one coordinated classroom activity. During such an activity, three to four classrooms are given a particular topic to study and each classroom concentrates on a specific

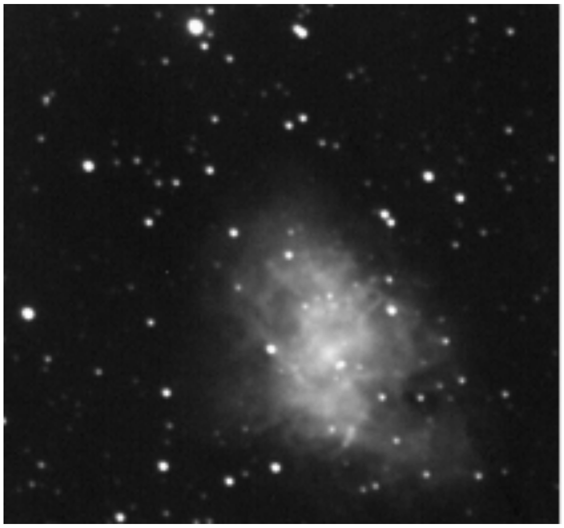
Figure 7: Crab Nebula taken from Baton Rouge.

aspect. Mentors from LSU and BRAS visit the classroom to discuss the topic and provide advice. Toward the end of the activity each class produces an exhibit on the results of their study and these are put on display at the observatory. Recently, a few of us (Guzik, Stacy, Wefel) have been awarded an IDEAS grant through the Space Telescope Science Institute. Under this new project we will attempt to develop a middle school activity that will make use of the observatory facility. A major priority of this IDEAS educational initiative is increased participation by K-12 students and teachers from traditionally underrepresented groups. Recent links established with educators and faculty at Southern University - Baton Rouge, the largest Historically Black College and University (HBCU) system in the country, will greatly aid in this effort

Our initial tests of the telescope and CCD camera indicate that the system will be able to support a much broader range of observational activities than was originally anticipated. The observatory site is located close to the southern boundary of Baton Rouge, Louisiana which is close to sea level altitude and generally has high humidity conditions. During the survey for the observatory site Highland Road Park had a measured limiting visual magnitude of about 5. These relatively poor conditions lead us to believe that a majority of our observations would need to be limited to objects brighter than magnitude 16. However, the advantages of the thinned, back-illuminated CCD for our application quickly became apparent during our initial tests of the system. For example, Figure 7 shows a picture of the Crab Nebula which was one of the first images taken at the Highland Road Park Observatory. At this stage the telescope had yet to be fully collimated, polar aligned and calibrated. To construct this image we used the Software Bisque CCDSoft software to control the Apogee AP7 camera and perform the image processing. Nine 10 second images were taken, dark frame subtracted, aligned and summed, but a flat fielding correction was not included. Given the inherent limitations imposed by the site and telescope state the image is quite impressive especially considering that, effectively, only a 90 second exposure was taken. Analysis of the image shows that the FWHM (full width half maximum) for unsaturated star profiles is about 5.2 arcseconds. This is somewhat wider than expected but may be the result of a combination of collimation, focusing, and image alignment errors as well as seeing conditions.

Among the features included in CCDSoft is the ability to perform a relative photometric measurement on a given image. This measurement takes into account the image scale of each pixel element (1.2 arcseconds) and the estimated "seeing" conditions. A reference star of known magnitude is chosen and then the magnitude for other stars in the field can be estimated. Using this CCDSoft feature with Figure 7 indicates that the faintest stars seen in the image are about magnitude 16. A similar analysis with a 120 second exposure of the Horsehead Nebula shows stars with an estimated magnitude of about 19.

This proven level of telescope / camera performance is more than sufficient to meet (and exceed) the requirements for student education and public observation. For the amateur astronomer projects, however, the telescope will need to be at peak performance. During March, 1998 Optical Guidance Systems and Comsoft will again visit the observatory to complete the instrument tuning. This will involve alignment of the optical tube assembly, collimation of the primary and secondary mirrors, and polar alignment of the mount. Further, we will need to perform a flexure data run. This involves using an automated PC-TCS utility to point the telescope to stars across the sky and centering the star in the field of view. This process produces a data file containing the deviations between calculated and measured star positions as a function of position in the sky. The data are then fit to a mathematical model which accounts for such items as polar misalignment, tube and fork flexure, and nonperpendicularity of the RA and Dec axes. The resulting coefficients are entered into PC-TCS which then corrects for these errors when pointing the telescope. Finally, we will need to measure the periodic errors produced by imperfections in the tracking gears. This combination of final alignments and calibrations will allow us to accurately center objects in the CCD field of view and to take long exposures (> 15 minutes) without the need to guide the telescope or combine images.

7. CONCLUSIONS

The unique collaboration between the LSU Department of Physics and Astronomy, the Recreation and Park Commission for the Parish of East Baton Rouge and the Baton Rouge Astronomical Society have successfully put into operation an observatory facility with the purpose to enhance training of astronomy majors at LSU, to increase public awareness and appreciation for astronomy and to support general science education in K-12 schools. The observatory includes a 20" Ritchey - Chretien reflector equipped with a back-illuminated CCD camera and is fully computer controlled. Much of the hardware and software for the observatory was purchased from commercial sources to minimize development cost, but we needed to implement our own software to provide remote control of the facility over the internet. Our approach for the remote control software makes extensive use of the high level and standardized internet communication capabilities inherent in current World Wide Web (WWW) and Java implementations. These capabilities provide interactive communications between the observatory server and a remote user equipped with only a Java capable WWW browser. Further, telescope hardware specifics are isolated to particular modules in the server application. This allows the remote control system to be highly portable and easily adapted to other systems. Fine tuning and calibration of the telescope will be accomplished shortly and preliminary tests indicate that the system exceeds expectations. In fact, even with the relatively poor conditions (i.e. low altitude, high humidity) at Baton Rouge, our initial, short exposure (~ 120 seconds) CCD images show stars as faint as magnitude 19. With this level of performance a very broad range of astronomical objects can be accessed for student training projects, amateur astronomy studies and to captivate the imagination of the general public.

8. ACKNOWLEDGMENTS

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