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Hardware Design for the Autonomous Visibility Monitoring (AVM) Observatory

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The hardware for the three Autonomous Visibility Monitoring (AVM) observatories has been redesigned. Changes in hardware design include electronics components, weather sensors, and the telescope drive system. Operation of the new hardware is discussed, as well as some of its features. The redesign will allow reliable automated operation.

I. Introduction

Extensive testing of original hardware for the engineering model of the Autonomous Visibility Monitoring (AVM) observatories has provided new specifications for the field hardware. The revised task allows improved capabilities and better specification of procured and manufactured components of the AVM hardware. Some of the original equipment has been retained. This article will outline the specifications for the hardware and describe the operation of the new system.

II. Objectives and Specifications

Several problem areas were identified with the hardware used in the engineering model. Based on experience operating the equipment, new specifications were developed for the observatory system. The objective of the AVM task is to develop an atmospheric transmission model for optical communications through autonomous visibility measurements of known stellar objects from several locations in the southwestern United States, and to update this model

on a quarterly basis. In order to meet this objective, autonomous observatories will be deployed to continuously monitor star transmission intensities. Atmospheric attenuation probabilities will be determined from these measurements.

To achieve this objective, the system must observe weather conditions and sky transparency for several years. Weather sensors must be able to withstand the environmental extremes of remote sites, and the system must respond to indications from these sensors in case of inclement weather. Sky transparency sensors must be able to discern cloud/no cloud conditions and measure atmospheric attenuation. Attenuation from sensor components must be calibrated to ensure accurate calculation of attenuation from the atmosphere only. The system must be designed to measure atmospheric attenuation to within ten percent error.

The sensor chosen for the sky transparency measurements is a charge-coupled device (CCD) camera mounted to a ten-inch Schmidt-Cassegrain telescope. To provide

data on the spatial correlation properties of the atmosphere, three identical autonomous sensor systems will be developed and deployed. Operations of these items and the associated control systems are discussed in the following paragraphs. A hardware block diagram is shown in Fig. 1.

A. Telescope Mount

The telescope mounts are the original mounts designed by Autoscope Corporation, with several modifications that have been made in the past few years. Open loop control of the mount's equatorial friction drive system was tested and found to be accurate to within 2.3 mrad. The redesigned system has an error of less than 0.4 mrad to match the camera's field of view through the telescope. In order to achieve this accuracy, encoders are used on the equatorial drives to provide closed loop feedback. Total error from the encoders, encoder mounting, and mount mechanical error is less than 0.4 mrad. A mount model may be used to further reduce the mount mechanical error. The encoders will improve system accuracy by removing errors associated with slippage, backlash, balance, and improper stepping from the motors. All components on the mount are rated to operate in temperatures from -20 to 40 deg C.

B. Optical System

A Meade ten-inch Schmidt-Cassegrain telescope focuses a star image onto a CCD camera, providing a field of view of 1.1 mrad. A filter wheel in the path allows selection of one of eight positions: three standard astronomical filters, V, R, and I; three narrow (10- or 20-nm) filters corresponding to laser wavelengths, 532 nm, 860 nm, and 1064 nm; plus a block position and a clear (no filter) position. Filter transmission curves are given in Fig. 2.

A telecompressor lens, which was used in the past, can increase the field of view up to three times. However, with a smaller field of view, daytime observations will provide better resolution of attenuation because of the decreased background sky per pixel observed. Longer exposure times are possible before saturation of the pixels. Increased pointing accuracy, achieved by using encoders, enables operation without the telecompressor.

The optical path will be calibrated before operations begin, so that losses through each of the optical elements will be well known. In addition, a calibration lamp will be placed in the dome to provide a reference source for changes in telescope losses. Observations of this source several times daily will indicate any changes in optics throughput due to dust accumulation or condensation on the Schmidt plate of the telescope.

C. CCD Camera

The CCD camera is a Spectra Source Lynxx PC camera with 192×165 pixels in an area of 2.64×2.64 mm and 12-bit resolution. It is responsive over the 500- to 1064-nm wavelength range, and has a pixel area small enough to discern stars from the background sky during the day. The pixels are rectangular, $13.75 \mu\text{m}$ (192 dimension) by $16 \mu\text{m}$ (165 dimension). Combining this CCD with the telescope gives an image size of 1.1 mrad with a pixel resolution of 0.005×0.006 mrad. The detector is cooled to -10 deg C inside a sealed housing. Quantum efficiency and responsivity are indicated in Fig. 3.

D. Control Computer

The observatory is controlled by a 386-based computer. This computer is placed inside an environmentally controlled electronics cart and is tested to withstand operating conditions at altitudes of 3000 meters, operating temperatures of 10 to 30 deg C, and storage temperatures of -20 to 40 deg C.

Control boards inside the chassis include CCD control, telescope and observatory control, communications ports, clock control, and a monitor driver board. The CCD board is matched for each camera. The telescope and observatory control board is capable of driving the telescope stepper drivers, encoders, and filter wheel stepper driver; monitoring mount limit switches and joystick control; and driving or monitoring various input/output (I/O) modules. This board runs with a C program and will control sidereal rate, ramp, and slew operations. It has a run-time library of commands for various interfaces with the board, a joystick matched for operations with the board, and adjustable control parameters to compensate for differences between the three telescope mounts.

Three communications ports are used for connections to the uninterruptible power supply (UPS), modem, and weather station. A clock board regulates the DOS clock to within 0.5 seconds in order to properly track sidereal motion. All control boards are rated to operate at altitudes of 3000 meters, operating temperatures of 10 to 30 deg C, and storage temperatures of -20 to 40 deg C.

E. Observatory and Telescope Integrated System (OTIS)

OTIS controls telescope movement, filter control, and various other observatory operations. A block diagram of its components and connections is shown in Fig. 4. Major components are the microstepper controllers for the mount stepper motors, a stepper controller for the filter

wheel, CCD thermoelectric cooler control, I/O modules, watchdog relay, and various cable interfaces. OTIS will be placed inside the electronics cart, so its components are rated for the same altitudes, operating temperatures, and storage temperatures as the computer.

The microsteppers that control the telescope mount motors are adjustable for fine tuning from 1/256 step to 1 step. Optimum adjustment is at 1/16 step. They efficiently transfer power to the motors to prevent excessive heating of the system, and supply a high voltage to allow for high-speed operation of the mount axes. Voltage supplied to the motors can be up to 60 V. Previous drivers used a maximum of only 24 V.

The filter stepper driver is a single-step 12-V driver compatible with the PC digital-signal-processing controller. The CCD thermoelectric cooler (TEC) is compatible with the existing sensor in the camera (AD590) and controls at -10 to within ± 0.05 deg C. The cooler has an analog output so it can be monitored by the computer.

The analog and digital I/O control modules receive inputs from devices needing computer monitoring (24 V ac or 5 V dc) and provide outputs for computer control (dry contact output, 117 V ac, 24 V ac). Items controlled by the I/O modules are the calibration lamp, roof open, roof close, watchdog alarm, roof alarms, UPS alarm, high cart temperature alarm, watchdog notification, roof limit switch status, rain alarm, and wind speed alarm. The watchdog relay uses a 24 V ac input to switch 24 V ac to inform the roof controller, alarm system, and computer if the timer has not been updated within ten minutes.

The OTIS power supply provides ± 12 V at 2 A each, +5 V at 10 A, and +48 V at 5 A. Various connector interfaces are also provided within OTIS.

F. Weather Station

The weather station monitors wind speed and direction, inside (cart) and outside (ambient) temperatures, and relative humidity. Sensors located on the weather mast are capable of surviving 90-m/sec gusts and temperatures from -20 to 40 deg C. Alarms are available to shut down the observatory in case of precipitation or wind speeds greater than 13 m/sec. The weather station allows for three additional 0–5 V analog signals to be monitored. The signals monitored through the weather station are the CCD temperature (from the CCD TEC), the calibration lamp intensity, and precipitation. Alarms for precipitation and high wind speed drive the alarm system and roof controller, and are input to the I/O modules in OTIS. Weather

conditions and voltage inputs are recorded via an RS232 connection to the computer. The new weather station was recommended by the National Oceanic and Atmospheric Administration (NOAA).

G. Enclosure Control

Observatory enclosures, including the building, roll-off roof structures, and electronics carts, must operate reliably through adverse weather conditions. New actuators were purchased to reliably control operation of the south walls of the buildings. They allow the walls to travel between fully upright and horizontal positions to allow full visibility to the south, and are sealed to prevent water contamination of the drive systems. The roofs must reliably close and open when instructed by the computer or alarm systems to allow quality observations and equipment safety. The original enclosure was not designed to operate under these expected adverse conditions. However, the second two enclosures, which are of a different design, have been operating reliably at high altitude sites. If the third observatory is moved from the JPL mesa to a new site, an improved enclosure will be required.

The electronics carts house all electronics that can be placed remotely from the sensors. The carts have been modified to allow temperature control by an industrial air conditioner, and have been strengthened to support more weight than originally designed.

H. Environmental Controls

An air conditioning and heating system controls the cart temperature, keeping it between 15 and 27 deg C. Normal operating temperature is 20 deg C. The air conditioner provides temperature control and dehumidifying of the cart using a closed-loop system, which recycles the air inside the cart to ensure a clean operating environment. The cart is vented between sections to improve air circulation. The heater is thermostatically controlled and turns on if temperatures fall below 10 deg C. It is rated to turn on in temperatures as low as -20 deg C. The observatory enclosure is vented to allow heat generated by the air conditioner to escape while the building is closed.

I. Power Conditioning

Power requirements for the observatory are 500 W for the main roof, 330 W for the south wall actuator, 1640 W for the air conditioner, and approximately 600 W for the electronics cart. A 1-kVA UPS provides backup power and surge protection for the instruments in the electronics cart. The roof motors and air conditioner have no backup power, but sites selected for the observatories should have

a backup generator for these items. The main roof can be closed manually in case of power failure.

J. Alarm System

The alarm system monitors eight alarm conditions plus power failures. It is a dialing alarm system, which will call a series of telephone numbers to report alarm conditions until an acknowledgment is received. The system can be programmed to respond differently according to the conditions of the individual alarms. It has a battery backup to retain memory in case of power failure. Inputs to the alarm system are dry contact closures.

III. Operations

The automated observatory will continuously monitor sky conditions by observing bright stars using the CCD camera and telescope optics. Observations through each of the filters will indicate atmospheric transmission at different wavelengths. The system is unattended, so all components must operate reliably without supervision for weeks at a time. Maintenance visits will be scheduled period-

ically for system upkeep. The system must be properly calibrated to accurately determine site conditions.

The system is controlled by an observing program written in C++. The program will schedule operational events based on a priority queue, and respond to varying environmental conditions. Data from daily observations are transferred via modem to JPL, where they will be analyzed. Data returned will consist of observatory and weather status and CCD observations in a flexible image transport system (FITS) format.

IV. Conclusions

The redesign of the automated observatories will provide a reliable system capable of collecting all required data. The engineering model that was developed over the past several years identified several components of the system that required redesign in order to ensure reliable operation. The hardware described in this article is a result of the lessons learned through development of the system. A hardware reference book is being kept that contains all specifications and manuals for hardware contained in the system.

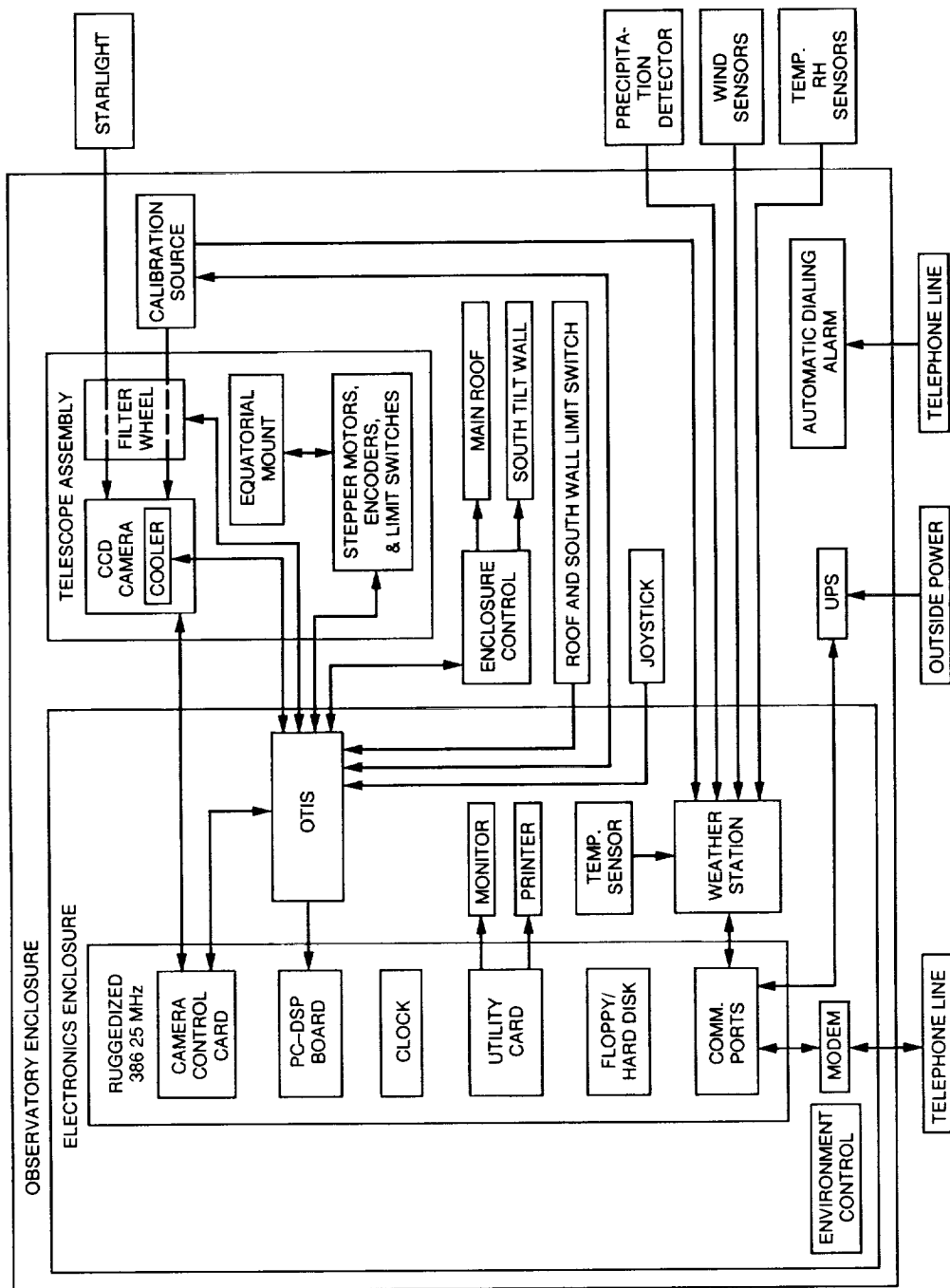


Fig. 1. Automated observatory hardware flow diagram.

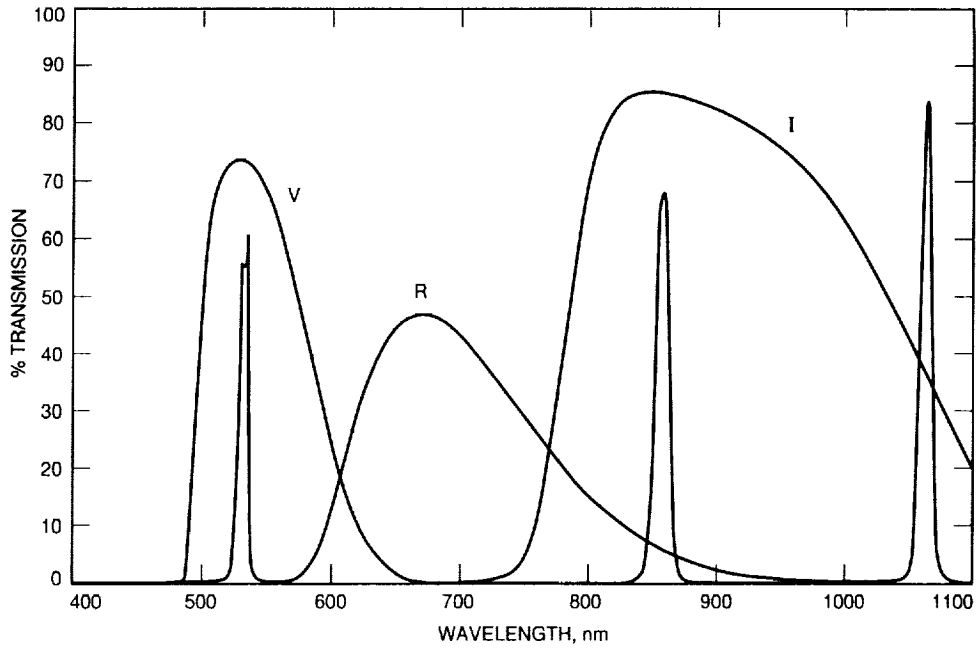


Fig. 2. Filter characterization of 1-nm resolution.

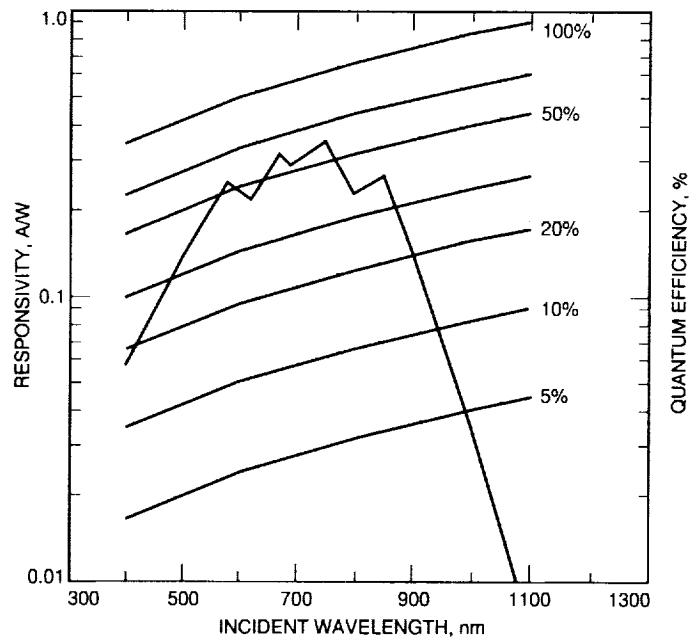


Fig. 3. Lynxx CCD sensor spectral characteristics.

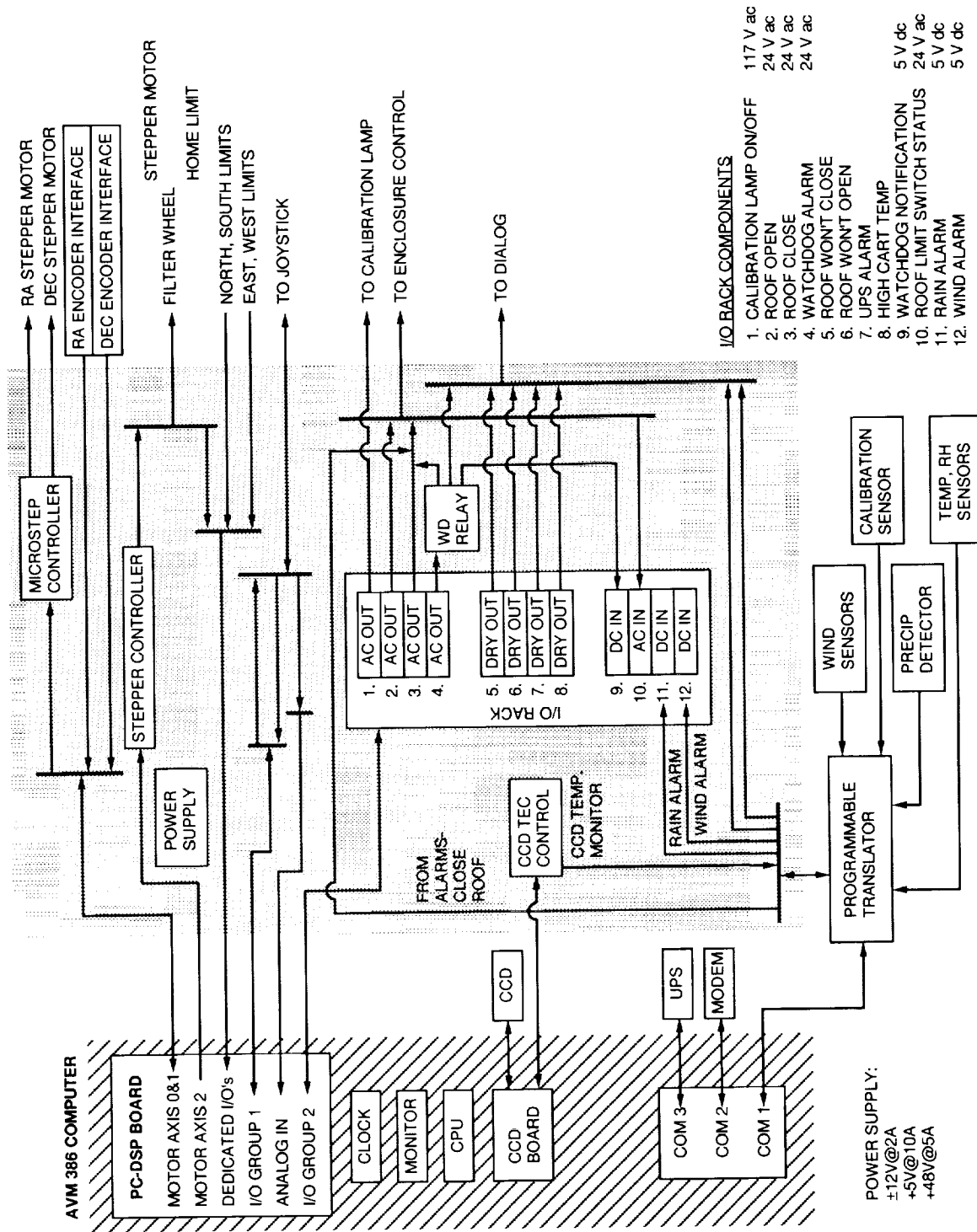


Fig. 4. Observatory and telescope integration system (OTIS).