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DESIGN CONCEPT FOR THE RETROFIT KAO 1M ROBOTIC TELESCOPE

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ABSTRACT

Korea Astronomy Observatory (KAO) is working to retrofit its 1m robotic telescope in collaboration with a company (ACE, Astronomical Consultants & Equipment). The telescope system is being totally refurbished to make a fully automatic telescope which can operate in both interactive and fully autonomous robotic modes. Progress has been made in design and manufacturing of the telescope mount, mechanics, and optical performance system tests are being made for re-configured primary and secondary mirrors. The optical system is designed to collect 80% incident light within 0.5 arcsec with f/7.5 Ritchey-Chretien design. The telescope mount is an equatorial fork with a friction drive system. The design allows fully programmable tracking speeds with typical range of 15 arcsec/sec with accuracy of ±5 arcsec/hour. The mount system has integral pointing model software to correct for refraction, and all mechanical errors and misalignments. The pointing model will permit positioning to better than 30 arcsec RMS within 75° from zenith and 45 arcsec RMS elsewhere on the sky. The software is designed for interactive, remote and robotic modes of operation. In interactive and remote mode the user can manually enter coordinates or retrieve them from a computer file. In robotic mode the telescope controller downloads the coordinates in the order determined by the scheduler. The telescope will be equipped with a CCD camera and will be accessible via the internet.

Key words: instrumentation, automatic telescope

1. INTRODUCTION

The design concept of the robotic telescope system has been developed and implemented over the last two decades. One of the earliest microcomputer based telescope control systems was introduced by Indiana University group (Honeycutt et al. 1978), followed by many investigators (e.g.,

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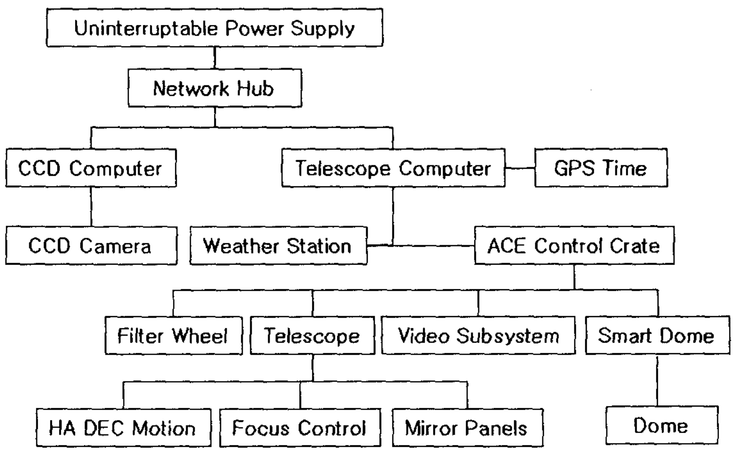

Figure 1. Hardware configuration of the KAO 1m robotic telescope system.

Genet 1986). The advantage of the computer based robotic telescope system was discussed elsewhere (Genet et al. 1989) for low operating costs with high operating efficiency and high scientific productivity. Some demonstrations of scientific usage of the robotic telescope were described by Lacy (1990), Hall (1995) and more recently by Kaye et al. (1999). The robotic control design concept developed further by applying internet access mode, and an example is introduced by Drummond et al. (1995).

The Korea Astronomy Observatory (KAO) 1m Robotic telescope system was initially purchased from an american company, Autoscope in early 1990's. However, their installation had never been successful and in 1996 their bankruptcy made the project unable to proceed. The project had been in great difficulties since then, and based on extensive exploration for suitable partner, KAO finally decided to collaborate with the company ACE (Astronomical Consultants & Equipment, located in Tucson area) to retrofit the telescope system in 1998. The existing 1m telescope was dismantled in 1998 to move for retrofit, and the telescope optics, servo motors, encoders, finder and other items were recycled for use in the new telescope. The new mount and control system is being manufactured by ACE. After the thorough optical performance tests in 1999, it was decided to re-configure the telescope optics for wider field of view (FOV) and better performance with the optics matched to the detector. Now the optical performance is being tested after repolishing. In this paper we present the design concepts for the telescope and control system and introduce some of the design considerations of the telescope system.

2. HARDWARE CONFIGURATION

The logical layout of the hardware is shown in Figure 1. Control revolves around two computers which form a local area network. One computer is used exclusively for CCD data acquisition since many CCD controllers require 100% of the computer usage when reading out frames. The other, more powerful computer, manages everything else. A weather station and a Global Positioning Satellite (GPS) time receiver are independent of the ACE Control Crate, which manages the telescope, dome, video and auxiliary instrumentation. All signals passing through the ACE Control Crate are optically isolated to provide protection against power surges caused by lightning. Key elements in Figure 1 are described in more detail.

2.1 Telescope Computer

The ACE Robotic Control System^{TM} is a native 32-bit Microsoft Windows NT application. A rack-mounted Pentium computer with a fast processor and 256 MB RAM manages the telescope, dome, and weather station. In order to conserve interrupts, and to maximize throughput, the on-board SCSI is used for disk drives and a read-write CD-ROM. The video card is a Creative Labs Savage-4 with 32MB video memory and a 300 MHz processor. It uses the on-board Advanced Graphics Processor (AGP) port. The standard video resolution is 1280 $\times$ 1024 which can be run at 80 Hz if the display monitor is capable. The motherboard has 2 ISA slots and 3 PCI slots, in addition to 1 shared ISA / PCI slot, and computer specification can be upgraded when more up-to-date components become available.

The telescope computer is equipped with two ISA bus motion control cards, each having four axes of control with encoder feedback, a 24 channel PCI bus digital input-output card, and a ISA GPS-based clock card for precision time keeping. Information from the Davis Instruments weather station is downloaded through a serial communications port. The video capture card is used to put real-time video on the computer screen and the internet. It uses a PCI slot, so there is just one PCI slot remaining for future expansion. Another computer manages the scientific detector, usually a charged coupled device (CCD) camera. This is necessary because of computing loads during CCD readouts, and the lack of available slots in the telescope computer.

2.2 Control Crate

The Control Crate is the interface between the computer and the instrumentation. It too is rack-mounted and three cables for the motion control cards and the digital I/O card provide communication between the crate and the computer. The ACE Control Crate contains power supplies and optically isolated relays (input and output) to protect the computer from spurious electrical spikes. All the control cables from the telescope, dome, filter wheel and video control are terminated at this crate.

2.3 SmartDome

The observatory dome is automatically slaved to the telescope. One of the most important aspects of remote and robotic observing is to ensure that the dome can always be closed. An embedded microprocessor, the ACE SmartDome, constantly handshakes with the computer. In the event of a computer crash the device automatically sends the dome home and closes the shutter(s). The device has an RS232 communications port to permit full dome status information to be sent to the control computer.

2.4 Video Subsystem

The video subsystem uses a commercial color PAL / NTSC video switcher to permit one of eight cameras to be viewed, or a quad display of the first or last four cameras. The view can be switched in software by sending a simple binary pattern to the switcher using the digital I/O PCI card. The output from the video switcher is also fed into an inexpensive video capture card to permit real-time video to be placed on the internet. The exact arrangement of the cameras is to be determined. Typical uses will be a color cloud camera, a low-light level infra-red camera for viewing the telescope at night, a dome camera to view the dome slit, a low light level color camera equipped with a 200 mm lens to view the Sun or Moon during eclipses for public outreach (broadcast live on the internet), and some

Table 1. Optical design parameters for KAO 1m telescope (in millimeters).

System Component	Properties	Value in mm
Primary Mirror	Diameter (Physical)	1046
	Diameter (Optical)	1046 with 1000 minimum test area
	Radius of Curvature	5508.9
	Focal Length	2754.5
	Focal Ratio	2.633
	Conic Constant	-1.109198 (weak hyperbola)
Secondary Mirror	Diameter (Physical)	332.4 nominal
	Diameter (Optical)	330.4
	Radius of Curvature	-2606.7
	Conic Constant	-5.638903
System Characteristics	Effective Focal Length	7845
	Effective Focal Ratio	f/7.5
	Field of View (Diameter)	0.466 (28 arcmin)
	Plate Scale	26.25 arcsec/mm
Spacing	Prime Focus Intercept	845.7
	Primary-Secondary space	1908.7
	Back Focal Distance	500

security cameras.

2.5 Filter Wheel

An eight position filter wheel to accommodate 3 inch square filters will be attached to the rear of the telescope. It is equipped with an absolute encoder and is driven by stepper motors. It was initially designed for 2 inch scale FOV, however after optical performance analysis, it was decided to utilize maximum focal plane and for wider scale FOV, up to 3 inches.

2.6 GPS Clock

A global positioning satellite (GPS) clock is used to keep the telescope computer clock synchronized to better than 0.05 seconds. It checks once a minute and resets the clock if there has been a drift. The CCD computer is also reset using a Windows-NT time service. The telescope control software calculates sidereal time knowing the universal time from the GPS card.

3. THE TELESCOPE

3.1 The Optics Design

The optical set is of the classical Cassegrain design. The primary mirror is a lightweight (70 kg) honeycomb design with a f/2.75 focal ratio. The mirror blank is 1040 mm diameter with an optical diameter of 1000 mm and a 140 mm central perforation. The mirror blank was manufactured by HexTek Corporation of Tucson. The front and back surfaces are approximately 11 mm thick and both are curved such that in cross section they are parallel to each other. The secondary mirror was newly designed, and has a 225 mm diameter optical surface. The effective focal ratio after repolishing is f/7.5, which gives an image scale of 26.25 arcsec/mm.

Table 1 gives the optical design parameters. The calculations are based on numbers taken from this table, in particular a focal length of 7845 mm, rather than assuming a 1000 mm f/7.5 system. The available field of view of the telescope is limited by two factors: the size of the hole in the primary mirror/baffle system, and, to a lesser extent, the amount of acceptable residual astigmatism. The hole in the primary is only 141 mm. The baffle system was designed to act as both the sky flood baffle and the mirror handling fixture. The wall thickness of the tube has been minimized to allow the largest possible light cone to enter. However, a typical R-C Cassegrain might have a central hole of approximately 225 $\sim$ 250 mm diameter. The honeycomb design of the mirror prevents us from opening up the size of the central hole by more than a few millimeters. However, we have gone ahead and done this to help insert the baffles.

Figure 2 shows the layout of the (partial) lower baffle system, primary mirror, guider box, filter box and focal plane. To use all of the available field 3-inch square filter are required. The figure shows a dual filter wheel, that is two wheels stacked on top of each other. There are 10 slots in each filter and so a maximum of 18 filters can be accommodated. One advantage of the dual filter wheel is that neutral density filters can be placed in the upper wheel to permit multicolor photometry of very bright objects using the lower wheel. The filter wheel can take a CCD dewar up to 200 mm diameter with a weight of 10 kg. The guider box is still under design. It will employ a small pick-off diagonal mirror, with a minor axis of approximately 25mm. The pick-off mirror can only reach the East, South and West sides of the CCD detector.

3.2 Focal Plane and available sensing area

Figure 3 shows a map of the 1.0-m f/7.5 R-C focal plane for various CCDs. The maximum fully illuminated field of view is 64 mm (28 arcmin) diameter and this value is set by the hole in the primary mirror. The partially illuminated field of view extends out to 150 mm diameter, at which point the illumination has fallen to zero.

For practical purposes a guide star should be acquired within the 50 % illuminated field of view. The detector has a rectangular format and so it is important to consider not field diameters but the illumination of a rectangle. The maximum inscribed fully illuminated square is 45.25 mm (19.8 arcmin) on a side. Therefore, the optimum size CCD for this telescope is a 3072 × 3072, 15 micron pixel size thinned back-illuminated device. Unfortunately, there is no such device commercially available.

Three rectangles are shown in the diagram, for a small 4096 × 4096 with 9 micron pixel CCD, the ideal (hypothetical) CCD, and the large format 4096 × 4096 with 15 micron pixel CCD. Note that the larger CCD is not fully illuminated. Two options are available for the fully illuminated focal plane (1) use only a part of this field with a small detector, and have a fully illuminated guider area (2) use all of this field with a large detector and have a partially illuminated (vignetted) guider field. The available guider field is then limited, and the effective aperture of the telescope falls off from 1.0 m to zero. The distance from the back of the mirror cell to the focal plane is 250.0 mm.

It is generally recommended to select a CCD with a pixel size of approximately 0.4 arcsec to achieve the proper sampling for an observing site with sub-arcsec seeing conditions. The plate scale of the telescope is 26.25 arcsec/mm at the Cassegrain focus. A pixel size of 15 microns is 0.39375 arcsec. Figure 4 shows the spots diagram at the center, at the midpoint of one of the sides of the array, and at the corner of the array for the large-format 4096 × 4096, with 15 micron pixel CCD.

3.3 Tube and Mounting

The telescope mount is an equatorial fork, designed for rapid movement during long slew motions across the sky. It uses friction drives rather than the traditional worm drives to minimize backlash. Table 2 shows the design parameters. The optical assembly will have an open truss design for optimum seeing performance and minimal mechanical and thermal inertia. The mirror cell will

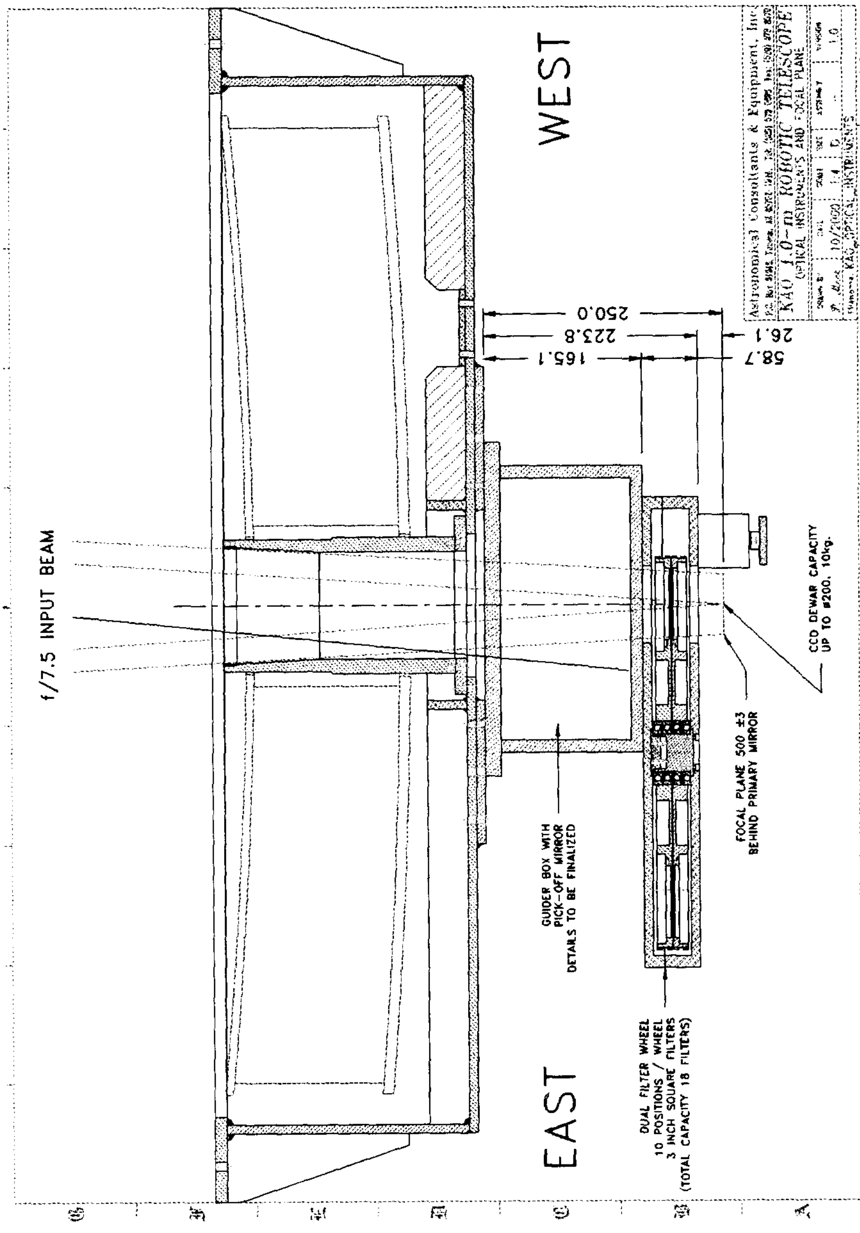

Figure 2. The layout of the (partial) lower baffle system, primary mirror, guider box, filter box and focal plane.

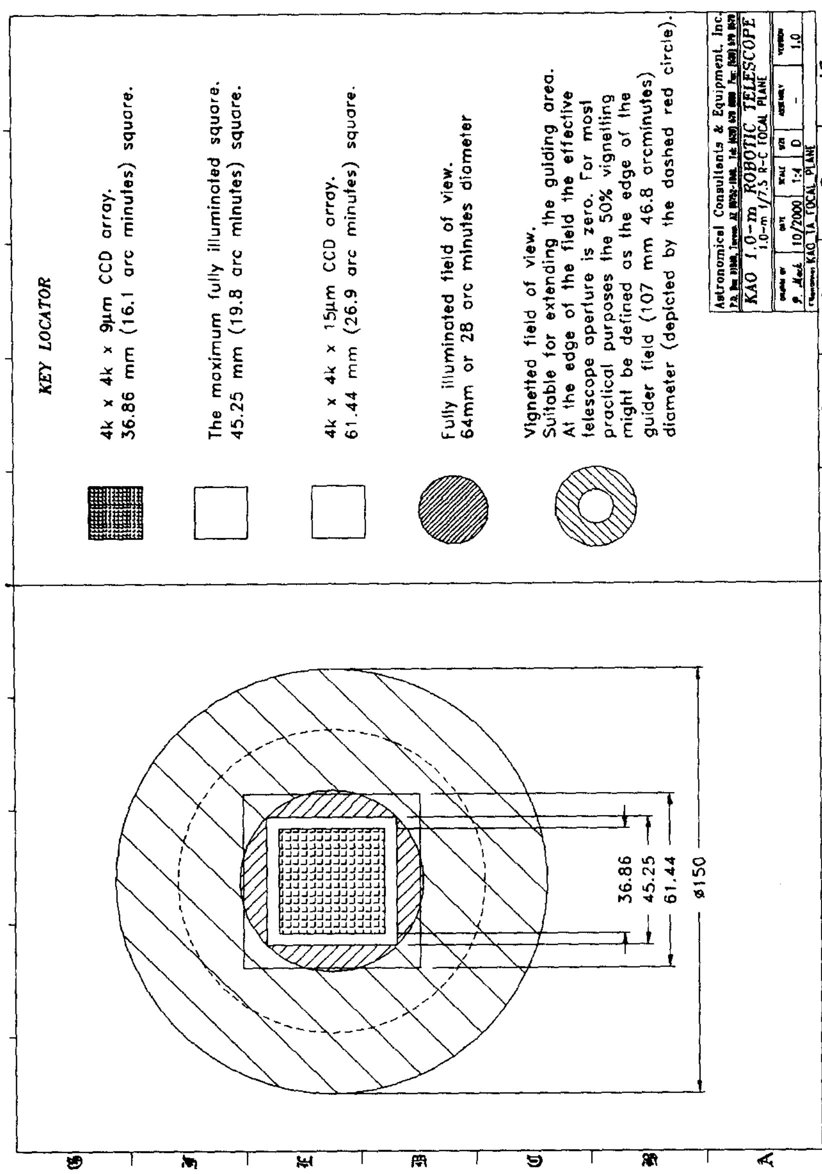

Figure 3. Optical arrangement of KAO 1m f/7.5 R-C focal plane for various CCDs.

Table 2. Telescope mount system parameters for KAO 1m telescope.

Parameters	Properties
Tracking	Fully programmable. Typically 15.0000 ± 3.0000 arcsec/s.
Guide speeds	Fully programmable. Typically value from 1 to 25 arcsec/s
Set speeds	Fully programmable. Typically value from 50 to 250 arcsec/s
Slew speeds	Fully tunable by the system engineer. Typical slew speeds 3 to 4 degrees / s with Acceleration of 2 to 3 degrees /s^2
Tracking accuracy	± 0.5 arcsec in 5 minutes, or ± 5 arcsec in 1 hour.
Pointing accuracy	Better than 30 arcsec RMS within 75° from zenith and 45 arcsec RMS elsewhere on the sky. Precision offsets ¡ 10° from a reference star to better than 0.5 arcsec.
Balance	Rolling trim weight on fork arm.
Structure	Equatorial fork mount with Open truss structure with fixed top assembly
Primary support	27 point wiffle tree design with 6 radial supports at the center
Secondary housing	Precision ball screw assembly with single drive motor and encoder feedback
Load Capacity	0 - 100 kg
Focal Plane	Adjustable by the secondary from 0 to 300 mm behind the mounting flange with the system optimized for 100 mm.

have automatic covers. Forced ventilation fans will be provided in the mirror cell but in practice the low thermal inertia of the primary may make them unnecessary. The top end of the optical assembly will be fixed so that only one secondary mirror is used. The secondary shall be supported using a four-vane spider. The focus ram will use a precision ball-screw driven by a stepper motor with closed-loop encoder feedback. The control system permits re-initialization of the encoder to the OUT position. Current focus values are retained, even during complete power-down.

The hour angle and declination axes are both friction disk drives employing Compumotor Dynaserve servo motors. These motors have sufficient static torque that they can hold the telescope even with the power off, assuming the telescope is in reasonable balance. If the telescope is purposefully placed out of balance, such as when changing instrumentation, a set of braces is used to keep the telescope tube pointing at the zenith. The telescope has a mercury tilt switch horizon sensor, which is set to 10 degrees. In additional there are sensors to prevent polar wrap and interference on the southern horizon with the fork arms. A home sensor permits automatic re-initialization of the telescope in the event of a computer malfunction.

4. CONTROL SOFTWARE

The user interface for interactive observing is shown in Figure 1. The same interface is visible on the computer screen for interactive, remote and robotic modes of operation. In interactive and remote modes the user can manually enter coordinates or retrieve them from a file. In robotic mode the telescope controller downloads the coordinates in the order determined by the scheduler.

The software controls the telescope pointing and tracking, focus. the finder-guider system, the filter wheels, video cameras, autoguider and dome. The software was written by ACE using Visual C^{++} and has a complete interface library. The full status of the telescope is available in ASCII format over the internet. As an added benefit a new user interface, in a different language (for instance Korean) can be easily written. The graphical user interface only need to read the telescope

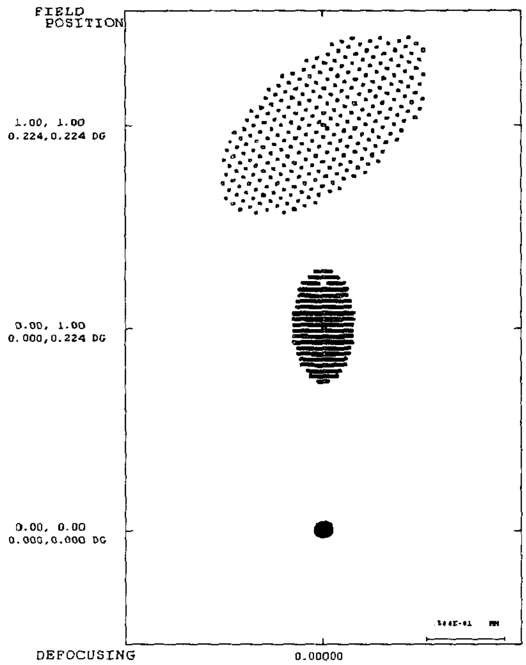

Figure 4. The spots diagram at the center, at the midpoint of one of the sides of the array, and at the corner of the array for the large-format 4096 × 4096 with 15 micron pixel size CCD.

status and to be able to send commands to the real telescope controller. More detailed discussion of the software system will be presented later, after system performance test.

5. AUTOMATIC (PROGRAMMED) OBSERVATIONS

The logical path for making autonomous observations has been designed following procedures. Users log onto a web site to make requests for telescope time. A username and password is required. Then users are assigned a priority code so that observers with high priority can always get time over low priority observers when a conflict in time occurs, or to get their objects observed as soon as possible. The web site has a simple form which permits objects to be observed multiple times, through different filters, only between certain dates, or when the Moon is down.

Requests from the web site are sent by ftp to the telescope scheduler, which is located on the same computer as the telescope control system. For security purposes this is a different computer than the host for the web pages. The user never knows the ftp address of the telescope controller. The scheduler regularly checks for new requests and adds the request to its database. Each request is assigned a unique number. The scheduler sends e-mail to the observer to confirm the request has been scheduled. The original request file is then deleted so as not to get reentered into the scheduler.

The scheduler builds a list of all the pending requests. Any requests which have been completed are deleted from the current database. This updated request database is then sent by ftp to the telescope control computer, which is a physically different machine from the web site / scheduler. This is done for security reasons.

When it is time to observe (and the weather conditions are suitable) the controller checks for an updated output from the scheduler. After completing the observation the request is marked as finished and the accompanying data file sent to the scheduler computer. The database is updated to show the observation completed. The next time the scheduler is invoked it sends e-mail to the observer with details of how to get the data from the scheduler computer. Finally, the database of previous observations is updated. All images are stored on-line so that previous observations can be retrieved.

6. SUMMARY

The KAO 1m robotic telescope is being refurbished to make a fully automatic telescope which can be used interactively as well as to take autonomous robotic observations. The design concept to retrofit the telescope system has been realized and implemented practically by the active collaboration of ACE and KAO. It is designed for CCD imaging with automatic retrieval of the data and rescheduling, which makes it competitive even in locales with relatively poor climatic conditions. After the extensive system performance test in the near future, the system will be fully integrated, and will be engaged in test observations to stabilize the whole telescope system for considerable time, around the Tucson area with excellent climatic conditions. We are expecting the telescope system will be used extensively with low operating costs and high operating efficiency for high scientific productivity.

REFERENCES

Drummond, M., Braising, J., Edgington, W., Swanson, K., Henry, G., & Drascher, E. 1995, in ASP Conf. Ser. 79, Robotic Telescopes: Current Capabilities, Present Developments, and Future Prospects for Automated Astronomy, ed. G. W. Henry & M. Drummond (San Francisco: ASP), 101

Genet, R. M. 1986, Automatic Photoelectric Telescopes, ed., D. S. Hall, R. M., Genet & B. L. Thurston (Mesa: Fairborn Press), 1

Genet, R. M., Hayes, D. S., Epand, D. H., Boyd, L. J., & Keller, D. F. 1989, Robotic Observatories: Remote-Access Personal-computer Astronomy (Mesa: AutoScope Corporation), 21

Hall, D. S. 1995, in ASP Conf. Ser. 79, Robotic Telescopes: Current Capabilities, Present Developments, and Future Prospects for Automated Astronomy, ed. G. W. Henry & M. Drummond (San Francisco: ASP), 65

Honeycutt, R. K., Kephart, J. E., & Hendon, A. A. 1978, Sky & Tel., 56, 495

Kaye, A. B., Henry, G. W., Fekel, F. C., Gray, R. O., Rodriguez, E., Martin, S., Gies, D. R., Bagnuolo, W. G., & Hall, D. S. 1999, AJ, 118, 2997

Lacy, C. H. 1990, in Robotic Observatories: Present and Future, ed. S. Baliunas & J. L. Richard (Mesa: Fairborn Press), 337