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A digital TV complex of the 6 m optical telescope BTA for identification of astronomical objects and guiding

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Abstract. A digital television complex of the 6 m telescope BTA has been created. The complex digitizes video information from the 3 foci of BTA. This allows more reliable identification of an object, guiding by its digital video image and also accumulation and processing of television images to be performed. The digital TV complex has been designed on the basis of the video server with a frame grabber VS56/VS60. The server has inputs for 4 independent television analog signals of the BTA TV guide cameras with programme-controlled selection of one of them for subsequent digitization of the video image. The programmes of the video server control and of the processing of television information, including guiding by the object digital video image, are written to run under the OS Linux. This enables connection to the video server from any computer in the local network of SAO and independent processing of observed images.

Key words: telescopes: BTA — techniques: image processing — methods: observational

1. Introduction

The latest achievements in the field of optical-electronic systems and computing facilities make possible a new approach to utilization of television means in astronomical observations.

High-sensitivity television detectors being created, it became possible to control the pointing to the object, its identification and guiding in the mode of television monitoring. As a result, at large telescopes there appeared working places remote from the light detectors, where all means of observation control were concentrated (control room at BTA).

Joining all television facilities of BTA in a unified complex with digitization of video signals enables solution of new problems:

- simultaneous control of several television systems with one computer;
- processing images from the BTA television cameras;
- adding up frames;
- archiving images;
- guiding by the object digital video image;
- read-out of the current image to the computer network of SAO.

The digital television data of BTA are accessible from any computer in the local net of SAO, with prospective implementation of remote control of observations at BTA. At present, it is possible to process up to 4 video images from different TV cameras simultaneously, either individual frames being read out or any number of frames being summed in the computer memory. For accelerating the image digitizing, a selected frame area can be processed.

2. Structural layout of the BTA television complex

The reduction of images from TV cameras at optical telescopes can be accomplished in two principal ways:

a) analog signals from all the TV cameras are sent to a specialized server where they are digitized and processed with the aid of a common video controller;

b) digitizing of images is performed immediately at TV cameras with transmission of digital signals to the computer net for further processing and archiving video images.

We have adopted a simple and accessible variant of digitizing analog TV signals with the aid of one controller of the company "Videoscan" in a standard computer as the central video server.

The observational equipment at BTA is installed at the 3 foci: the prime (PF) focus and secondary Nasmyth foci (N 1 and N 2). The foci are separated from the BTA control room by 150–200 m on the average. This defines the structure and technical parameters of the video net.

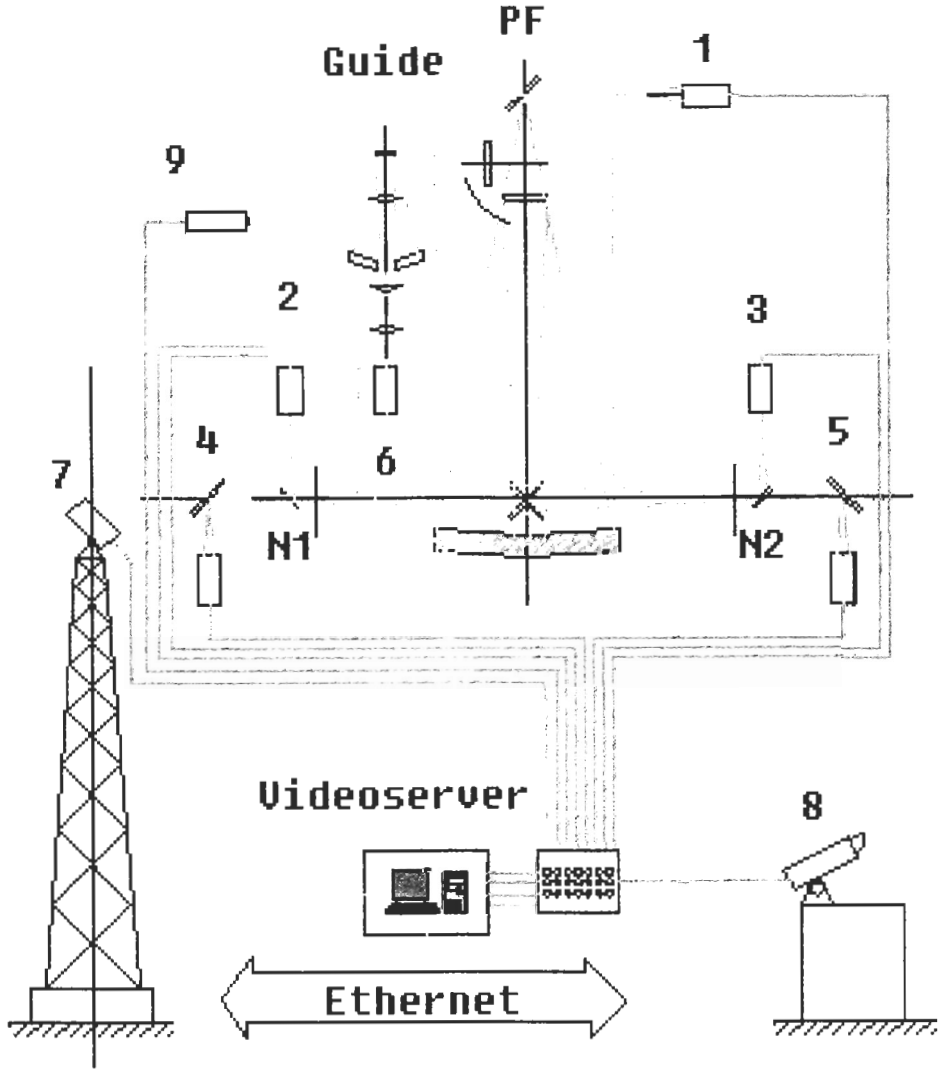

Figure 1: *The scheme of the BTA TV complex: 1 – TV cameras at the PF (I-SIT, ICCD, CCD), 2 – field TV guide at the N1 focus (ICCD), 3 – field TV guide at the N2 focus (I-SIT), 4 – slit TV guide at the N1 focus (I-SIT), 5 – slit TV guide at the N2 focus (I-SIT), 6 – TV camera of the Guide (I-ICCD), 7 – outside-dome camera to survey the sky region near zenith with a* 100° *FOV (CCD), 8 – outside-dome panoramic sky-view camera with a* 30° *or* 70° *FOV (SIT), 9 – inside-dome TV camera for telescope position checking (CCD).*

The video net of BTA (Fig. 1) is a television complex in which signals from all TV cameras arrive at the video server "sky.bta.sao.ru" for subsequent digitizing, computer control and reduction of images of observed objects. The digital TV complex consists of:

- TV cameras of the field view and slit view of the spectrographs at the foci N 1 and N 2,
- TV cameras of the slit view of the PF spectrographs,
- "control" TV camera for obtaining direct images at the PF,
- TV camera of the Guide,
- outside-dome TV cameras for surveying the sky above BTA,
- video camera for checking the telescope position in the dome,
- VS56/VS60 video controllers (frame grabber),
- video server based on a personal computer,
- unit control block of the TV cameras.
- user's interface for observations,
- software.

3. Principal requirements to the receiving units of the BTA video net

When identifying and guiding astronomical objects the light flux in the TV guides changes by 6–8 orders of magnitude depending on the brightness of the observed objects and sky background. That is why, the TV cameras used to carry out astronomical observing programmes must have a large dynamical range along with the high sensitivity in the standard interlaced scanning of the TV signal (625 lines, 25 frames/s). For the present-day TV cameras of medium format (768 × 576 pixels), this corresponds to the luminance range from $N_{min} \sim 1 - 2$ photon/channel/s — the average background, the night sky luminance, equivalent to the brightness of a star with an apparent stellar magnitude of about 20^m, to $N_{max} \sim 10^6$ photon/channel/s, which is equivalent to 0^m in the visible spectral range.

The visualization of faint astronomical objects, the illumination from which in the V filter at the entrance of the TV cameras is $E \sim 10^{-6}$ lx, corresponds to recording $N \sim 2$ photon/channel/s, that is, it coincides with N_{min}. Thus, the TV cameras at light fluxes of $E_{min} \sim 10^{-6}$ lx operate under the condition of recording one-electron events observed on the display of a video-control monitor (VCM) as individual scintillations.

The fundamental requirements to the TV cameras of the BTA video net are as follows:

- sensitivity, which is defined by the size of the image intensifier tube photocathode under the condition of recording one-electron events;
- field of view (FOV), which is determined by the size of the photocathode of the entrance image intensifier tube (on the average, 25 mm × 15 mm);
- TV signal standard should be CCIR TV mode (interlaced, 625 lines, 25 frames/s);
- stability of the raster location is to be within the influence of the Earth's magnetic field, but not worse than 0.5–1 picture dots;
- resolution should be not worse than the maker's data sheet of the image intensifiers, TV tubes and CCD (on the average, 400 TV lines).
- simplicity of operation and adaptation to the BTA communication lines and weather conditions at an altitude of 2000 m above sea level;
- standard composite video signal with a possibility of observation on a standard VCM in the BTA control room, the video cable length being 150-2000 m;
- remote sensitivity control;
- noise immunity – noises on the VCM display caused by the distant character of operation of the TV guide cameras must not exceed the video signal circuit noise.

4. Configuration of the BTA TV cameras

Three types of TV cameras which comply with the above requirements are used in the television complex being described. To construct the BTA TV guides, generally known approaches of making high-sensitivity TV cameras by the principles I-SIT and ICCD (Khromov, 1982) were chosen. The main parameters of the TV guides at the BTA foci are given in Table 1. The limiting apparent stellar magnitude of 1 frame (40 ms) for each TV guide was obtained at a seeing better than $2''$.

4.1. I-SIT television cameras

The TV camera having transmission tubes with a photocathode and a silicon diode matrix as a target and with an electrostatic image section is designated as SIT TV camera (SIT – Silicon Intensified Target). Such a camera provides an electron amplification up to 10^3 times. However, in order to ensure a reliable recording of events above the TV system noises, such an amplification is not sufficient. For this reason, for the BTA TV guides SIT cameras with additional image intensifier, I-SIT ones (Fig. 2), are used (Abramenko et al., 1984).

As SIT devices, supervidicons LI-702 are used in the TV cameras of BTA. The presence of the LI-702 fiber-optics washer at the entrance ensures its reliable coupling to the image intensifier tube (IIT), which increases the sensitivity of the joined system 100 to 10^4 times, depending on the type of the IIT employed. IITs of two generations are used in the BTA TV guides:

- Gen. 1 – electrostatic single-camera IIT,
- Gen. 2 – IIT with microchannel amplification.

Sky background recording by the I-SIT TV cameras with Gen. 1 IIT is provided by very high (up to 20 kV) voltages at the entrance photocathode, which is not always favourable under certain weather conditions (for instance, appearance of a corona as humidity increases). In Gen. 2 IIT high amplification is achieved through the employment of microchannel plates providing a high coefficient of amplification of primary photoelectrons, up to $\sim 5 \cdot 10^4$.

Important advantages of the Gen. 2 IITs with microchannel plates (MCP) are their compactness, a comparatively low voltage supply and a simple way of coupling to other IITs. For this reason, the MCP was chosen as the basic IIT for the BTA TV guides.

4.2. ICCD television cameras

Over the past few years, in TV devices CCDs have displaced vidicons at the level of illumination above 10^{-3} lx. The latest developments of TV guides at

Table 1: *Main parameters of BTA TV guide cameras*

N	Install. place	Guide object	Camera configuration	Device type	Camera field size	Sensitivity limit (mag.)
1	N2	Field	I-SIT	Gen. 1 LI-702	3′	12
2	N2	Slit	I-SIT	Gen. 2 MCP LI-702	39″	15
3	N1	Field	ICCD	Gen. 2 MCP CCD1/2″	3′.5	17
4	N1	Slit	I-SIT	Gen. 2 MCP LI-702	40″	19
5	PF	Slit UAGS	ICCD	Gen. 2 MCP CCD1/3″	4′	20
6	PF	Telescope control	CCD	CCD1/3″	32″ × 26″	9.8
7	Outside	Sky	SIT	LI-702	75°	4.5
8	Guide	Field	I-ICCD	Gen. 1 Gen. 2 CCD1/3″	1°.5	13.5
9	Inside	Telescope position	CCD	CCD1/2″	88°	f=3.5mm 0.005 lx F=1.4-64

BTA are also aimed at the application of CCD. Their high sensitivity, geometrical stability of TV raster, small dimension and power consumption, the possibility of accumulation of signal and, what is also of importance, the sharp drop in prices for CCDs of format up to 1/2″ make it possible to build cheap but high-quality video systems for astronomical observations. The first CCD camera incorporated in the digital TV complex was a CCD 1/2″ based on the camera SONY CCB-M27B/CE for input of black-and-white images to a computer of type IBM PC/AT. It was used at BTA in the version "Tandem" (in conjunction with the controller VS56) for sky cloudness monitoring (Vitkovskij et al., 2001). Having a view angle of about 100°, the camera was used for the wide-angle surveying of the near-zenith region above BTA.

The camera CCB-M27B/CE forms the video signal and accumulates it on the CCD chip. The output television scanning is interlaced. However, the image read-out is possible both once per half-frame and once per frame, which actually provides progressive scanning. The signal acquisition time is up to a minute, which increases its sensitivity many times. It should be taken into account that the image acquisition with the CCD (without its cooling) causes appearance of individual points in the obtained image, the brightness of which differs from that of the surrounding ones. Nevertheless, in surveying the night sky above BTA, the average integration was 1 minute, whereas on a dark cloudless night it was up to 2 minutes without image quality degradation.

To obtain direct images at the PF, a TV camera CCD1/3″ made on the basis of the microcompact SONY CCD camera of series KPC-400 is used. In the TV mode it provides observations of stars with magnitudes ranging from 2^m to 9.8^m. Presently, this "control" camera is used to check the precision of the telescope pointing and tracking. Another TV camera CCD1/2″ based on the SONY EX-View CCD HITRON System MDC5C23 does round-the-clock monitoring inside the BTA dome with read-out to Internet home page of SAO (*http : //www.sao.ru/BTAcontrol/TV/bta_webcam.html*).

The detection limit of CCD-cameras used for identification and guiding should be of moonless night-sky brightness magnitude ($\sim 22^m/\square''$ at the BTA site) in a continuous observational mode, with time sampling of 25 frames/s. For this reason, new BTA TV guide cameras were made with the Intensified Charge Coupled Device (ICCD) (Fig. 3), where CCD is coupled with the Gen. 2 MCP.

Several ICCD cameras of different configuration are used in the BTA digital television complex:

- a camera for observations in slit-view mode with the spectrograph UAGS in the BTA PF cabin;
- a television camera of the 70 cm TV Guide;
- a field-view camera at the N1 focus.

5. BTA video server

Working out the unified video net of BTA, we chose a simple and cheap way of video signal digitization

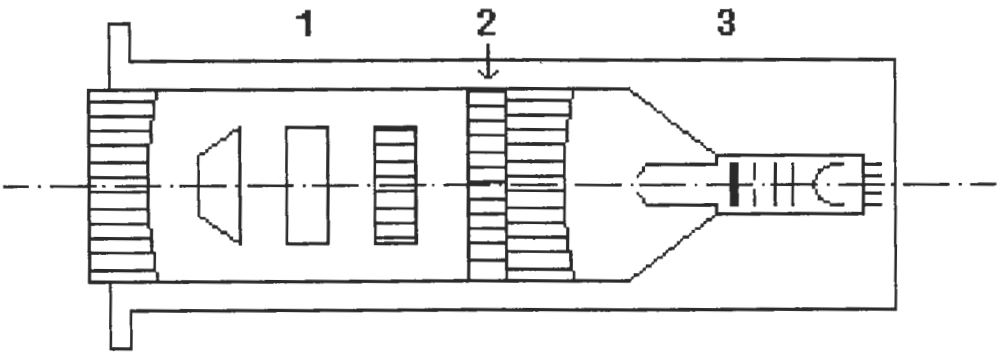

Figure 2: *Structure of the I-SIT camera. 1 – Gen. 2 MCP, 2 – fiber-optical washer, 3 – supervidicon SIT.*

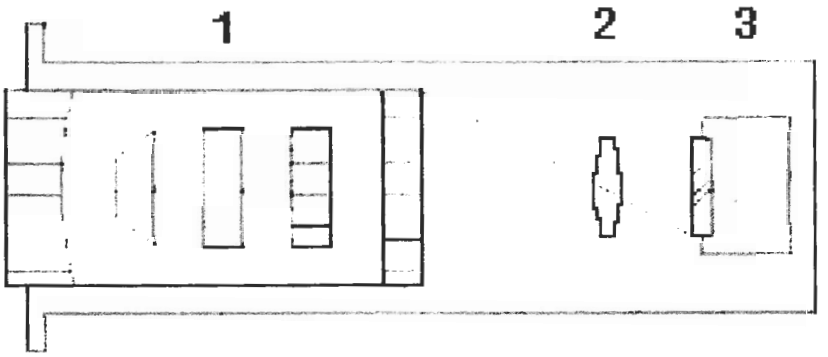

Figure 3: *Structure of the ICCD camera. 1 – Gen. 2 MCP, 2 – demagnifying optics, 3 – CCD.*

with the aid of the 4-channel controller VS56 (ISA) and subsequently making use of a faster frame grabber VS60 (PCI) of the company "Videoscan" in the BTA videoserver based on the computer Pentium 200 MMX.

The video server is located in the BTA control room, where the mains from the three foci come to. It should be noted that apart from fitting up the main foci of BTA with TV guides of the field and slit, in the process of observations a need for auxiliary television channels was revealed:

- TV camera for the field-view Guide,
- outside-dome TV cameras for night sky observations,
- inside-dome TV cameras for monitoring the telescope position,
- video cameras for monitoring the video communication in the control rooms

The video server has inputs for 4 independent television signals with programme-controlled selection of one of them for subsequent digitization of the video image by the frame grabber (Fig. 4). The controllers VS56/VS60 are made on the basis of programmable logic array (PLA) programmed by the user. They capture the input television signal with different format of presentation. Characteristics of the controllers are given in Table 2. It is important to note that every time prior to triggering the controllers VS56/VS60, all the functions are reprogrammed: part of them are reprogrammed by the user and part of them are rigorously defined by the PLA, which specifies actual performance characteristics of the video controllers. The programme of the PLA can be loaded into the controller at any moment of time and any number of times (the loading takes about 80 ms) and ensures the following:

- input of the image from the source of the standard television signal of definite format and frequency of signal digitization, image input time being 40 ms,
- image input through any of the four channels,
- 4 in/out of transitor-transistor logic (TTL) levels,
- use of the controller internal memory.

Before starting operation of the video server, it is necessary to initialize the grabber, that is to programme all the functions of the controller. After that

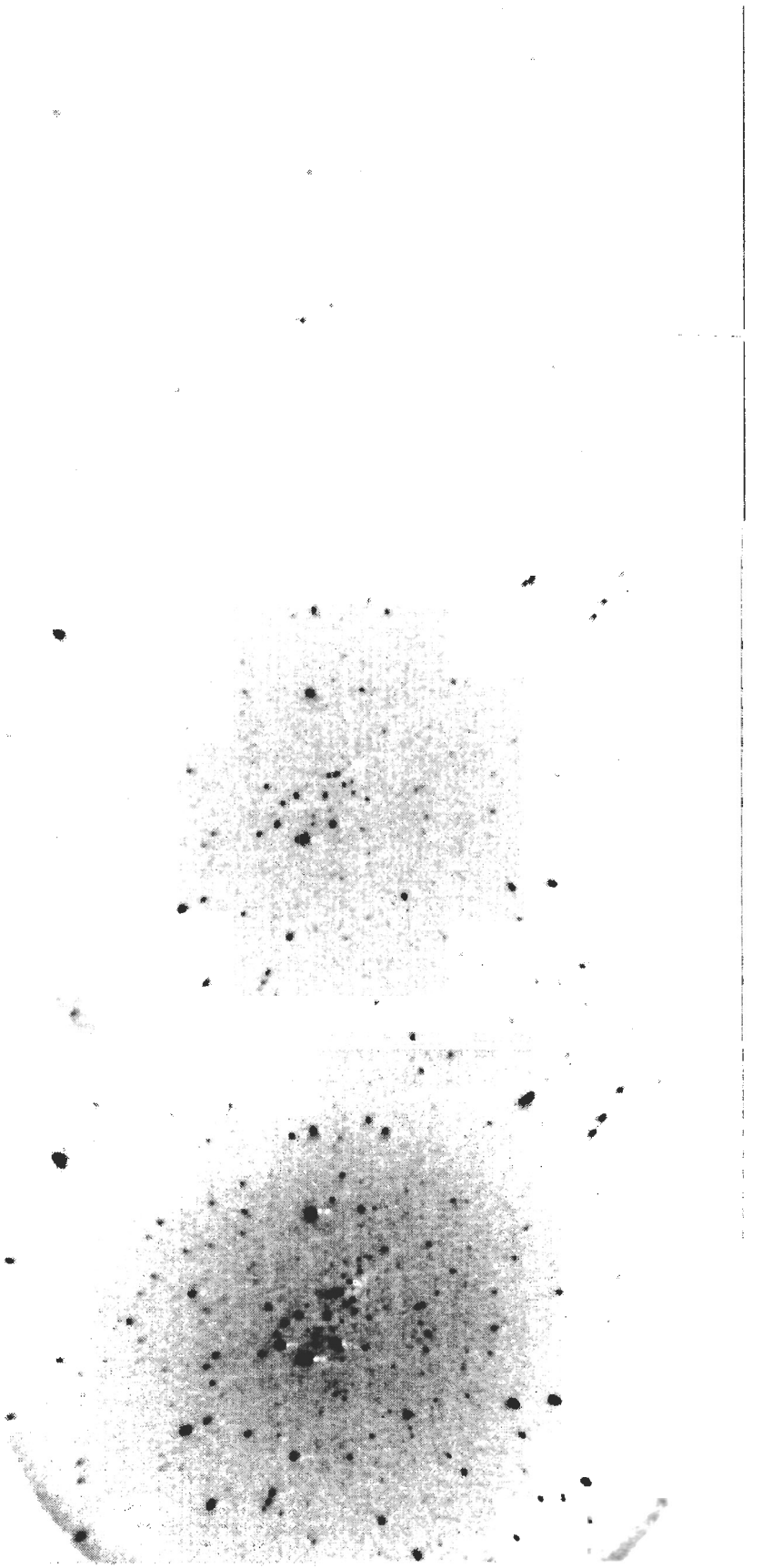

Figure 4: *Digitization of the image from the I-ICCD camera of the Guide. From top to bottom: 1 frame (40 ms), 10 frames accumulated, sum of 30 frames.*

Table 2: *Characteristics of the video controllers — frame grabbers VS56/VS60 as part of the BTA digital television complex*

Parameter	VS56	VS60
Bus type	ISA	PCI
Input video multiplexor	4 inputs	4 inputs
Input video signal, standard	CCIR	CCIR
Digit capacity of ACP, bit	8	8
Memory, Mb	1	4
Format at standard TV signal input, pixel	512 × 512	768 × 576
	768 × 512	1024 × 512
	768 × 576	2048 × 1024
Time of TV signal input, ms	40	40
Image input into the computer memory, frames/s (at resolution)	2.5 (512 × 512)	25 (768 × 576)
Number of scales of grey level	256	256
Clock frequency of expansion, MHz	up to 20	up to 20
Electronic adjustment of scale of white level	0–63	0–63
Possibility of control of the CCD in the mode "Tandem"	available	not available

the input analog video signal selected by the user comes from the multiplexor to the analog-to-digital convertor (ADC) input.

The ADC has electronic regulation of the white level, which permits tuning to the input video signal. The limits of regulation are 0V to 1.5V. The electronic regulation is a 6 bit digitizer: digital-to-analog convertor (DAC) which can be programmed by varying the value of the white level from 0 to 63. After the digitization, the data come to the input LUT located in the housing of the ADC with organization 256×8. Then the data are recorded in the grabber memory. When there is no data input (with the latter switched off or during a blanking pulse), a programme access to the data in the controller memory is possible from the central processor of the video server. The blanking pulse occurs once during each half-frame (20 ms) and lasts for 4 ms.

6. Software and observer interface

The creation of the unified BTA video net demands adequate software to accomplish the following operations in observations:

- object identification,
- guiding the object by its digital video image,
- operation control of the television cameras,
- image accumulation,
- frame-by-frame averaging,
- introduction of tag signals into the image,
- standard image processing,
- archiving the image.

Friendly observer interface is also needed. In the present-day television coders many of these functions are provided for by hard- and soft-ware (the user cannot reprogramme the functions of the controllers). When using VS56/VS60, one can change the operation of the controller to comply with the requirements of different observational modes, therefore for the operation of the BTA video server, programmes of control of the complex and reduction of the television signal were written. The programmes are realized in the OS Linux, allow connection to the video server from any computer of the local network of SAO and independent processing of digitized images. An interface has been created that opens up to 4 windows at the same time. An independent image from one of the BTA television cameras is visualized in each of them.

It is possible to digitize a single frame of the observed object and then add together any number of frames (Fig. 4). To speed up the frame read-out, the video server can process not the whole frame but only part of it. Besides, the video server realizes automatic tracking of the object by its digital video image (autoguiding). A special autoguiding interface has been made with the aid of which the measured discrepancy between the computed and the observed location of the object on the digital image of the TV guide is sent to the BTA automatic control system (ACS) for correction.

Fig. 5 shows precision characteristics of autoguiding of the reference source observed at the PF.

Curves 1 are the trend of the star with respect to the centre of autoguiding in azimuth (A) and zenith distance (Z).

Curves 2 are the plot of the sum of corrections in A and Z.

- The first 1000 s – the autoguiding of the object is on. The tracking stability in A was $\pm 1''$, in Z $\pm 0.15''$.
- From the 1010th second – short-time forced

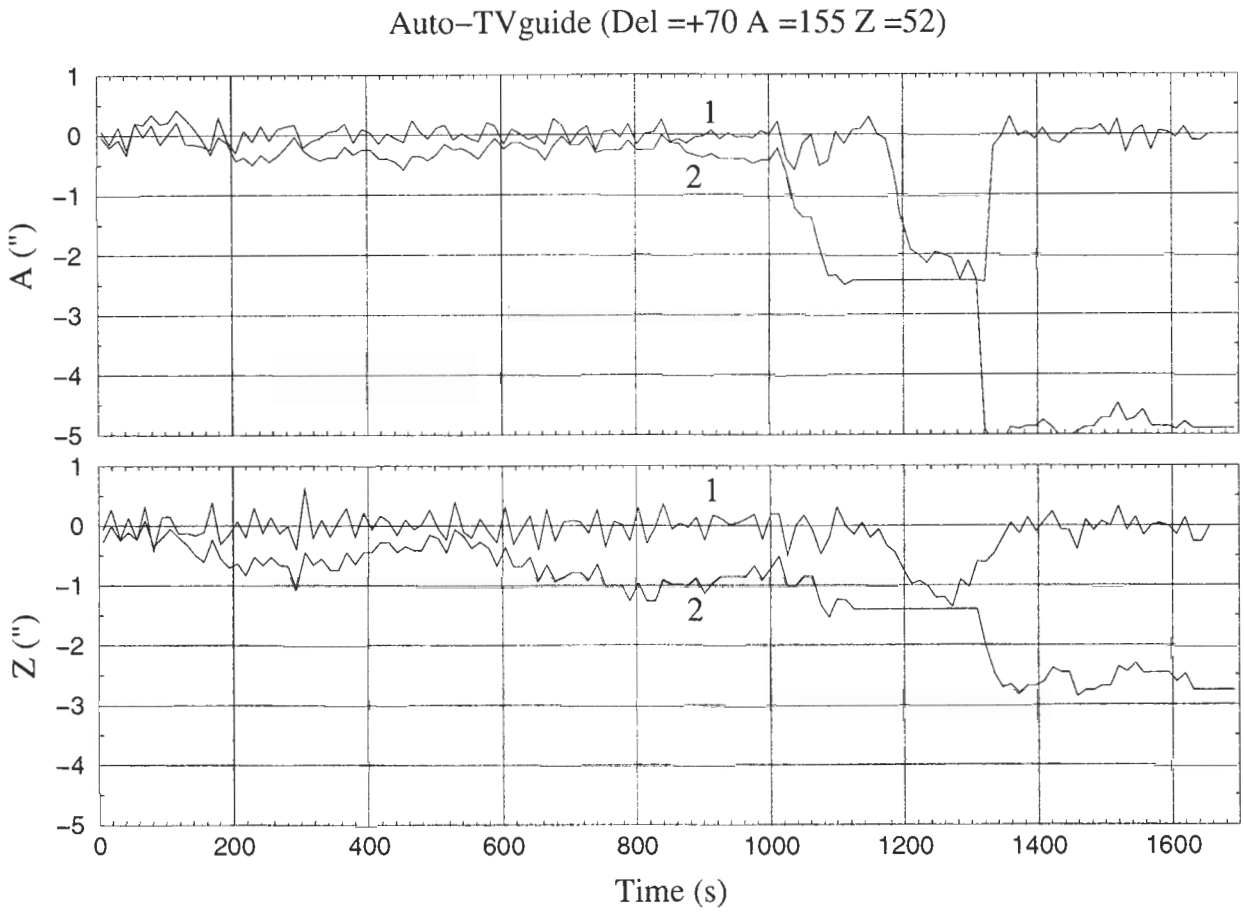

Figure 5: *Autoguiding of a source by its digital TV image of the "telescope control" CCD1/3" TV camera at the prime focus of BTA.*

deviation of the telescope in azimuth. As a result, the object is displaced, but recovers to the centre, and the sum of correction changes.
– After the 1100th second – the autoguiding of the object is off (the transmission of data to the ACS is stopped) and the short-time deviation of the telescope is continued. As a result the source begins to depart from the centre in A and Z.
– Starting from the 1250th second – the autoguiding is on (the transmission of data to the ACS is resumed). As a result, the guiding object rapidly recovered to the centre of autoguiding.

For the secondary foci, the autoguiding has to be often carried out by the object under investigation (as a rule, there are no reference sources in the field observed). The created system for local correction of the star location of the N2 focus in the BTA video server provides a real time read-out and analysis of the frames of the digitized object image and definition of the star centre location. A permanent trend or a great departure of the source from the slit appearing, the programme forms commands of the telescope position correction. Such a tracking system makes up considerably for the variations of the star centre location in the frequency range below 0.5 Hz. The gain in flux estimated both theoretically and from the results of the first observations with the corrector is from 0.5 to 1 stellar magnitude (Ivanov et al., 2001).

7. Principal results

7.1. Improvement of identification reliability and guiding

A digital television system of the 6 *m* telescope has been created. The system makes easier the work of the observer and increases the efficiency of using the observational time. Owing to the addition of frames the transparency of the TV guides increases, which makes it possible to see fainter field objects, enables fast and more reliable finding of the object under investigation and keeping it in the given position in autoguiding.

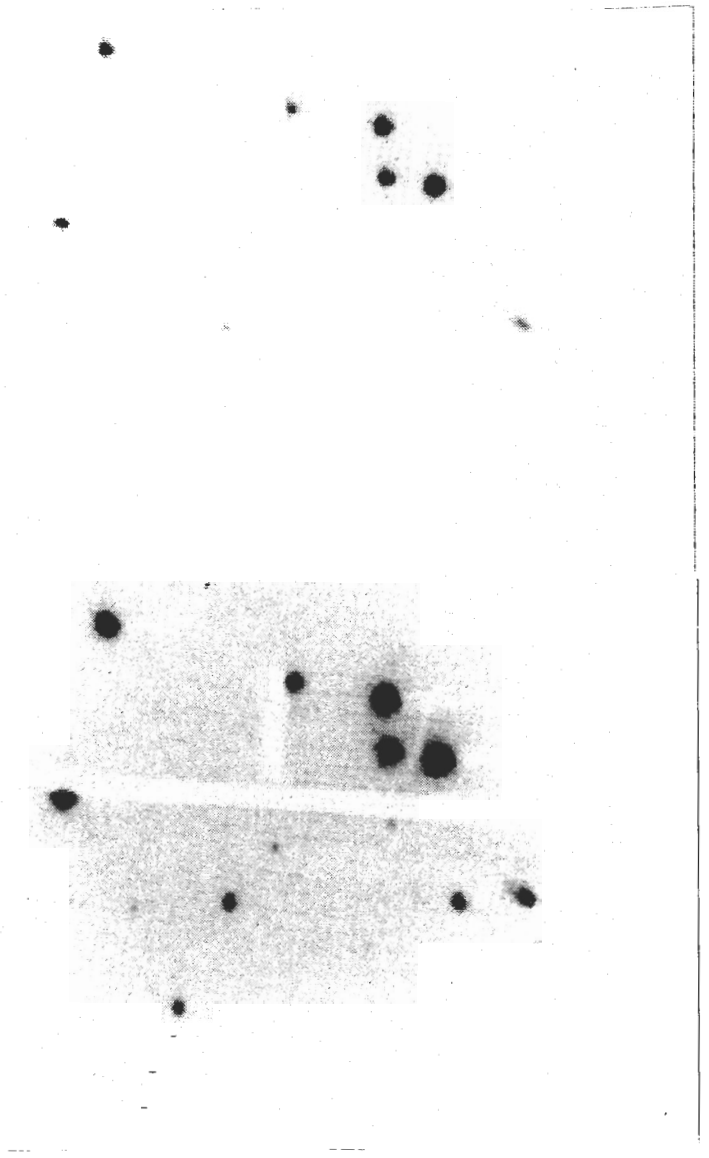

Figure 6: *Digital frame of the NGC 7790 field of standards obtained by means of the I-SIT camera of the slit TV guide of N1: top panel - 1 frame (40 ms), bottom panel - accumulation (addition of 10 frames).*

7.2. Accumulation of television image of the target

The television mode of observation ensures continuous real time control of the object position. The image acquisition time in the vidicon target or CCD chip during one frame is 40 ms. The video server adds together any number of frames, thereby performing accumulation of the signal and improving the sensitivity of the system. In Fig.6 are shown the digitized images of the slit TV guide at the N1 focus with different accumulation of television frames. The sensitivity limit achieved in the TV monitoring mode with frames of 40 ms duration is 19^m (Fig. 6, top panel). The gain in light flux is 1–2 stellar magnitudes, depending on the number of accumulated frames.

7.3. Autoguiding the object observed

The mode of autoguiding the object is realized, i.e. correction of the telescope position by the digital image of the target observed. This is a new technique in the procedure of observations with the TV guides which provides the following advantages:

- keeping the target in the specified position increases the amount of recordable light energy from the object,
- rules out the influence of telescope oscillations,
- improves the stability of the star image center location at the N2 focus by a factor of 2.5 (at good seeing) as compared to the mode without autoguiding.

7.4. Rapid digital check of the BTA TV guide cameras

Making use of the digital television complex of BTA, one can store in the computer memory the images of the TV guides of the field and slit of each focus. This makes it possible to obtain objective and documented results when determining the parameters of the TV guides, which the user must know in the preparation for observations. Systematized data for all the BTA TV guide systems are presented for the first time (Table 1).

7.5. Rapid procedure of determination of the telescope precision parameters

A change-over to present-day CCD recording in solving the problems of BTA investigation and check of its state has been realized. By means of digitization of images it turned out possible to obtain **prompt** and, at the same time, **objectively documented** result of determining the telescope precision characteristics and studies of the atmospheric conditions. Repointings of the telescope to 20 objects were carried out on a technical night during one hour. The coordinates of the objects were close in azimuth A and different in zenith distance Z (9° to 77°). At the same time discrepancies between the computed and actual locations of the objects on a digitized image were calculated.

8. Remote access to the digital television complex

Access to the BTA video server in the computer network of SAO from any working place makes possible remote operation of the television channels of the 6 m telescope (Vitkovskij et al., 2000a). The programmes written in the OS Linux allow the remote user to work in the same manner as being directly at BTA. It is possible

- to observe the operation of the four TV channels that can be connected to the video server,
- to accumulate the signal of the selected TV guide and process the image with one's personal computer,
- to record individual frames or the result of frame-by-frame accumulation with storage of the images in the standard formats (FITS, GIF, JPEG).

The installed TV camera of checking the telescope position sends the video signals not only to the BTA ACS, but also to the web-page of SAO, which permits the observer to have visual information about the telescope position at a given moment and also about the illumination in the dome.

9. Conclusions

The creation of the BTA TV complex is the next stage in the development of the telescope television systems. The authors' intention was to show that such a complex can be created at moderate expenses, i.e. making use of cheap devices. Everything described above was managed to be implemented with the aid of a computer of class Pentium 200MMX which accumulates and reduces all television information. Certainly, one also needs both the communication lines for the transmission of analog signals to the site of digitization of TV images with a video range of up to 10 MHz and for the transmission of digital video images from 10Mb/s (Chernenkov et al., 2000). The transmission of a video signal of up to 25 frames/s requires telecommunication no less than 100 Mb/s. At the present time, BTA is provided with such communication lines even from the Lower scientific site (Vitkovskij et al., 2000b). This allows further upgrading of the techniques of astronomical observations which use the BTA TV guides.

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