THE TASS MARK IV PHOTOMETRIC SURVEY

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Abstract

The Amateur Sky Survey (TASS) has developed its next generation wide-field CCD camera system. This paper describes and discusses the potential contributions the Mark IV can have for the AAVSO.

1. Introduction

Tom Droege, a retired Fermilab engineer, has been building CCD systems for a number of years. These systems have been designed for amateur use, but instead of selling these systems, he has been giving them to interested parties. The concept is that he provides the hardware, and the recipients then write software for acquisition and analysis of the data. In essence, this is a barter system: the recipients are being paid in hardware to write software, and are further responsible for actually using their systems to acquire data and for making those data publicly available in a timely fashion. Droege has formed a loose association of interested parties, called The Amateur Sky Survey (TASS), and manages a maillist for TASS. Michael Richmond is managing a web site for TASS that can be found at http://www.tass-survey.org.

The barter concept was initiated with the Mark III system, a drift-scan triplet of cameras that surveyed the equatorial zones (described in Richmond *et al.* 2000). The Mark III survey resulted in a catalog of V and I measures for 300K stars, available both on the web site and through Vizier. This paper describes one of the Mark IV systems as installed at the U. S. Naval Observatory, Flagstaff Station (NOFS).

2. Hardware

A more detailed description of the hardware will be presented in a future paper. The basic design is a two-telescope system placed on a common inverted fork mount. Both telescopes image the same region of sky, and since each has its own CCD, simultaneous observations of a given region of sky in two standard colors are possible.

Each telescope is a 100mm f/4 5-element refractor. Elliot Burke of HiTide Instruments (http://www.hitide.com) did the lens design. This is a novel system in that all five elements remain the same, but since each telescope only needs to cover a restricted wavelength (the filter bandpass), you can adjust the spacing of the elements to retain chromaticity and good image quality across the entire field.

At the rear of each telescope is a CCD camera head, containing one of the four standard Johnson/Cousins BVRcIc bandpass filters along with a thermoelectrically cooled (TEC) Loral 442 2048x2048 front illuminated CCD. The residual heat from the TEC is removed from the system by a water cooling system. Each camera head has a shutter of a two-vane variety, driven by a remote-controlled airplane rotary servo motor. The CCD scale is 7.5 arcsec/pixel, for a field of view of about 4.2 x 4.2 degrees. The image plane is flat and has some cubic distortion along with a small amount

Figure 1. V-band image of M31 from the NOFS Mark IV camera (1 hour exposure). North is up, east is left, field of view about 3 x 3 degrees.

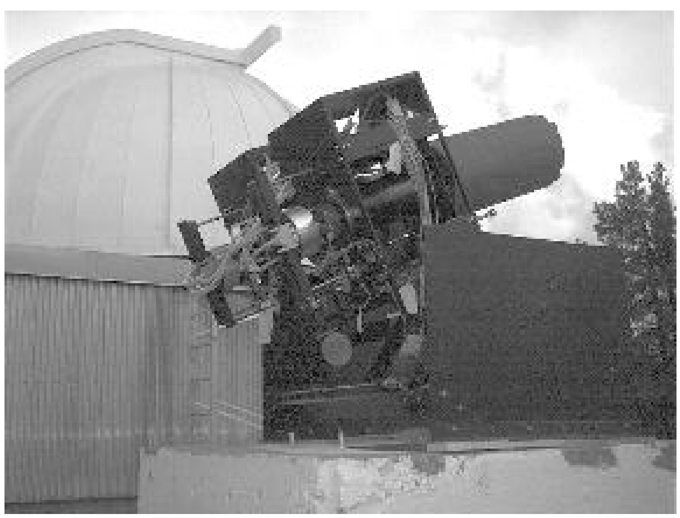

Figure 2. NOFS Mark IV camera installation.

of coma. Typical image fwhm is 2 pixels. The limiting magnitude for a dark site is about V=16 in a 5 minute exposure. The faintest practical depth is about V=17, as demonstrated in the NOFS Mark IV image of M31 shown in Figure 1.

Since there are two similar telescopes on a single mount, each is configured for a particular standard filter, usually Johnson V and Cousins I. For a few mounts, the configuration will be Johnson B and Cousins R, where the B-filtered CCD will be Lumogen-coated to improve its quantum efficiency. The declination drive is a belt-driven stepper motor yielding about 4 arcmin/step. The declination drive can run from southern horizon to about 20 degrees past the North Pole. The right ascension tracking motor is a 0.3m radius sector drive with a lead screw turned by a stepper, yielding 2 arcsec/step. Since a sector is used, the RA drive can only cover about 2.5 hours of hour angle, usually centered on the meridian.

All electronics are mounted on the fork next to the telescopes. A BASIC Stamp computer controls the individual functions and communicates with a remote host computer over a standard RS-232 serial link. The CCD data are downloaded via a parallel protocol to a custom ISA memory card installed in the host computer. This high-speed link works with up to 30m between the CCD camera and the host computer.

It takes about 43 seconds to read out both CCD cameras and download the data into the ISA memory card. At that point, software on the host computer writes the images in FITS format onto a local disk for later analysis and archival.

A total of 40 lens sets were manufactured. These will be made into approximately 15 Mark IV systems with spares. A typical installation is shown in Figure 2. This is the NOFS Mark IV, on an existing pier next to the 1.0-m telescope.

3. Software

The BASIC Stamp microcontroller is programmed in BASIC, and handles all of the necessary operations of the mount and sequencing of the CCDs. A more formidable challenge is the acquisition software on the host computer. This needs to move the mount to specified positions, time the shutter open/close, display and store the CCD images, and execute a schedule of observations for an autonomous nightly program. There will be two such acquisition programs, one for Microsoft Windows and one for Linux.

The data reduction pipeline is still in the developmental stage. IRAF has been initially used for the NOFS Mark IV to dark-subtract and flatfield the CCD frames, as well as to locate and measure all star images on each frame. Additional steps to locate the stellar field and perform astrometry need to be incorporated, as well as for photometric transformation and calibration. The final output product will be a set of astrometric and photometric calibrated starlists for each night. Subsequent analysis programs will create generic databases, search for variable stars and transient objects, and create a master starlist, either site-by-site or for a combined program.

4. Photometric survey

One of the primary goals of the NOFS Mark IV is to create a master V and I photometric catalog of all stars brighter than V=16 visible from Flagstaff. This will be used in conjunction with the UCAC astrometric catalog (Zacharias *et al.* 2000) to create a dense catalog of stars with good photometry and astrometry. One or more of the southern Mark IV sites will extend this catalog to Southern Hemisphere stars.

Such a catalog has enormous potential for AAVSO application. For example, the creation of visual sequences around program stars requires both high-accuracy V magnitudes as well as star colors. Targets of opportunity, such as novae and gamma-ray burst counterparts, can be immediately followed since calibrated stars will be visible in every field. The photometric survey catalog can also be used to help classify known variables on the basis of color.

A preliminary catalog of a few thousand square degrees is now available in the directory: ftp://ftp.nofs.navy.mil/pub/outgoing/aah/tasscat/ which contains a readme file document as well as zone files in a format similar to *USNO-A2*. This catalog will be updated on an infrequent basis, with a final version available in a couple of years.

5. Variable star studies

Since the mount can be pointed in both RA and DEC, and can follow a specific field for approximately 2.5 hours, there are a large number of variable star programs that can be accomplished by a Mark IV.

If a star has a period less than 2.5 hours, its entire cycle can be covered by a single Mark IV site. An example is the high-amplitude delta Scuti star CY Aqr, with an 88 minute period. A simultaneous V and I light curve for this star, as seen by the NOFS Mark IV, is shown in Figure 3. The I-band measures, (on an arbitrary scale) are shown with open circles, while the V-band measures are filled circles. The photometric accuracy is around 0.02 magnitude, with improvements expected since the NOFS Mark IV was not properly focussed or polar-aligned during this period, and the cloudy weather at the time prevented some exposures from having very high signal/noise. Note one of the major advantages of the Mark IV is simultaneous two-band photometry, very important when a variable can change brightness by large amounts between exposures.

As another example, the large-amplitude eclipsing variable BP Vul was followed on seven nights in the Fall of 2000. Most of the light curve of the variable was covered in pieces. Multiple sites, spaced every 2.5 hours of longitude, could follow such a variable and obtain a complete light curve during a single cycle. This is similar to the

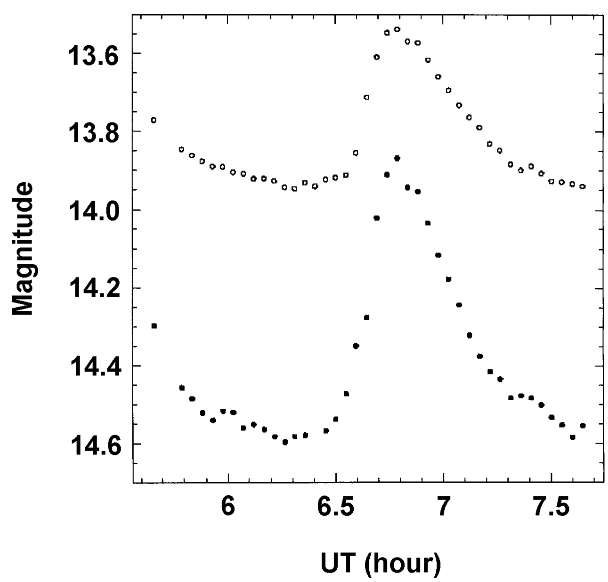

Figure 3. Light curve of CY Aqr as taken by the NOFS Mark IV. I-band measures are open circles, V-band measures are filled circles. Magnitudes are purely instrumental.

Whole Earth Telescope concept, except that here all systems are virtually identical, making combination from multiple sites much easier and more accurate.

While BP Vul was being studied, each camera imaged 5000 other stars in the 4.2 x 4.2 degree field. This larger region includes ten other known variables, such as the symbiotic variable PU Vul and the RR Lyr variable FF Del. Light curves of these variables can be obtained from the same frames as were used for the BP Vul measures. Other studies (*cf.* Henden and Stone 1998; Paczynski 2000) have shown that approximately one percent of all stars are easily identified variables. This field should therefore contain approximately 40 other variables beyond the ones mentioned; an investigation is underway to search for such new variables in these frames.

Since the mount can be positioned within a minute or two to any reachable field, and CCD readout can be multiplexed with such movements, the efficiency of operation can be quite high. For example, a Mark IV system can observe around 100 individual fields per winter night. Such a system could monitor 100 cataclysmic or suspected cataclysmic stars per night, looking for outbursts and not only communicating the outburst information to Headquarters, but also obtaining accurate photometry on a daily basis.

6. Conclusions

The TASS Mark IV camera system is now fact rather than fiction, and seems to be fulfilling its anticipated goals. Large portions of the final software pipeline still remain to be written, but the design and implementation are underway. Each site has large potential in contributing to the AAVSO program. Hopefully, the Mark IV will remain a viable source of photometric information for years to come.

7. Acknowledgements

The Amateur Sky Survey is a worldwide organization of people who have contributed to the design of the hardware and software, not only for the Mark IV but for prior models as well. Only a few have been recognized by name in this paper, but all are acknowledged in spirit.

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