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NEW DIGITAL $H\alpha$ OBSERVATION BY SOLAR FLARE TELESCOPE AT BOAO

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ABSTRACT

Recently, we have set up a new digital CCD camera system, MicroMax YHS-1300 manufactured by Roper Scientific for $H\alpha$ observation by Solar Flare Telescope at Bohyunsan Optical Astronomy Observatory. It has a 12 bit dynamic range, a pixel number of 1300×1030, a thermoelectric cooler, and an electric shutter. Its readout speed is about 3 frames per second and the dark current is about 0.05 e^-/p/s at -10°C. We have made a system performance test by confirming the system linearity, system gain, and system noise that its specification requires. We have also developed a data acquisition software which connects a digital camera controller to a PC and acquires $H\alpha$ images via Microsoft Visual C++ 6.0 under Windows 98. Comparisons of high quality $H\alpha$ images of AR 9169 and AR 9283 obtained from SOFT with the corresponding images from Learmonth Solar Observatory in Australia confirm that our $H\alpha$ digital observational system is performed properly. Finally, we present a set of $H\alpha$ images taken from a two ribbon flare occurred in AR 9283.

Key words : Sun: flare - Instruments: CCD

I. INTRODUCTION

Ground-based $H\alpha$ observations have been regarded a key traditional tool for monitoring optical brightness during flaring activity (Zirin 1988, Denker et al. 1998, Moon et al. 2000). They make it possible to observe the chromospheric fibril structures including flares in Hα line. Even though recent space observations such as Yohkoh and SOHO have provided us with a lot of interesting findings on solar active phenomena, $H\alpha$ observations by ground-based observatories are still thought to be important due to the following reasons.

(1) There is no space counterpart for Hα observations.

(2) Thanks to digital CCDs recently introduced, higher quality images can be obtained more efficiently than before.

(3) Since ground-based observatories are spread all over the world, it is possible to make multiple observations for the same features and simultaneous observations for various features on the Sun.

Solar Flare Telescope (hereafter, SOFT) at BOAO has monitored solar active phenomena such as solar flares and prominences by white light, $H\alpha$ filtergram, and filter-based magnetogram for a local area of the Sun (400"× 300") since 1995 (Park et al. 1997, Moon et al. 1999). Its main detectors are Sony-XC77 video CCDs which are capable of acquiring images at 30 frames rate per second. Output data for video CCD observations have been stored in a data acquisition PC and displayed on a monitor via data acquisition softwares made in Visual C++ (Moon et al. 1996, Kim 1999). The $H\alpha$ filtergram uses a very narrow band Lyot filter whose passband is 0.025 nm. However, Video camera has its own weakness as follows: (1) it has a small dynamic range of 8 bit, (2) it is subject to several noises, while analogue signal is transferred to an analogue to digital (hereafter, A/D) converter in a PC, and (3) since the video rate is fixed at 30 frames per second, it is hard to obtain a high quality image with a short exposure time which can freeze atmospheric seeing effects.

Recently, high performance digital CCDs with low noise and relatively fast readout speed have been developed by several CCD companies which improved the system's signal-to-noise ratio, the sensitivity and the accuracy of measurements. Thus the new observing system using digital CCD cameras has been implemented at several solar observatories such as (1) Hiraiso Solar Terrestrial Research Center in Japan (Akioka et al. 1997) with high resolution digital full-disk Hα images with 2 K by 2 K pixels CCD, (2) $H\alpha$ full disk observation of the Sun from Big Bear Solar Observatory (BBSO) with high resolution digital with 2032 by 2028 pixels CCD (Denker et al. 1998) and (3) the digital vector magnetograph of BBSO with 1 K by 1 K pixels in 12 bit for high quality polarimetric observation (Wang et al. 1998, Spirock et al. 2001). They have produced a lot of high quality images, thanks to digital CCD systems which have several advantages over previous video CCD systems; (1) digital CCD systems have relative large dynamic ranges, (2) they have low dark current, (3) they have low noises since observing signals digitized by A/D converter in the digital CCD controller are directly transferred to a PC, and (4) their exposure times can be adjusted because electric or mechanical shutters are adopted for exposure time control.

In selecting a digital CCD camera, we took into consideration the following features: dynamic range, pixel size and read out speed. Based on these criteria we have selected a new digital camera system, MicroMax YHS-1300 manufactured by Roper Scientific with a ST-133-5 MHz controller. In this paper we describe our newly selected digital CCD system together with the data acquisition software. The hardware part of $H\alpha$ digital system is presented in Section II, its performance test in Section III, the data acquisition software in Section IV and observational results in Section V. Finally a brief summary and discussions are given in Section VI.

II. $H\alpha$ DIGITAL CCD

Figure 1 presents a schematic diagram of our new digital CCD system for $H\alpha$ observation, which is composed of a interline transfer CCD, a digital CCD controller, and a data acquisition software. Its basic characteristics is summarized in Table 1. The hardware part of the new system has two main components, namely camera head and controller.

(a) Camera Head

The interline transfer imaging sensor in the camera head is made by Sony ICX-061 chip with an array of 1300 by 1030 pixels whose pixel size is 6.7 μm×6.7 μm. An electrical shutter is used for the control of exposure time, which ranges from 6ms to several seconds. The maximum quantum efficiency of the CCD sensor is about 25% at 656.3 nm. The CCD arrays have several essential functions; once photons are transduced to electrons, the electrons are integrated and stored, and finally they are read out. The readout time is approximately given by

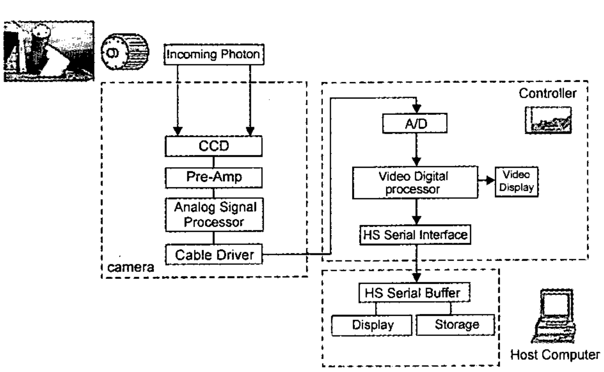

Fig. 1. Schematic Diagram of a $H\alpha$ observation system.

Table 1. Basic characteristics of the digital CCD system

Dynamic range	12 bit
Pixel number	1300×1030
Pixel size	6.7 μm×6.7 μm
Sampling size	~0.3 arc sec
Chip	Sony ICX-061
System non-linearity	~0.4%
System gain	1.1 electrons/ADU
System noise	2.1 electrons
Controller weight	5.45 kg
Storage temperature	−20°C~50°C
Relative humidity	less than 80%

$$t_R = N_x N_y (t_{sr} + t_v) + N_x t_i \quad (1)$$

where N_x is the smaller dimension (1030) of the CCD, N_y is the larger dimension (1300) of the CCD, t_{sr} is the time required for shifting the most distant one pixel to a register (serial or horizontal), t_v is the time needed for digitizing a pixel, and t_i is the time to shift one line into the shift register. The estimated total readout time is about 0.29 sec, which results in the maximum frame rate of about 3 frames per second. To reduce the thermal noise of the CCD sensor, a thermoelectric cooler (hereafter, TEC) of a multi-stage Peltier type is used. It has a capability of cooling up to −25°C with stability of ±0.05°C over the entire temperature range with the system's dark current of ±0.05 $e^-/p/s$ at −10°C. Incoming lights detected through the CCD sensor of SOFT produce electronic signals (photo-electrons) over a two-dimensional space, converting the energy of photons into the corresponding number of electrons.

(b) Digital CCD Controller

The controller contains an A/D converter, its power supply, the analog and digital electronics, the scan control and exposure timing hardware, and controller I/O connectors, all mounted on user-accessible plug-in modules. The controller is a compact, high performance CCD camera controller for a TE-CCD 5 MHz camera type. It is designed for high speed and high performance image acquisition by converting analogue data to digital ones with the use of a specially designed, low-noise electronics, supporting a scientific grade 12-bit A/D converter. The digital data is transferred at a high speed of 5MHz to a PCI Interface card in the host computer and subsequently the host computer RAM using Direct Memory Access (DMA). Thus, our 12-bit digital camera system has a greater dynamic range than our previous 8-bit video CCD system. The interface from the controller to the data acquisition software determines how the computer communicates with the controller by a high speed PCI serial interface. The CCD camera is operated by a Pantium-lll type PC with the operating system of windows 98 running at 700 MHz including 512 MByte RAM.

III. SYSTEM PERFORMANCE TEST

Before setting up the digital camera, we have made performance tests in laboratory, in which system linearity, system gain, and system noise are estimated. These tests are important for evaluating the quality of a camera system (Janesick 1987). A region of interest (ROI) of 50 ×50 pixels around the center of the entire array was selected on the CCD. In general, the system non-linearity can be expressed by the sum of the maximum positive $Max(D^+)$ and negative deviation $Max(D^-)$ divided by the maximum signal $Max(S)$ as a percentage:

$$\text{Nonlinearity}\ (\%) = \frac{Max(D^+) + Max(D^-)}{Max(S)} \times 100\,. \quad (2)$$

Figure 2 shows a good linear relationship between averaged intensities and exposure times. The estimated system non-linearity is about 0.4%.

The random uncertainty in any measurement is generally affected by several factors such as random variations in the number of photons emitted or absorbed, variations in setting the instrument at the desired position, errors in measuring time, and contamination by reagents. All of these factors contribute to the standard deviation of the final result according to the rules of variance. The gain and noise of the system are characterized by a technique that the photons are changed to electrons and transferred to digital values. A method of obtaining the system gain is very much like the linearity test method given above. For a given exposure time, we computed the intensity average difference between flat-field and biased images and the variance of the difference between the two flat-field images with varying incoming lights (Backer et al. 1996). The resulting intensity average difference (Mean flat - Mean bias) as a function of variance is given in Figure 3, where the system gain is determined by a slope of the linear portion of the plot. The estimated system gain is about 1.1 electrons/ADU (analog-digital unit). In addition, the bias level is about 113ADU and the system noise is about 2.1 electrons which is defined as the multiplication of the system gain and the standard deviation for the difference of two biased images. All of the estimates made for the system performance test are very well met with those that the specification requires.

IV. DATA ACQUSITION SOFTWARE

We have developed a data acquisition software which is capable of storing digitized data as well as controlling the digital CCD system. This software has been made

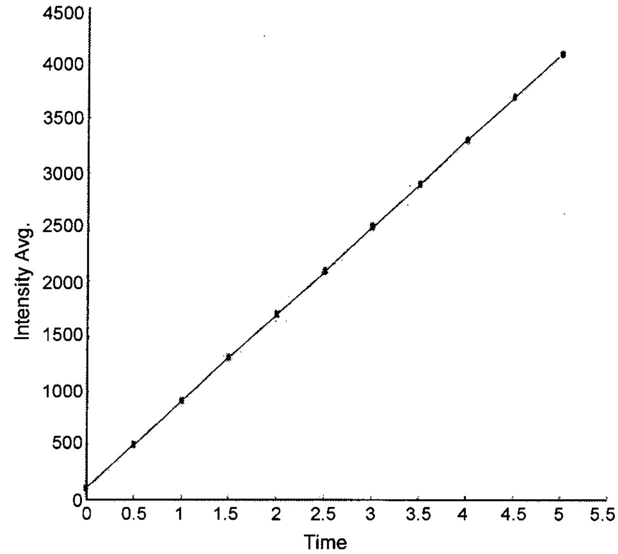

Fig. 2. Averaged intensity over the central region of the CCD sensor as a function of exposure time.

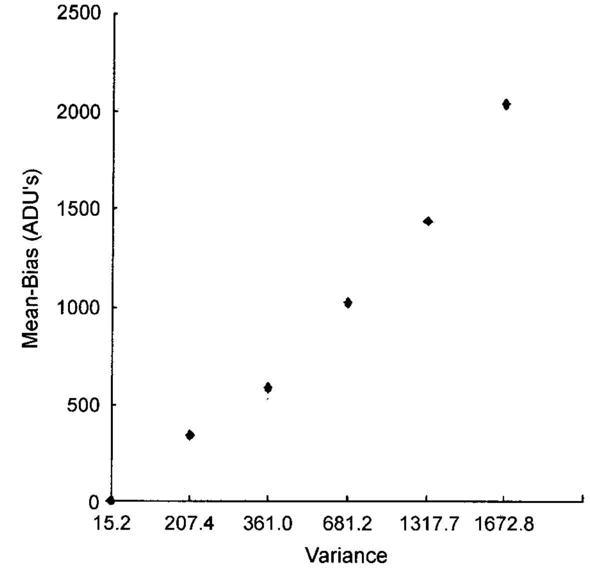

Fig. 3. Intensity average difference (Mean flat - Mean bias) as a function of variance.

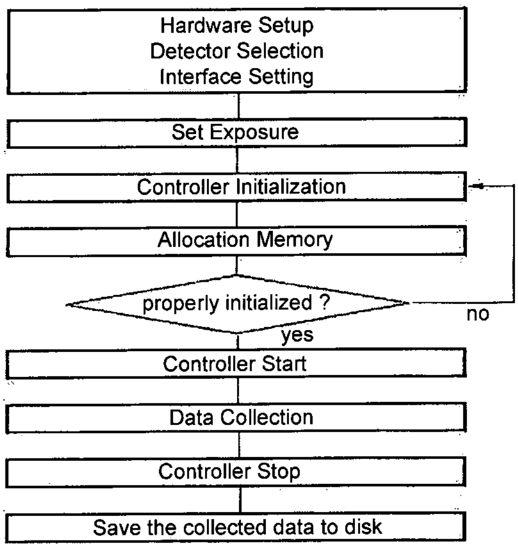

Fig. 4. A flow chart of the data acquisition software.

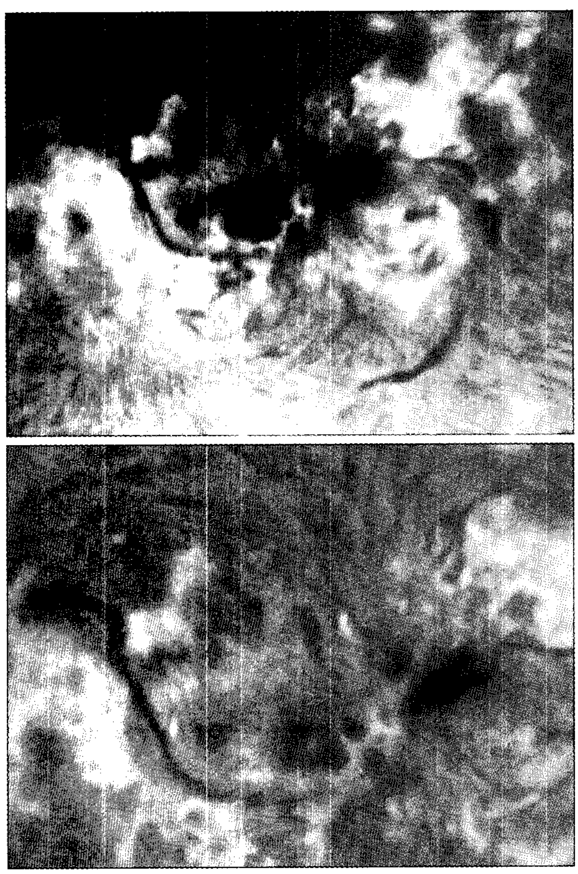

Fig. 5. Comparison of two $H\alpha$ filtergrams acquired from SOFT(upper panel) and Learmonth Observatory (lower panel) in Australia for AR 9169 on Sep. 24, 2000. The two images were acquired at UT 05 : 57 for the nearly same region of the active region. The adopted Learmonth's image was taken from a WWW site provided by the Space Environment Center at http://sec.noaa.gov/solar_images/index.html.

Fig. 6. Comparison of two $H\alpha$ filtergrams acquired from SOFT (upper panel) and Learmonth Observatory (lower panel) in Australia for AR 9283 on Dec. 29, 2000. The SOFT's image was acquired at UT 03:03 and the Learmonth's one at UT 03:00 for the nearly same region of the active region. The adopted Learmonth's image was taken from the solar image WWW site provided by the Space Environment Center at http://sec.noaa.gov/solar_images/index.html.

via Microsoft Visual C++ ver 6.0 under Windows 98 using the command library, Princeton Instruments Controller Module (hereafter, PICM). The PICM is composed of a set of C library and header files PICM which provides users with the capability of collecting frame data from Princeton Instruments CCD detectors through the PIXCM32.DLL (Princeton Instruments External Controller Module Dynamic Link Library).

Figure 4 shows a flow chart of acquiring an image via the acquisition software as follows. (1) The controller, the CCD chip, and the interface are defined automatically. (2) Since the cooling temperature in the camera head settles down to –25°C usually within 5 minutes, we can set an appropriate exposure time. (3) We initialize the data structures in the software library as well as the hardware of the controller itself. Both can be done without actually starting the controller, so that as soon as the separate start command is provided, the controller is ready to begin operating the detector which improves the response time in real time systems. (4) A proper memory is allocated for data storage. The data are saved in the memory with a two dimensional array in which

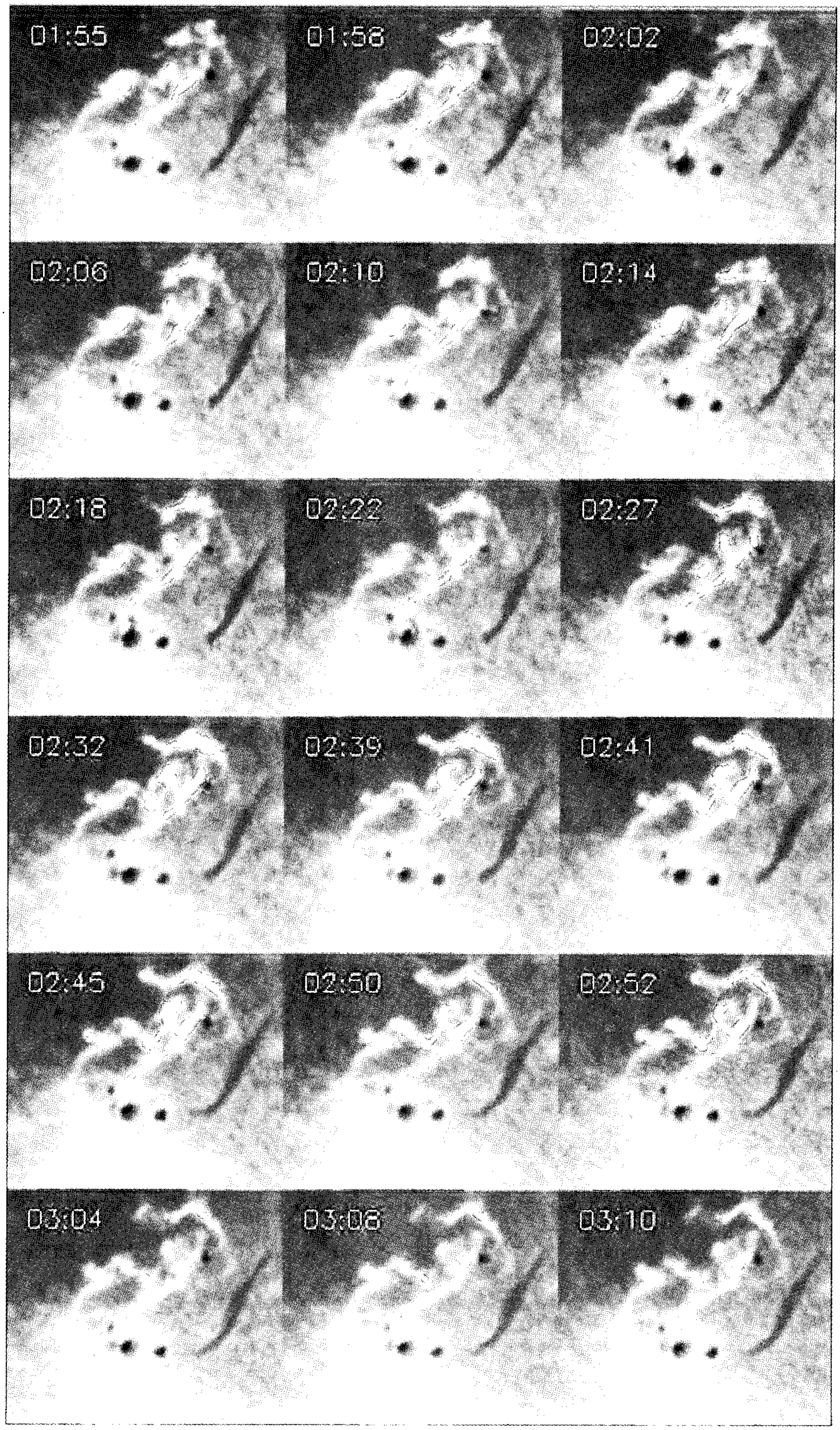

Fig. 7. A set of $H\alpha$ flaring images of AR 9283 acquired by SOFT on Dec. 29 in 2000.

each pixel has two bytes of memory. (5) When the above two processes (controller initialization and allocate memory) are properly executed, the controller starts to work. (6) Otherwise, we have to return back to the process of controller initialization. (7) We acquire images of observing targets. This can be done continuously or occasionally with the use of PICM, allowing the software to perform other processings while new data are being collected, improving overall system throughput. (8) After the images are temporally saved in RAM, the controller stops to work. (9) They are then saved in the hard disk of the data acquisition with a FITS (Flexible Image Transform System) format. The resulting memory without binning for each image is about 2.7Mbytes. Finally the software resources allocated at the beginning of execution are released.

V. OBSERVATIONAL RESULTS

Since setting up the new digital CCD system, we have made several test observations by obtaining higher quality images from a lot of active regions than those by our previous video CCD system. Because we replaced the video CCD by the present digital CCD, it is impossible to make a direct comparison of the quality of images acquired from the two different detectors. Thus we compared the $H\alpha$ images of AR 9169 (Figure 5) and AR 9283 (Figure 6) taken by SOFT with the corresponding ones taken from Learmonth Solar Observatory in Australia at a nearly same time. As can be seen from Figures 5 and 6, fibril and filament patterns around sunspot and flaring images are quite similar to each other, demonstrating the validity of our new digital system. Some differences seen in the figures could be associated with their grey intensity levels, the central wavelength positions of used $H\alpha$ filtergrams and so on. In addition we have made several series of $H\alpha$ observations for flaring events occurred in AR 9165, AR 9193, AR 9218, AR 9240, and AR 9283 etc. As an example, we present a set of $H\alpha$ flaring images obtained from SOFT occurred in AR 9283 on Dec. 29, 2000 in Figure 7, where we can see relatively detail features of chromospheric $H\alpha$ brightenings around a typical two-ribbon flare. At that time, this active region was located in a β-γ region which includes a complex of magnetically separate sunspot groups. A MPEG movie of the flaring data given in Figure 7 is available from the World Wide Web at http://www.boao.re.kr/~yjmoon/gallary/gal_boao_has_han.htm.

VI. SUMMARY AND DISCUSSION

In this paper we introduced a new digital CCD camera system, MicroMax YHS-1300 manufactured by Roper Scientific, for $H\alpha$ observation by SOFT. It has a 12 bit dynamic range, a pixel number of 1300×1030, a thermoelectric cooler up to −25°C, and an electric shutter. Other basic characteristics are summarized in Table 1. We have made a performance test by estimating system linearity, system gain, and system noise.

The main results from this study can be summarized as follows. (1) From the performance test, the system non-linearity is found to be about 0.4%, the system gain, about 1.1 electrons/ADU, and the system noise, about 2.1 electrons. (2) We have developed a data acquisition software which links a digital camera controller to a PC, and $H\alpha$ images are acquired via Microsoft Visual C++ 6.0 under Windows 98. (3) By comparing the images of AR 9169 and AR 9283 obtained by SOFT with the corresponding images from Learmonth Observatory, we have confirmed the validity of our digital CCD observing system. (4) Finally, we presented a set of high quality $H\alpha$ flaring images of AR 9283 for a typical two-ribbon flare on Dec. 29 in 2000.

SOFT at BOAO has observed solar active phenomena such as sunspot, solar flare, filament, and prominence since 1995. In 2000, we have developed a near real-time flare alerting system using the GOES X-ray fluxes (Moon et al. 2000). Now we have established a digital CCD system for high spatial resolution and high dynamic range observations with very low noises. Thanks to these systems, we are able to make $H\alpha$ flare observations more efficiently than before. As seen from Figure 5 through Figure 7, our $H\alpha$ images are nearly comparable with other images available at several WWW sites. Our $H\alpha$ observational system can be effectively used for solar activity studies on flare, prominence, and filament as well as for space weather studies. We plan to convert other video cameras for white light and filter-based magnetograph to digital ones in the near future.

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