Marine Physical Laboratory

Delivery and Development of a Day/Night Whole Sky Imager with Enhanced Angular Alignment for Full 24 Hour Cloud Distribution Assessment

Janet E. Shields, Richard W. Johnson, Monette E. Karr, Richard A. Weymouth, and David S. Sauer

Supported by the
Chief of Naval Research
Contract N00014-93-D-0141-DO#11

Final Report

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Abstract

The Whole Sky Imager is a ground-based digital imaging system for assessment of cloud cover over the full upper hemisphere. Using a fisheye lens and a slow scan CCD sensor, it acquires imagery under daylight, moonlight and starlight conditions. This contract funding enabled Marine Physical Lab to provide a new Whole Sky Imager to the Air Force, with several enhancements. The primary enhancements funded under this contract included more accurate alignment with respect to the sky field, detailed documentation, and enhancement of the software to allow interactive modification of the data acquisition from remote sites.

1. Introduction

The Day/Night Whole Sky Imager is an automated digital imaging system for acquiring imagery of the full upper hemisphere during both day and night. The WSI was developed by the Marine Physical Laboratory, based on many years experience with earlier daytime-only WSIs, which were also developed at MPL. At the time of the initiation of this contract, MPL had developed and fielded two Day/Night WSI units under funding from Air Force, Army, and Navy. In addition, two more units were under development for use in global warming research by the Department of Energy. This contract was for delivery of a new Day/Night WSI to the Air Force with several enhancements.

2. *Goals of the Contract*

Under this contract, MPL provided a new Day/Night WSI to the Air Force with several enhancements. Many of the enhancements were developed under the DOE program, and as a result it was possible to provide them with no development costs to the Air Force. These enhancements included an improved solar/lunar occultor and improved environmental housing for the instrument.

The developments funded by the Air Force included more accurate alignment of the instrument, and enhanced documentation. During the contract, at the sponsor's request, some of the documentation was deferred until a follow-on contract; in order to allow MPL to put significant time (beyond the scope of the original contract) into software development. The documentation has been delivered at this time, under the follow-on contract, which will be reported separately. The software development was directed toward adapting the WSI software for compatability with a Scramnet communications system, so that the user can communicate with the WSI from a remote computer.

3. *Discussion of the Results*

This section discusses the instrument which was delivered, and the enhancements developed during the contract.

3.1 System Description

The WSI is shown in Figure 1. In this illustration, taken during the sponsor training period, the white box is the environmental housing that enables all-weather outdoor use of the instrument. The optical dome may be seen in the center of the top plate. The structure above the optical dome shades the optical elements from both sunlight and moonlight, and is called the solar/lunar occultor. Figure 2 shows a typical WSI controller, with the monitor, field-hardened computer, two Accessory Control Panels, and optional rack for additional archival capability. The

Air Force controller is quite similar, however it does not include the supplementary archival. The Air Force occultor is a more sophisticated version than can be seen in the image in Fig 2, and it blocks a smaller portion of the sky (about 2%).

The optical configuration is shown in Figure 3. The WSI uses a high quality fisheye lens, and a very low-noise 16 bit digital camera. This camera yields 65,536 grey levels, with a readout noise of approximately 1 count. The system performs near the theoretical best performance, ie it is generally shot-noise limited, even under starlight conditions. The optical system also includes a filter changer with spectral and neutral density wheels, a shutter, and a fiber optic taper, as shown in Fig 3. The sensor is protected in an environmental housing, as shown in Fig 4. This housing provides protection for the camera electronics unit, keeps the unit thermally cooled or warmed as required, and physically supports the camera housing and the solar\lunar occultor. Additional details of the hardware configuration are presented in Section 2 and 4 of the Operations Manual.

As discussed in Section 3 of the Operations Manual, the WSI is fully automated. Once setup is completed, the system is designed to run automatically, acquiring digital images of the sky at 650 and 450 nm during the day and under moonlight. Under starlight, broadband visible images are acquired. The angular resolution is approximately 1/3 degree, for a resolution of approximately 10m for a typical cloud altitude of 2 km. The system can apply a cloud decision algorithm in real time on the system if desired, and it is networked with a remote computer. A summary flow chart of the data archival program is shown in Figure 5.

3.2 General Enhancements

The illustrations reflect several of the enhancements which were developed under funding from other sponsors and were included in this delivery (at no cost for the development effort). The environmental housing is considerably stronger than the previous one delivered to the Air Force (Shields et al 1994), and it includes an upgraded cooling system. The camera chip is cooled to -35C by a triple-stage thermo-electric device. The hot side of this thermo-electric cooler must be cooled by liquid coolant. In addition, it is necessary to keep the camera electronics unit (CEU) reasonably cool. In the older designs, both of these were accomplished with liquid coolant. In the current design, the whole chamber is essentially sealed, and is kept at fixed temperature by a thermo-electric heater/cooler, so that the CEU is much better protected. Liquid coolant for the camera chip's cooler is still provided to keep the camera chip at about -35C.

The new solar/lunar occultor is shown in Fig 1. This occultor is designed to be more maintainable over a many-year period. It uses a set of arcs which move from east to west, and a trolley which moves along the arcs from north to south. It is still necessary to keep the trolley lubricated, and occasionally check the tension on the chains, but the chains are easily replaced, and should be more maintainable than the earlier designs which were difficult to adjust.

The primary upgrades which may be seen in Figure 2 are the division of the Accessory Control Panel into two panels, and the addition of several feedbacks to the ACP and the computer. The camera chip temperature, camera housing temperature, and environmental housing temperature are now monitored at the ACP. The software checks these temperatures regularly, and can turn the camera off if the operating conditions become dangerous for the camera. In addition, the pressure of the purge gas in the camera housing, the relative humidity of the inside of the environmental housing, and the flow rate of the coolant are monitored and recorded.

New software features funded by other sponsors include the creation of diagnostic files based on real-time QC of the instrument and its behavior. In addition, a real-time version of the cloud decision algorithm was developed, and was delivered with the system. This real time algorithm evaluates the images, in particular with respect to the spectral signature of each pixel, to identify the presence of clouds in each pixel. The algorithm has been discussed in the Theory of Operations manual.

3.3 Enhanced Alignment

The goal of the enhanced alignment is to have a pointing accuracy of 1/2 degree. To obtain this accuracy, it is necessary both to align the camera accurately with True North, and to calibrate the angular position, in object space, of a given pixel position in image space.

The procedure for determining the angular position of a given pixel is called the geometric calibration. The geometric calibration was accomplished in two ways, so that there would be sufficient redundancy in the procedure to detect significant errors. First, an accurate indexed rotary table, accurate to 1 minute, was purchased, and the WSI was mounted such that the lens was centered on the center of rotation. This was set up so that it could view a target about 10 feet away. The camera is then rotated to acquire the pixel position of the target at fixed angles of rotation. There is an uncertainty of about 2 mm in the position of the front aperture of the lens (it can be measured accurately, but it varies slightly depending on the angle of the incident light). A 2 mm variance at 10 feet introduces an uncertainty of about 2 minutes of arc. Secondly, a series of visual targets were set up at 10 degree intervals in the test room, using a transit. A single image is then acquired, and the pixel position of each of the targets extracted. These results can be compared with the positions obtained with a single target and multiple images..

As mentioned above, it is also necessary to align the camera chip with respect to true north in order to have pointing accuracy. In order to do this, an alignment jig was built to hold an accurate transit, as illustrated in Fig 6. The procedure for aligning the chip is as follows:

a. Since the chip may not be precisely aligned with respect to the camera and camera housing, the first step is to acquire images of lines on the bottom of the transit jig, and align the jig so that it is in line with the chip columns and rows, as detected by the imagery.

b. The next step is to align the sighting transit with the transit jig. Both steps a and b may be done prior to deployment.

c. A True North benchmark must be established, either with as GPS, as done in the in-house tests, or by other means.

d. The WSI Environmental Enclosure is mounted, oriented, leveled, and secured, in alignment with respect to True North to an accuracy of 1 - 2 degrees.

e. The alignment device is mounted on the camera housing, and the transit aligned with the True North benchmark (using the cross hairs on the telescope). The offset angle should be 1-2 degrees. Then the camera housing is rotated and the transit realigned, until the transit is aligned with the True North benchmark at 0 degree rotation.

In short, the geometric calibration determines the angle of each pixel when the chip is properly aligned. The steps a and b above allow one to align the transit with respect the the chip, and steps c through e allow one to move the camera housing such that the transit is also aligned with respect to north. The procedure can be verified by recording the position of the sun or moon. The procedures were documented in detail in a memo provided to the sponsor with the instrument.

3.4 Documentation Enhancements

A substantial amount of documentation was written under this contract. This documentation included: a preliminary operations manual (Tech Note 236); a detailed trouble shooting manual (Tech Note 241); memoranda documenting the software, the alignment procedures, the alignment tests, and the software deliveries; setup instructions; components lists; and a list of delivered spare parts. Tech Note 241 was partially funded by another sponsor, and it includes instructions for normal maintence as well as detailed instructions for trouble shooting and repair. It contains approximately 130 pages. There was additional documentation delivered throughout the contract, such as monthly reports, drawings, memos on various aspects of instrument performance, and software memory maps.

Additional documentation was deferred to a later contract in favor of providing networking (communications) software, as noted in Section 2. This additional documentation, which has been delivered, includes a more detailed operations manual (Tech Note 240) with more detailed descriptions of the components and their purpose, and a theory of operations manual (Tech Note 243).

3.5 Networking Enhancements

The Whole Sky Imager is now networked via a Scramnet card to a remote computer, designated the WSI Display (WSID) computer. At the time the proposal was written, it was envisioned by the sponsor that this networking would be accomplished by the sponsor or by subcontract. Soon after the start of the contract it became clear that it would be very helpful for MPL to develop the WSI portion of the link, and this was done. MPL worked in cooperation with the sponsor and the sponsor's designated representative who was working on the WSID end. At the time of delivery, the system could:

a) Transfer images to the display computer.

b) Transfer other recorded parameters related to status to the display computer

c) Transfer instructions from the display computer. These instructions allow the remote computer to choose which images are transferred, choose the archival interval (such as 10 minutes or 2 minutes), choose whether to archive data to the tape drive on the WSI, and choose whether to perform algorithm processing such as the red/blue ratio or the cloud decision image.

The display on the WSID computer associated with the status (item b above) is shown in Figure 7, and the display associated with the available instructions (item c above) is shown in Figure 8. Additional features have been added to the communications software under a follow-on contract, and will be discussed in a separate report.

3.6 Delivery of the System

The Whole Sky Imager was delivered to the sponsor on 13 December 95. Delivery was accepted at MPL, at the sponsor's wish. The delivery included documentation as discussed earlier. As part of the delivery, the sponsors participated in a software test, in which the WSI data acquisition program was erased, and was recompiled from delivered software source code and delivered compilers. In addition, the sponsors were trained in the use of the instrument, and trained to install the instrument. Part of this training included disconnecting the instrument and putting it in its shipping configuration, at which time the sponsors set up the instrument following the setup instructions, and tested it to verify that it still was operational.

4. Conclusion

The Whole Sky Imager has been further developed to meet the sponsor's requirements for a very reliable instrument which can acquire imagery under all natural outdoor lighting conditions. It provides assessments of cloud cover if desired, and can be used to evaluate cloud distribution, cloud location, and temporal dynamics. The documentation has been upgraded to allow the sponsor to operate the instrument with little interaction from MPL. The pointing accuracy has been upgraded to allow a more precise definition of the cloud locations. Networking has been added, to allow a remote display computer to receive the images, and adjust the data acquisition to changing test scenarios. We believe we have met or exceeded all of the contract requirements. The instrument has been successfully installed by the sponsor, and it has worked quite well since the completion of the contract.

5. References

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Shields, J. E., R. W. Johnson, M. E. Karr, D. R. Sauer, and R. A. Weymouth (1996), "Theory of Operations and Interactive Optimization; Day/Night Whole Sky Imager", Technical Note No. 243, Atmospheric Optics Group, Marine Physical laboratory, University of California, San Diego

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Fig. 1

Whole Sky Imager
in its Environmental Housing

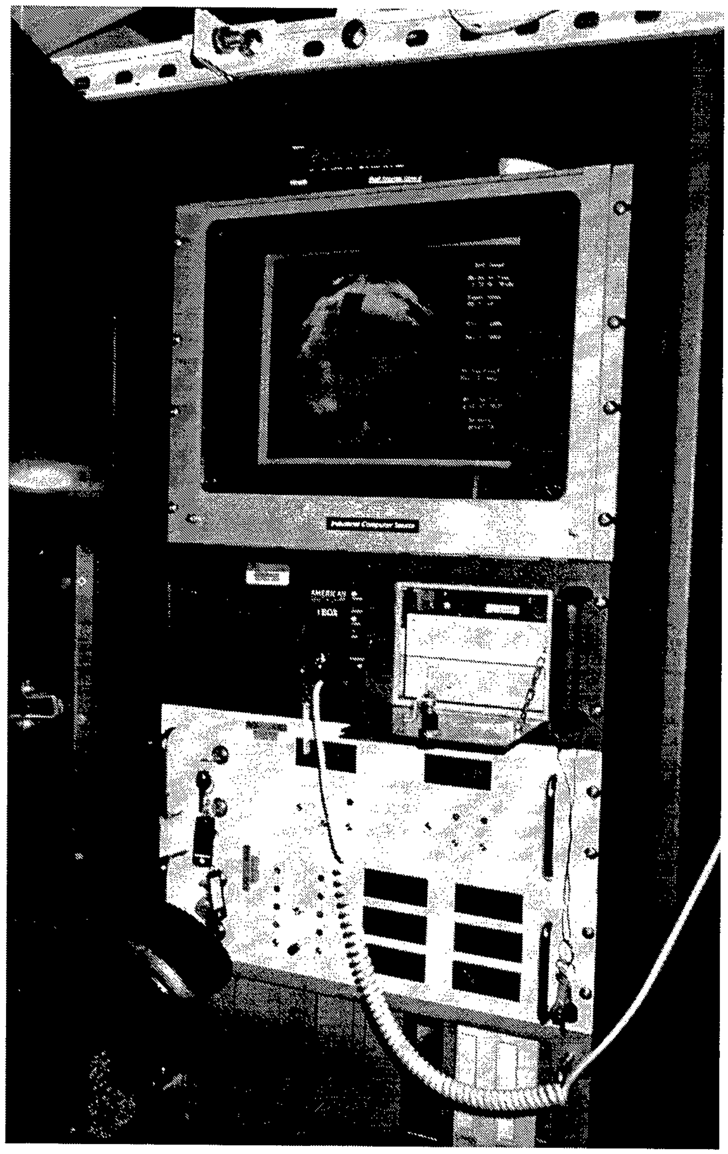


Fig. 2

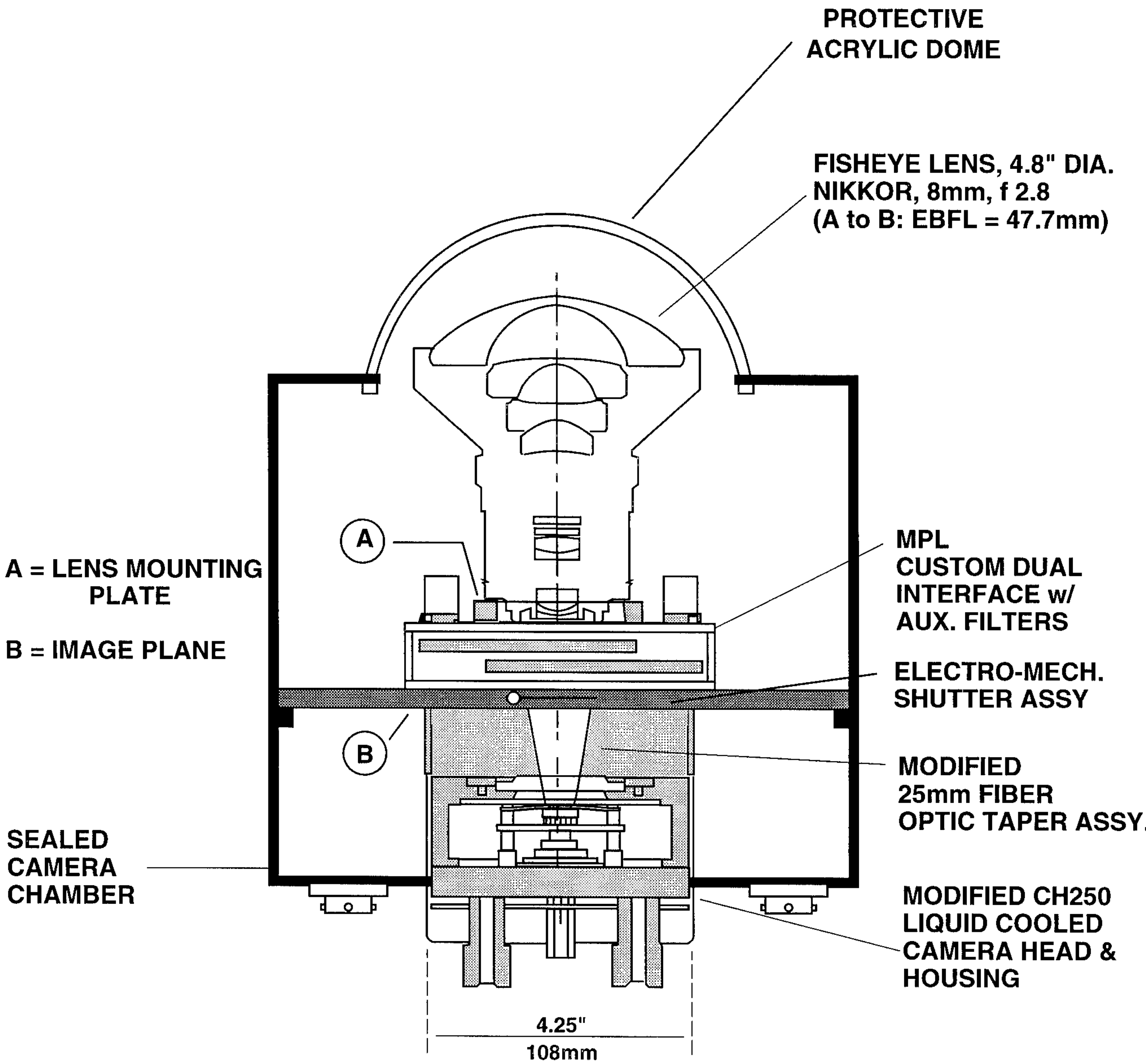
Whole Sky Imager Controller

Fig. 3

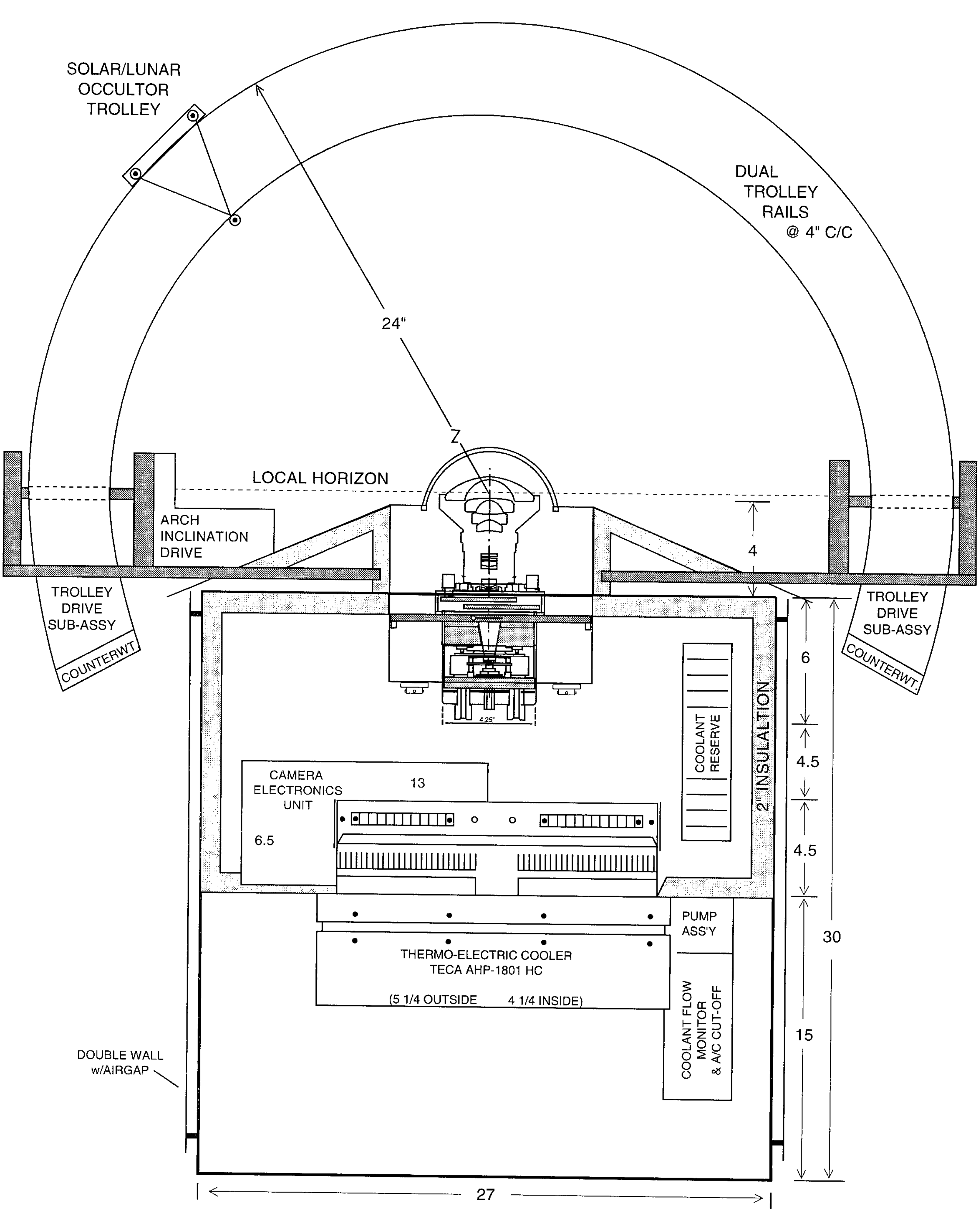
DAY/NIGHT WSI SENSOR SUBASSEMBLY

EO CAMERA SYSTEM 6A

(NOT TO SCALE)



cr.69.WSI D/N Sensor Assy



DAY/NIGHT WHOLE SKY IMAGER ASSEMBLY
E/O CAMERA SYSTEM 6A
(Approximate Scale)

cr.68WSI night imager

Fig. 4

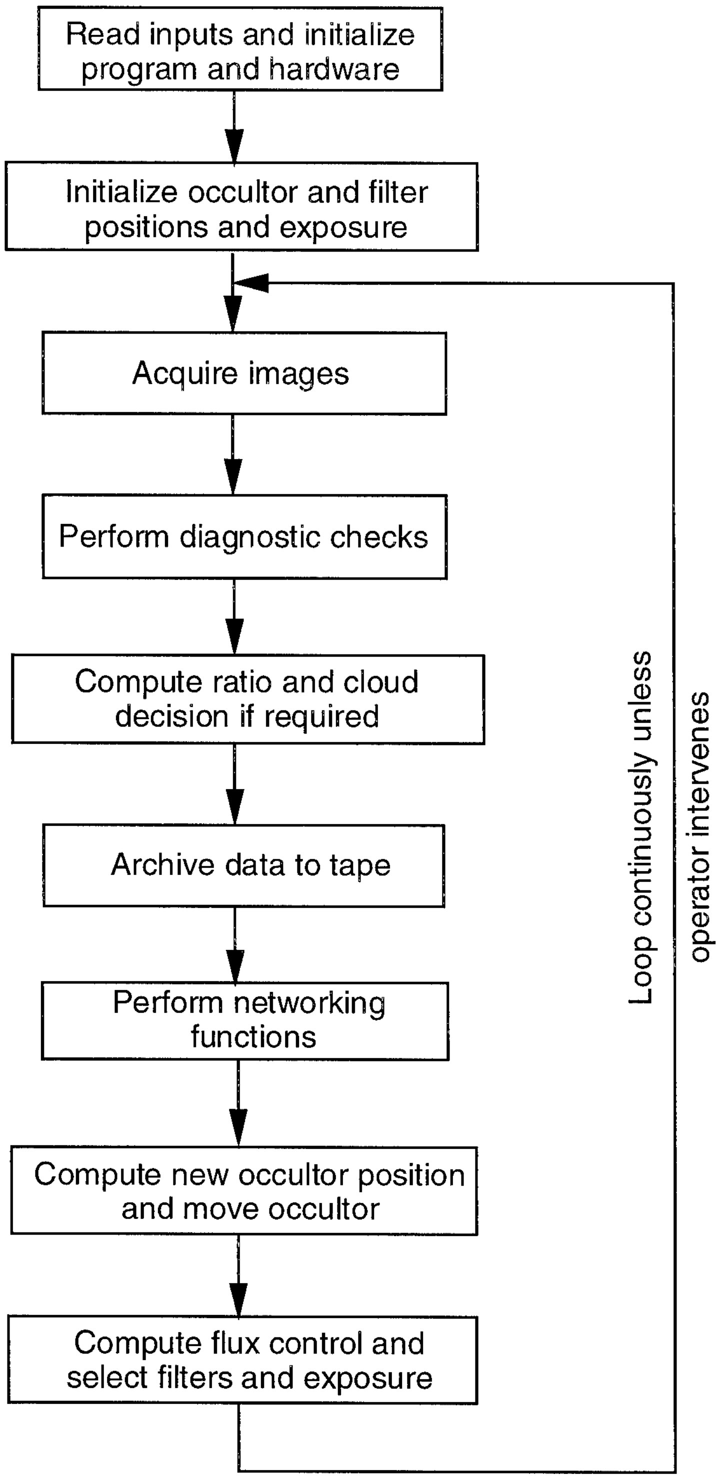


Fig. 5 Run WSI Overview Flowchart

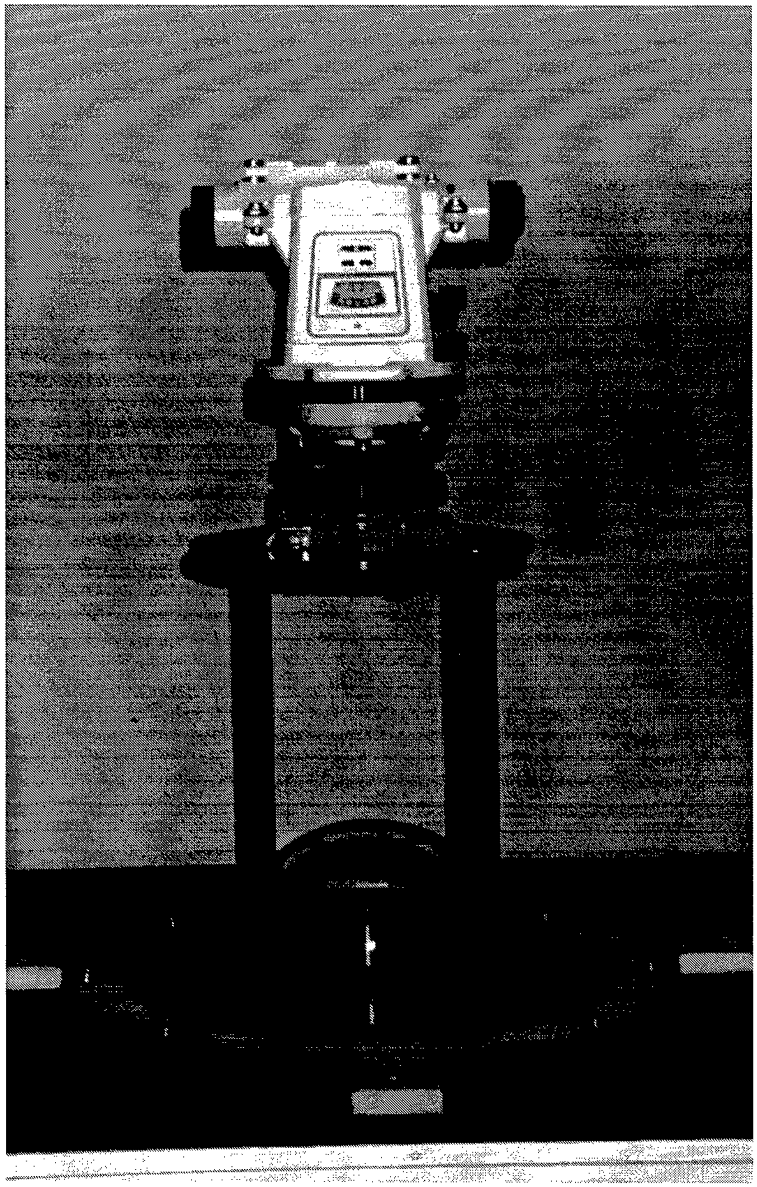


Fig. 6

Whole Sky Imager Alignment
Jig with Transit

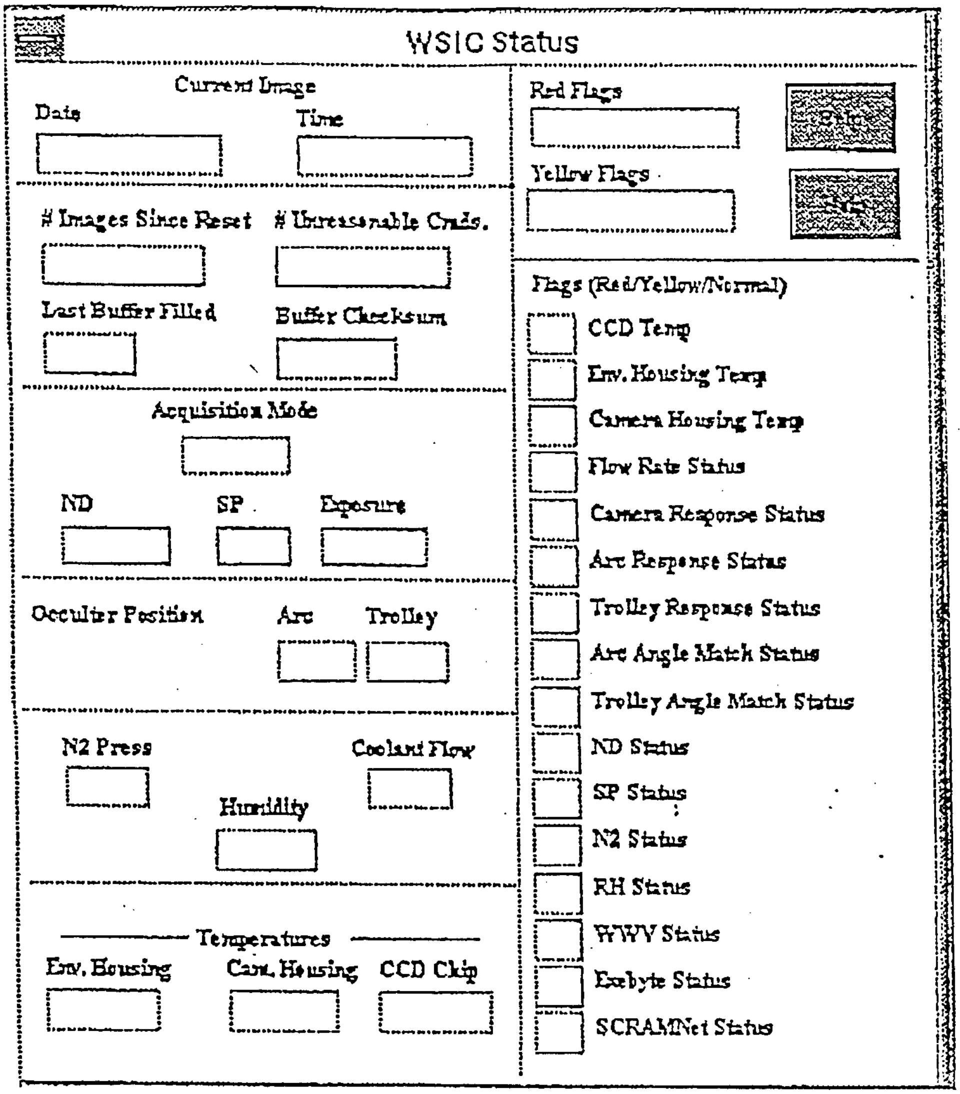


Fig. 7

WSI Status Display on
networked WSID Display Computer

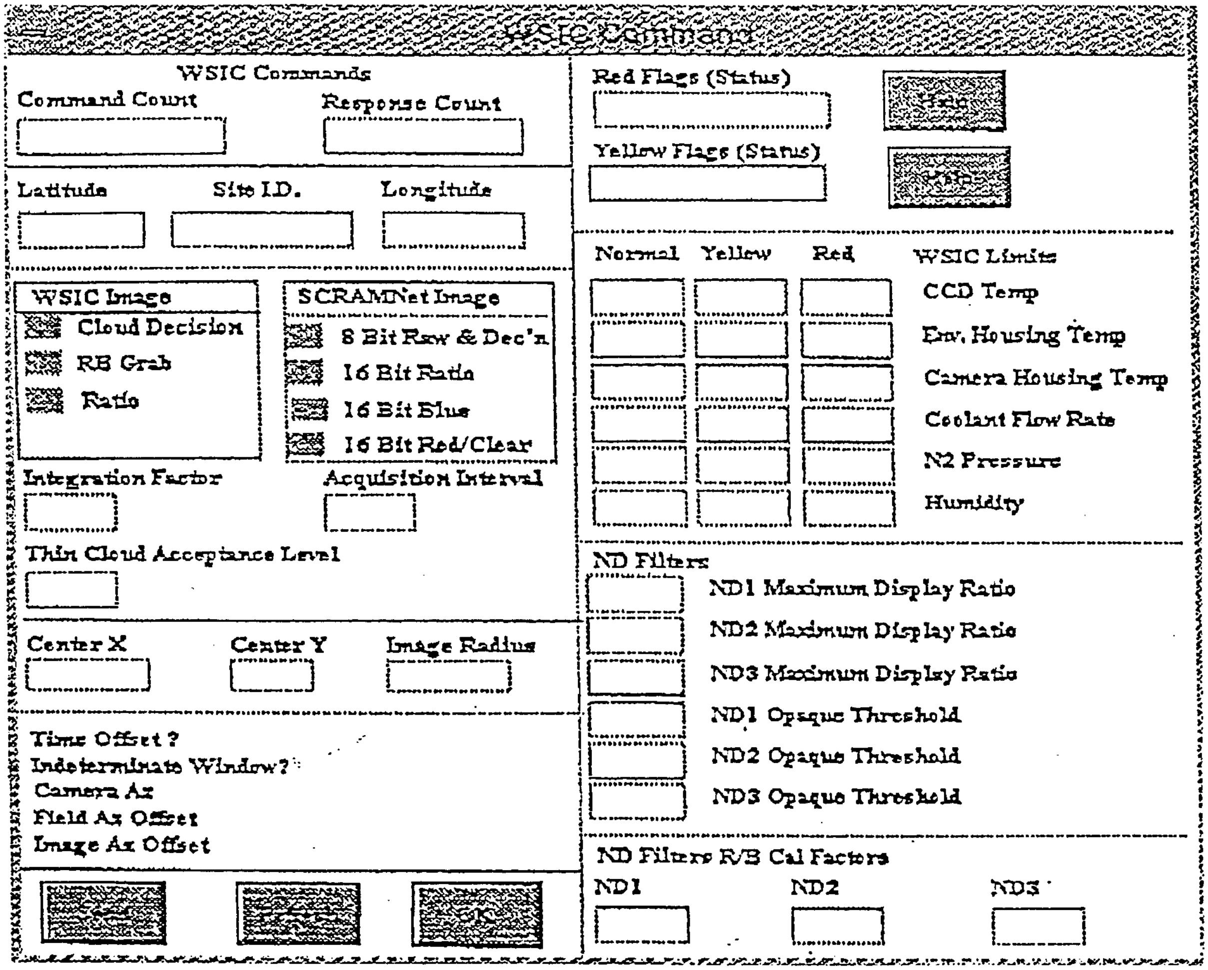


Fig. 8

WSI Command Display on
networked WSID Display Computer

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