An automatic, rapid, wide-field optical camera (WFOC) for the search for optical transients and Gamma-Ray Burst prompt emission has recently been deployed in the North Caucasus. The main parameters of the camera are the following: the Field Of View (FOV) is 17x20 degrees, the angular resolution is 1 arcminute, and the frame frequency is 7.5 Hz. The limiting magnitude in the band close to V is 11.5 mag (for a single frame exposure, 0.13 s). The camera can automatically detect optical transients and generate alerts in real time, and calculate their brightness and coordinates. The camera operated in a test mode from May to November, 2003; since November 2003 it has been working in the commissioning phase, observing synchronously a portion of the HETE-2 FOV of wide-field X-ray Monitor (WXM). The camera will also observe the FOV of the Burst Alert Telescope (BAT)/Swift, when available. Large FOV and fine time resolution make it possible to search for non-catalogued space debris and calculate orbit elements of low-orbiting satellites. Because of the large volume of data we do not plan free access to the data; however, we encourage the community to request raw data to support projects as needed.

Even though Gamma-Ray Bursts (GRB) were discovered in gamma-rays, they are now truly all waveband events: the emission has been detected from radio up to high energies (GeV). However, GRB identifications start with $\gamma$-rays (i.e. omni-directional $\gamma$-ray detectors report them first), and practically nothing is known about the prompt emission in other wavebands. Discovering and investigating this prompt emission may give clues to the physics of the GRB central engine. The mystery of the optical prompt emission seemed to be ready for resolution after the observation of GRB990123 [1]. However, in the 5 years following this discovery no synchronous emission (during the GRB onset) and only a few cases of the prompt one (during the active phase of GRB in $\gamma$-rays) have been observed: GRB990123 ( = $8^{m}.9$), GRB030329 (upper limit > $5^{m}.1$), GRB040825 (>
10 m), GRB041016 (> 13 m .1), GRB041219 (= 19 m .4), GRB050215b ( > 10 m), GRB050309 (> 3.8 m .8), and GRB050401 (= 16 m .8). The problem is that the astronomical telescopes and the observation methods when using them are not fully suited to the problem.

To register the prompt emission we need to look for celestial optical transients (OT) independent of the alert system. Although the time delay between a GRB trigger and an optical observation has been drastically reduced with the new generation of space observatories (HETE-2 and Swift), it will never vanish completely. Hence, an alert-based observation cannot register either an early prompt emission, or possible optical precursors, or afterglow, or the prompt emission from short duration bursts [2]. In any case the early observations are the most likely way to find optical counterparts.

To ensure that an OT is a counterpart to a GRB one needs to confirm the event in $\gamma$-rays. Simultaneous observations with space-borne GRB missions are therefore needed. It is not necessary, however, to correlate the optical and $\gamma$-ray data in real time; we need only assure that both telescopes observe the same field of view of the sky simultaneously. The joint correlation analysis may be done later. Observation of only a specific part of the sky decreases the amount of data to be stored in comparison with all sky surveys [3, 4], and allows the time resolution of the survey to be improved.

The FOVs of the telescopes and the time resolutions of the detectors are crucial points in the search strategy. Astronomical telescopes have smaller FOVs compared to space-borne X-and $\gamma$-ray telescopes (e.g., the Burst Alert Telescope (BAT) of the Swift mission has FOV of 1.7 steradians). Specialized telescopes may have a wide FOV (19.5 x 19.5 degrees with 30 s time resolution, such as RAPTOR [5]), but do not possess a sufficient sensitivity with the appropriate time resolution or vice versa (1.85 x 1.85 at 4 s, ROTSE-III [6]). To detect the prompt emission efficiently the time resolution should be better than, or nearly equal to, the duration of the event. If the prompt emission consists of short duration optical flashes (e.g., [7]), then a high time resolution detector should be used. Moreover, if the nature of the prompt optical emission is similar to that of the $\gamma$-ray emission, a fast variability may be expected down to the millisecond range.

Obviously, the larger the FOV of the telescope, the larger fraction of the GRB error-box can be observed simultaneously, and a more sensitive detector has a greater chance of detecting a faint OT from a GRB. On the other hand, in a simple case of a fixed detector size (e.g., a CCD-matrix), increasing the FOV decreases its sensitivity. (More sophisticated cases are discussed elsewhere [4]). One can show that the number of detected GRB optical events per a fixed accumulation (exposure) time and a fixed size of the detector may be expressed by the formula

$$N_{Detected} \sim (D/\alpha)^{3/2} \ast FOV,$$
where $D$ is the telescope aperture, $\alpha$, the angular resolution, and the $FOV$ is expressed in steradians; here we assume the 3-D Euclidian space and a uniform distribution of GRB sources $N (> S) \sim S^{-3/2}$. One can see that the telescope with the larger FOV can detect more OTs, and the OT detection probability can be maximized while observing simultaneously with a given space-borne telescope.

In view of this strategy we have developed a low cost optical camera for a wide field survey and an autonomous search for OTs [8]. We use an image intensifier both to reduce the size of the image in the main objective lens focal plane to the small size of the TV-class CCD matrix, and also to amplify the light to compensate for the light lost in transmission through the optical system. The details of the camera are the following. The main objective lens (15 cm diameter, F/1.2) of the camera projects the 17x20 degree area onto an image intensifier photocathode of 90 mm in diameter (the quantum efficiency is 10%, the gain is 150, the scaling factor is 0.22). A special optical system transfers the image from the intensifier to the VS-CTT285-2001 TV-CCD camera (1280x1024 pixels with the size of 6.5 microns each) at the frame frequency of 7.5 Hz (the exposure time of 0.13 s).

The practical parameters of the instrument are the 17 x 20 degrees FOV with the spatial resolution of $\sim 1'$ and the limiting magnitude (the 3$\sigma$-level) of $11.5$ for the 0.13 s exposure time. The limiting magnitude of $13^m$ is reached for a 13 s the exposure (stacked in the PC memory). The spectral sensitivity is close to V. The instrument is mounted on an appropriate equatorial mount with the pointing and tracking accuracy of a few arc minutes and better than 1' in 2 hours, respectively.

The relatively poor spatial resolution is the result of a compromise between the cost of an instrument and its wide field of view. Indeed, a precise spatial resolution in fast observations of stationary astrophysical objects is less important than the early detection: the precise localization can be done later by more sensitive large aperture telescopes provided the coordinates will be promptly transmitted and a robotic large aperture telescope immediately slews [9]. Because of the high readout noise of the TV-CCD, the sensitivity of the camera is restricted by the noise at minimum exposure time, and by the sky background at maximum exposures.

In order to process the 13 Mb per second real time data stream coming from the camera a special software suited for the data storage, detection, and investigation of OTs has been created.

The software is installed on three PCs running the Windows (the frame grabber and data storage) and the LINUX (real-time data analysis) operating systems. One additional PC is used for the automatic pointing control. The incoming information is a sample of 1280x1024 pixel CCD frames with the an exposure time of 0.13 s. The low-level software performs the following tasks: the real time data transfer to the LAN; the accumulation of
raw data (up to 0.5 Tb per night) at the RAID. The data reduction in real-time, i.e. the
detection of OTs, determination of their equatorial coordinates and stellar magnitudes,
and identification of the OTs with known objects; distribution of information about newly
discovered OTs to the local and global networks (the alerts distribution) are produced by
the high-level software.

The real-time OT detection algorithm is based on the comparison of a current frame
with a reference frame, being the frame averaged over 10-100 preceding ones, and
consists of the following steps: extraction from the current frame of all pixels with
intensity deviating from the reference frame by a given fraction of the RMS noise;
location of continuous regions of such pixels on the current frame and determination of
their parameters, i.e. coordinates and fluxes. All these regions are considered to be optical
transients (OTs), if they exist on at least 3 successive frames. The shortest optical
transient which can be detected automatically has a duration of $\sim 0.4 \text{ s}$. The next steps
of the algorithm include the analysis of the OT’s shape (on a single frame) the and the
proper motion of the region center; classification of OTs as meteors, satellites, or
stationary transients, and parameter estimation (the trajectory, light curve, etc.); for the
two last cases – for comparison of the object parameters with those of the known objects
taken from star and satellite catalogues (it should be noted, however, that the available
satellite catalogues are not complete); for stationary transients with no known (catalogued) events, the information about their parameters can be sent locally and into
the alert distribution networks (such as the GRB Coordinate Distribution Network [10]).

The high time resolution raw frames are stored in a data base for a limited time (usually
2 days), and within the 2 days can be used for the detailed analysis. The long term data
base consists of stacked images (of 100 original frames of $\sim 13 \text{ s}$ exposure time) and may
be used for the search/analysis of long term variable sources. Every raw data set for a
night is also transformed into a $\sim 3 \text{ minute}$ film for a visual post check of observation
parameters, and the film is stored in the long term data base, too. Finally, for an event
identified as an optical transient (of any nature), the equatorial coordinates, brightness,
and UT are stored in a long term data base and can be used for the correlation analysis,
together with the data related to different wavelengths. In the case of an event having
been classified as the non-stationary one, the coordinates can be used for the trajectory
determination. The accuracies of the automated calculation of coordinates and of the
reference time are acceptable for calculation of the accurate orbit elements of low-

The camera has been operated in the test mode since the end of May 2003. During the
operation periods up to October, 2005 the total number of good nights, i.e. during which
the WFOC observed the part of HETE2 WXM FOV, is 257. The average rate number of
meteors brighter than $9^m$ is between 8 and 20 per hour. No synchronous GRB observation
by use of the HETE-2 was recorded, which, compared with the HETE-2 GRB rate in
2004/2005, is lying well within statistical expectations. Most autonomously generated
alerts were due to active spacecraft and space debris. The average number of moving objects associated with satellites is about 300 per night. A few objects per night are still non-classified, i.e. no correlation has been found either with satellite catalogues or with gamma-ray/X-ray triggers. Examples of the non-classified events are available on the website (http://rokos.sao.ru/favor/selected.html). More statistics (or confirmation by other telescopes) is needed, however, to establish the astrophysical nature of such types of events. The events should be, henceforth, considered as artificial ones generated from non-catalogued space debris.

The primary purpose of this WFOC is to perform continuous, alert-independent observations of optical transients and variable astrophysical sources simultaneously with space-borne X-and γ-ray telescopes. This fully autonomous camera can detect and perform an early photometry of the prompt optical emission from both the long and the short duration GRBs, optical flashes preceding the gamma-ray emission in the GRBs, GRB afterglows not identified in γ-rays (orphan afterglows), optical outbursts related to the Soft Gamma Repeaters, and possible fast optical supernova precursors. Large FOV and fine time resolution make it possible to search for non-catalogued space debris and calculate the orbital elements as a by-product, while the camera is hunting after astrophysical objects.

Acknowledgments

This work was supported by US Civilian Research and Development Fund (RP1-2394-MO-02).
