An Instrument/Sensor Analysis of the MMSF Automated Photometric Telescope Indiana University Computer Science Department TR# 597

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June 16, 2004

1 Introduction

The Morgan-Monroe Station (MMS) of the Geothe Link Observatories is situated in the Morgan-Monroe State Forest (MMSF) about 12 miles north of the Indiana University campus and is moderately protected from light pollution. The MMS site houses a 16-inch automated telescope known as RoboScope and a new 50-inch automated telescope known as SpectraBot. These are active research facilities that operate most clear nights, and both are used for photometric studies. Each telescope has a separate dome. RoboScope is devoted to long-term monitoring of cataclysmic variable stars and related objects, typically obtaining one or two 4-min exposures of about 100 objects every clear night. SpectraBot will be devoted to automated long-term monitoring (both CCD imaging and spectroscopy) of time-variable sources. The "guide camera" attached to it may also be used for other scientific observations. Roboscope has been in near-continuous usage since 1990 (?) and Spectrabot is still being developed.

This paper gives a computer scientist's view of the site as a source of streaming data. In this paper, a *sensor* is an instrument that produces a single measurement type. That is often provided as a single data stream, but need not be so. Some electronic weather stations will produce a single stream, and the data packets in it contain a temperature, pressure, humidity, wind speed, and wind direction measurement. Although a single instrument producing a single data stream, this would

be identified as a set of five sensors. This distinction is for clarity and is not a deep philosophical matter.

2 Instruments and Sensors Categories

Identifying what are the sensors and instruments at a site is not trivial. Part of the problem is that a large ensemble might form a single site, and the MMS site has at least thirteen sensors of likely importance. They functionally fall into three categories:

1. **Object Data Sensors** take the scientific images from the sky. Here "object" means the object of direct scientific interest. The other sensors are auxillary in that they serve only to determine the quality and setting of the object data.

2. **Environmental Data Sensors** help to make open-up and close-down decisions, and more generally provide metadata about the temperature, humidity, and environment associated with the object data.

3. **Instrument Setting Sensors** could also be called control data. These provide the status of instruments, control the telescope and dome motion, and relate events such as dome shutter open/close, dome orientation, telescope direction, etc. The control file that gives the sequence of stars to observe during a night's run could also be considered an control data sensor.

The last two categories are not completely disjoint. For example, as described below SpectraBot has a camera fixed on Polaris, which is used to determine the cloudiness at the site. That can then be used to determine whether or not to carry out a set of runs (control data), or it can be used to evaluate the quality of an observation that was made (environmental data). However, using the categories as a partitioning is generally helpful.

2.1 Object Data Sensors

Two major sensors belong in this group:

- CCD Cameras are sensitive digital cameras, and both RoboScope and SpectraBot have liquid nitrogen cooled, thinned CCD. RoboScope only provides 512x512 pixels per picture while SpectraBot had 1024x1024 pixels. The actual CCD readouts are 562x512 pixels from RoboScope and 1050x1024

pixels from SpectraBot with 16 bits/pixel since each line has a bias value appended. This bias is readout by specifying a length larger than 1024 in the access function. Each CCD gives a FITS [1] format file which stores the actual images as well as the date and time of observation, the name and location of the telescope, and the weather at the time of the observation. FITS (Flexible Image Transport System) was developed by astronomers as the standard format for data transport between installations. A FITS file is comprised of a sequence of Header and Data Units (HDUs). Each HDU consists of a header made up of lines containing keyword=value statements in printable ASCII, describing the format and structure of the data which immediately follows the HDU. Currently, a FITS file includes ASCII and binary parts. The ASCII part includes all the environmental and control data as well as the description of the binary frame data, and the binary part has the frame data of CCD image. This information will help us to serialize the data stream into soap message later. The MMS CCD data is pulled out by a function call every five minutes.

- Spectrographs are instruments that split light into different colours. Only SpectraBot had spectrograph, and it combines unattended photometry and spectroscopy in the same telescope. Spectrograph gives 1024x1024 image with 16 bits/pixel and 2Mbytes/picture. What is recorded on computer is actually a 32 bit integer, because the analysis programs are in Fortran which does not support unsigned integers.

2.2 Enviromental Data Sensors

The Enviromental Data Sensors include Polaris transparency monitor, precipitation detector and temperature detector.

- Polaris monitor. This fixed camera always points to the north star (Polaris) and determines the cloudiness or haze in that direction. This is used by a program to determine whether or not to open the domes. The monitor is connected to a 8086 Leading Edge PC, with data sent out every minute. The digital signal is converted to an analogue voltage on the Leading Edge machine, and then is sent to the MicroVAX machine (stella) where it is converted back to digital. A negative voltage indicates cloudiness. The camera has a 75 mm lense, the maximum that can be used and still assure that the small circle that Polaris enscribes during a day will stay in the square

of pixels of the camera's CCD. The manufacture no longer supports it, so it may become inoperable after at most 18 months. Some astronomical sites have an all-sky cloud instrument, that determines the haziness in a 360 degree angle. MMS typically has weather fronts moving from the north, however, which allows a (cheaper) single-star sensor for this.

- Precipitation detector. This determines high humidity or rain. If it is raining outside, the dome will not open. The precipitation meter consists of a set of parallel exposed wires, with low current flowing through them. In case of rain or high humidity, the current is shorted out. The sensor output is thus binary: flow or no flow. A hot plate keeps the wires ice-free in winter. This detector sends out data continuously.

- Temperature. This is part of an outside weather center, located on the top of the microwave antenna tower that connects MMSF back to IU. Although the weather center provides humidity, rain guage, wind direction and speed as well, only the thermometer has been found to be reliable and worth using. The data is sent out every 10 minutes, and analog voltage signal is converted into degrees by MicroVAX National Instruments cards.

2.3 Instrument Setting Sensors

This set of sensors controls movement of telescopes and domes.

- Guide Camera. This is located on the 50" scope, and is used to keep the telescope centered on a star for the time (4 minutes for the 16") of an exposure. This corrects for clock skew which occurs on all telescopes. It provides 1024x1024 image to help CCD Camera focuse on the particular star.

- Dome Orientation. The dome needs to be rotated so the shutter is oriented towards the object of observation. Power is supplied to the dome slit motor via a tensioned power cable which is fixed to the top of the moving dome on one end and to a boom on the other. Continuous dome rotation in one direction is not allowed because the power cable would be twisted beyond its limits. Only up to ± 2 dome rotations from the home position are allowed.

- RA/DECL indicators. RA stands for right ascension, and DECL is for declination. They are a system of coordinates used by astronomers to keep track of where stars and galaxies are in the sky. They are similar to the system of

longitude and latitude used on the Earth. These form the coordinate position for an astronomical object, and give the direction for a telescope to point. The system converts the local hour angle to right ascension, and converts altitude and azimuth to declination. It then initializes the AX controllers for slew and moves telescope to specified RA and DECL.

- Filter Setting Indicator. The light from the telescope is filtered before reaching the CCD camera. Both RoboScope and SpectraBot have U,B,V,R,I filters. The U filter stands for ultraviolet and it allows light of wavelengths between about 320 nanometers(nm) and 400 nm to pass through. The B filter is for blue, and it filters light of wavelengths between about 400 nm and 500 nm. The V, R, and I filters stands for visible, red and infrared respectilvely, and their respective wavelength ranges are 500 nm to 700 nm for V, 550 nm to 800 nm for R, and 700 nm to 900 nm for I. When the filter setting is chosen, a GOTOFILT routine moves the filter wheel to the specified filter. It should be set every 5 minutes.

- Liquid Nitrogen Scale. The liquid nitrogen tank sits on an electronic scale to determine the level of nitrogen container. It checks the weight of the container to make sure it is not empty. The data is collected every 4 minutes.

2.4 Sensor Table

Table 1 presents the data flow of all the sensors. The five fields are as follows:

- **Sensor Name** This column shows the related sensors with one per row.

- **Output Quantity** This field describes the quantity which sensors first output. Most sensors give an analogue signal which is converted later into digital signals, such as precipitation detector and Polaris monitor. Some of sensors produce a digital signal directly, such as CCD camera.

- **Derived Quantity** It presents the actual quantities which will be preserved as environmental data and may be sent to control motor for telescope and dome movement.

- **Frequency** This column tells us how often the data comes out. Some of sensors need to update every exporsure, some of them may output data continuously.

- **Where is the date stored currently** The sensors go to the different machine for control handling, so this column states where the data is stored. All the data will be stored in the log file for later analysis.

- **Collection Machine** It states the current machines used to store data. The outputs of most of sensors are sent to MicroVAX for Roboscope and to Linux box for SpectraBot.

3 Observation Process

Roboscope follows a program UNATTEND and Scheduling software selects the next object from among about 120 program stars on the basis of the orbital ephemeris of each star, the position in the sky of each star, and elapsed time since the last observation of each star. The telescope, dome and filter are positioned subject to the instrument setting sensors and environmental constraints. A single unguided CCD exposure is obtained of the desired field. If repeated observations of a single star are desired, then that star is repeated in the list.

Figure 1 shows Automated Photometric Telescope (APT) night observation demo work flow based on [2] observation mode, and we see a high-level overview of how APT works from this diagram.

- First it selects the star from a list of binary stars which must be observed at particular orbital phases called "ephemeris" stars, and "interval" stars which are to be observed at any orbital phase but at specified average interval of time. The information which UNATTEND program uses to schedule the observations is contained in an ASCII "exposure" file for each star. These exposure files are assembled into a real-time database and it resides in shared memory and can be accessed by UNATTEND to choose the next star.

- After star selection, it performs a number of checks including polaris transparency monitor check and precipitation detector check. There may be some other checks to make sure the star will remain in the observing window set by the hour angle and altitude limits of the telescope for the duration of the exposure, and whether dawn has arrived. The ENVIRON program samples each five minutes a number of analog inputs containing environmental information including telescope temperature, percipitation monitor,

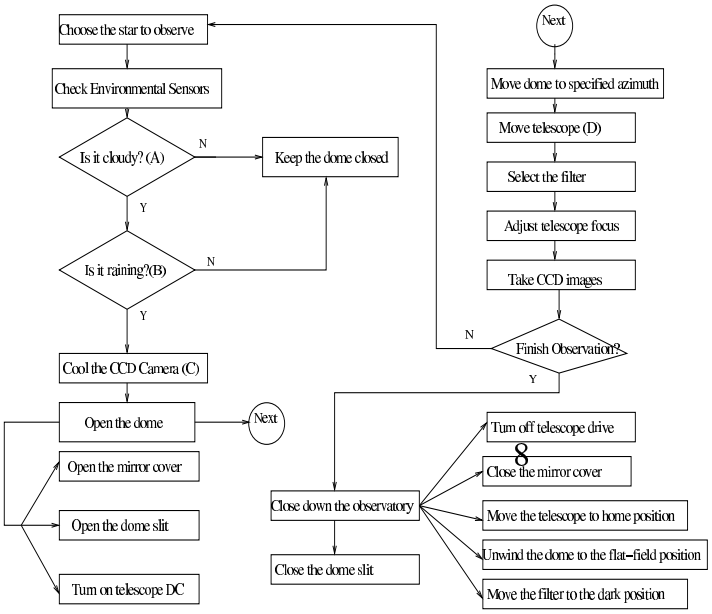
the level of the liquid nitrogen storage dewer, and the Polaris transparency monitor.

- Then it makes the decision on whether or not open the dome. The UNATTEND will never open the dome for the whole night if it is cloudy. It opens the observatory by opening the mirror cover of the telescope, opening the dome slit and turning on telescope DC.

- Before processing the observation, it checks the temperature of the CCD camera and determines whether or not liquid nitrogen is needed. It calculates the apparent position of the star using corrections for precession, aberration, refraction, and flexure. The focus is calculated from the current telescope temperature by using existing calibration. It rotates the dome to specified azimuth, and positions the telescope under the control of RA and DECl sensors, and sets the filter for each exposure of each star.

- Next the CCD image is exposed and is read out. The information about how many stars were found in the previouse exposure can be used to aid in the close-down decision for UNATTEND. When greater than five exposures in a row have less than two starts, UNATTEND closes the observaory.

- Close down procedure positions the telescope and dome to the home position. In this position the liquid nitrogen can be added without moving the telescope, and the telescope is pointed at the dome-mounted flat-field screen. The mirror cover extends itself upward and down onto the top of the closed-tube telescope. It also unwinds the dome cable, since only up to ± 2 dome rotations from the home position are allowed.



A: Polaris Transparency Sensor B: Precipitation Sensor C: Liquid Nitrogen Scale D: Right Ascension Sensor (RA) & Declination Sensor (DECL)

Figure 1. Data Work Flow of APT Night Observation

Sensor Name	Output Quantity	Derived Quantity	Frequency	Where is the date stored currently
CCD Camera	16 unsigned integer[a]	No change	4 minutes	
Spectrograph[b]	2Mbytes/picture	No change	4 minutes	Linux box
Temperature Detector	0-10 voltage	degree	10 minutes	stella [c]
Precipitation Detector	0-10 voltage	shorted out or not	continuous	
Polaris monitor	0-10 voltage	%	1 minute	8086 PC
RA	angle of rotation	degree	5 minutes	stella(16')/Linux box(50')
DECL		hour	5 minutes	
CCD Temperature	0-10 voltage	degree	10 minutes	stella
Dome Shutter		binary	day	
Dome orientation	angle of rotation	degree		stella
Filter setting	U,B,V,R,I[d]	particular spectrum	5 minutes	
Guide Camera	same as CCD Camera		4 minutes	
Liquid Nitrogen Scale	weight		4 mintues	

Table 1: Sensor Description Table

[a] 50-inch has 1050x1024 pixels; 16-inch has 562x512
[b] only 50-inch has spectrograph
[c] MicroVAX:convert analog signal into digital signal
[d] U:ultraviolent B:Blue V:visible R:red I:infrared

References

[1] *A User's Guide for the Flexible Image Transport System (FITS).* `http://www.cv.nrao.edu/fits/documents/overviews/users_guide.ps`.

[2] R. K. HONEYCUTT AND G. W. TURNER, *Architecture of the software for the Indiana CCD automated telescope*, in Robotic Telescopes in the 1990's, A. Filippenko, ed., p. 45.