Baltic Astronomy, vol.8, XXX–XXX, 1999.

WISE OBSERVATORY SYSTEM OF FAST CCD PHOTOMETRY

E.M. Leibowitz[1,2], P. Ibbetson[1], E.O. Ofek[1,2]

[1] *Wise Observatory, Tel Aviv University, Israel*
[2] *School of Physics and Astronomy, Tel Aviv University, Israel*

Received October 19, 1999.

Abstract. We have developed a data acquisition and an online reduction system for fast (a few seconds integration time) photometry with the Wise Observatory CCD camera. The method is based on successively collecting frames, each one is a mere small fraction of the entire CCD array. If necessary, the observer is able to place the object star and the comparison star on one and the same row or column of the CCD chip by rotating the image plane, an option available with the Wise telescope. In so doing, the rectangular frame that has to be read out may have a small area of only some 30 columns or rows, even when the two stars are far away from each other. The readout time of the small frame is thus reduced to merely one or two seconds. Thus photometry with an integration time of 5 seconds and up becomes possible. The system is a network of 3 computers. One controls the telescope, one is controlling the camera whilst the third computer is used, during the exposure of each frame, for data reduction of the previous one in the observing sequence. The online photometry is performed using standard procedures of the IRAF CCD photometry package. It yields an instrumental magnitude of the object star, relative to one or more reference stars that are present in the frame. The light curve of the object star is displayed with a delay of a single frame relative to the one currently under acquisition.

Key words: instrumentation – CCD – photometry

1. INTRODUCTION

The WET organisation has been using a photo-multiplier (PMT) photometer as its standard data acquisition instrument since the beginning of its operation some 10 years ago (Nather et al, 1990). There were good reasons for adopting this technique and it has indeed proved to be effective and fruitful. The original 2 star photometer was designed and built by Ed Nather and collaborators (Kleinman, Nather and Phillips, 1996) and significant improvements have been made in the operation and the performance of the instrument, especially by the Vilnius group (e.g. Kalytis, 1998). The proliferation in the last decade of CCD technology in all branches of observational optical astronomy put the CCD camera in an inevitable competition with the PMT photometer. The merits and shortcomings of CCD relative to PMT have been discussed in the past (Howell, 1992). The pressure to move from PMT to CCD technology has been constantly mounting, and has recently lead the Wise Observatory (WO) group to develop a system of data acquisition suitable for WET operation, that is based on a standard CCD camera. Here we describe the Wise CCD system and present an example of a short light curve of one of WET's objects that was obtained with it. Comparison with PMT measurements of the same object confirms the expectations that CCD photometry is superior to PMT performances.

2. CCD vs. PMT PHOTOMOETRY

Comparison between qualities and characteristics of CCD photometry and those of PMT has been already made in the past and also in the present conference. In this section we therefore only summarize in a tabular form the main features of each technique in which it has an advantage over the other (Table 1).

2. A CCD BASED FAST PHOTOMETRY OPTION

As indicated in Table 1, the major advantage of PMT photometry is the virtually zero dead time in its operation. In the standard use of CCD cameras, particularly with large CCD chips, the readout time of each frame is of the order of tens of seconds. This makes CCD cameras, if operated in the common standard manner, useless for most WET observations.

One approach to overcome the dead readout time limitation of CCD photometry is the use of a frame transfer CCD chip (FTC). It does indeed practically eliminate this problem, for sequences of observations with sampling frequency smaller than 1 Hz. The only difficulty with this solution is economical. Because of its very special usage, an FTC camera is not among the standard pieces of equipment in most observatories. Since its price is not negligible, WET members in most observatories do not have such a system available.

With the standard CCD camera of WO we have tested another solution to the readout time problem, relying on the ability to read-out merely a small area of the CCD chip. As the readout time depends strongly on the area that is being read, with such an approach it can be reduced considerably.

3. SETTING UP THE SYSTEM

When using the old twin channel photo-multiplier photometer, finding the object is a rather tedious matter of looking through an eyepiece and then centring the object in an aperture. With a CCD camera it is accomplished much more simply by taking a single frame of the field. It is then possible to identify the object in the image, along with one or more surrounding stars which may be used for comparison.

With the Wise CCD camera, the user has an option to read out not the entire image frame but only a rectangular partial area of it. Since the readout time is a strong function of the area that is being read, specifying a small box reduces the dead time considerably. If the user requires a reference star that lies far away from the object star, if necessary he or she can rotate the image plane rotator of the Wise telescope so that a rectangular strip of the CCD matrix, consisting of only a small number of rows or of columns, will include these two stars. A rectangular box defined on the CCD frame usually exposes also an area of sky required for the photometry reduction programme.

One more frame of the defined area is then taken to ensure that it includes the required object star and comparison star or stars, and enough surrounding sky to ensure a reliable reduction. The setting up process can be easily accomplished within three to five minutes.

With typical boxes of the order of 600 x 100 pixels we have succeeded in reducing the dead time to under 2 seconds. In our test runs so far, however, we have adopted 3 seconds time loss. Thus in a ten second observing period there is seven seconds of observation. The three seconds of dead time are devoted to processing. One incurs a thirty percent loss of observing time but the quantum efficiency of the CCD more than makes up for this when it is directly compared with a photo-multiplier aperture photometer.

4. NETWORKING

The next basic trick is to minimise the load on the computer that operates the CCD camera. This is being achieved by an immediate transfer of the acquired data to another computer for handling and reduction. Thus the task of the camera control computer is reduced to a minimum of operations. They include: opening the shutter, exposing the chip for a defined period, and closing the shutter. This is followed by transferring the data from the small rectangular area of the chip to an image buffer in the computer. The small image buffer is then transferred to a disk file, but simply as a sequence of two byte sixteen bit words, that is to say, raw data with no header information. To ensure that the data is properly time binned, each observing sequence is started on a ten second bin of the computer clock, namely, the computer clock final second digit is a zero. There may be methods of speeding up each of these individual operations but since the bulk of the time involved is downloading the CCD, there is probably not much to be gained by putting a great deal of time and effort into this particular avenue.

This is all that the CCD control machine is doing. It can easily be done within a 10 second observing period. But how then, can we inspect the data, detect that the tracking and guiding are performing correctly, add headers to the images for processing, and display a light curve on line? In other words, how do we make the interaction of the observer with the machine system as close and intimate as in the 2 star photometer with its original 'quilt' photometry programme? The answer lies in networking and using a set of machines to perform the various additional operations.

There are three computers used during an observation. One positions and guides the telescope. The second controls the CCD chip and data acquisition. The third retains and reduces the data. The latter two must be networked. It is convenient if all three computers are networked.

At the beginning of an observation session, the CCD computer writes a base data file onto the third, data reduction computer. This file contains fundamental information like the dimensions of the observed rectangle, the length of the observation, exposure time plus dead time, and the ten second bin when the first observation is to start. During the run, each acquired data file from the CCD computer is written onto the disk of the reduction machine, which displays it and adds a fits header whilst the next observation is accumulating.

5. REDUCING THE DATA

Before the initiation of the continuous sequence of observations, the user feeds the CCD control computer with parameters for the data reduction procedure. This operation is preferably done when the image of the confirmation frame (see Section 3) is displayed on the monitor. The required parameters include the marking of the object star and 1-10 reference stars on the image, the definition of radii (in pixel units) of 4 apertures to be used in parallel in the aperture photometry process, and the definition of an anulus for sky subtraction. It is a straight forward modification to allow the user to utilize also the PSF (point spread function) option of the DAOPHOT package. For well isolated stars, however, aperture photometry is adequate, perhaps even superior to the PSF procedure (Howell, 1995).

The third machine running IRAF under Linux is best suited to reducing the data. The data file with the basic reduction parameters is written directly by the CCD control computer to a disk on the data reduction computer, as are the images of the acquired sequence of data frames. This can be accomplished whilst the observations are coming in by using the DOS/Windows networking package called Samba which is available in Unix and Linux systems.

The third machine is equipped with the standard IRAF CCD photometry routines. They are applied on the incoming FITS format frames supplied over the network. The output of the third computer is 4 instrumental magnitude values of the object star, as computed with the 4 different apertures chosen by the user, relative to the magnitude of the reference star, or to the weighted mean magnitude of the reference stars, if they are many. The computing time of this process is of the order of 1 second. One of these magnitude values is being displayed graphically on the monitor, adding one point to the light curve of the object star that is being built in real time. All the four magnitude values along with the corresponding error estimates, as computed by program APPHOT, are being stored in a final table. All the images of the sequence are also being stored for checks and further analysis, if required.

6. EXAMPLE

Figure 1 is a one hour light curve of the prototype WET object GD358(Winget et al, 1994). It was measured with the Wise Observatory fast CCD photometry system on July 28, 1999. The observing conditions were rather bad, with the full moon in the sky and seeing of no better than 3-4 arcsec. The size of the circle signs in the graph represents the statistical error in the measured magnitude values. This graph is favourably compared with the light curves of the same star obtained at the Wise Observatory with the 2 star photometer, on a dark night under better sky conditions.

More details of the software of the Wise Observatory system are displayed in the Wise Observatory Web site http://wise-obs.tau.ac.il.

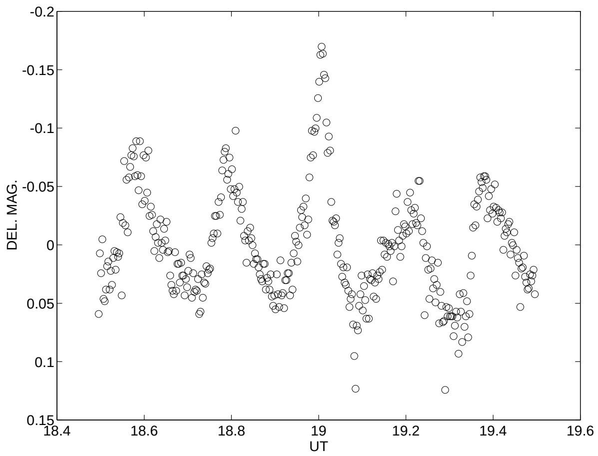

Fig. 1. Light curve of the DB pulsator GD358, measured at the Wise Observatory on July 28 1999 with the fast CCD photometry system. The circular symbols diameter is of the size of the statistical error in the measured relative magnitude values.

Table 1. Comparison between characteristics and qualities of PMT and of CCD photometry techniques.

Feature	PMT	CCD
Quantum efficiency		+
Seeing effects		+
Finding the object		+
Setting the telescope		+
Sky measurements		+
Few refrence stars		+
Guiding		+
Standard equipment		+
Dead time	+	
Raw output	+	

Note: The "+" sign indicates superiority

ACKNOWLEDGMENTS. Astronomy at the Wise Observatory is supported by the Israel Science Foundation.

REFERENCES

Howell, S.B., 1992, in "Astronomical CCD Observing and Reduction Techniques", S.B. Howell, ed., ASP Conference Series, Vol. 23

Howell, S.B., 1995, IAU Symposium No. 167, "New Developments in Array Technology and Applications", A. G. D. Philip, K. A. Janes and A. R. Upgren, eds., Kluwer Academic Publishers, Dordrecht, p.167

Kalytis R., 1998, Baltic Astron., Vol. 7, 329

Kleinman S.J., Nather R.E., Phillips T., 1996, PASP, 108, 356

Nather R.E., Winget D.E., Clemens J.C., Hansen C.J., Hine B.P., 1990, ApJ, 361, 309

Winget D.E. et al, 1994, ApJ, 430, 839