RevMexAA (Serie de Conferencias), **45**, 20–23 (2014)

III Workshop on Robotic Autonomous Observatories (Torremolinos, Malaga, Spain, 7-11 October 2013)
Editors: J. C. Tello, A. Riva, D. Hiriart & A. J. Castro-Tirado

MINI-MEGATORTORA STATUS UPDATE

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RESUMEN

Acá damos un reporte de estado de sistema de próxima generación, multiobjetivo y sistema de monitoreo transformador, MiniMegaTORTORA, con dos variantes (MMT-6, basado en intensificadores de imagen con CCDs rápida y MMT-9 equipado con varias Neo sCMOS Andor) ahora bajo construcción y puesta a punto en SAO RAS. Este sistema combina un campo ancho con una resolución temporal menor al segundo en régimen de monitoreo, y es capaz de reconfigurarse a si mismo, en fracciones de segundo, para el modo seguimiento que tiene mayor sensibilidad y provee información multi-color y polarimétrica para fuentes transitorias detectadas simultáneamente. Se exponen también soluciones de Hardware y Software utilizadas para estos sistemas, al igual que perspectivas de operación.

ABSTRACT

Here we give a status report on the next generation, multi-objective and transforming monitoring system, MiniMegaTORTORA, with two variants (MMT-6 based on image intensifiers with fast CCDs and MMT-9 equipped with Andor Neo sCMOSes) now under construction and commissioning at SAO RAS. This system combines a wide field of view with subsecond temporal resolution in monitoring regime, and is able to reconfigure itself, in a fractions of second, to follow-up mode which has better sensitifity and provides us with multi-color and polarimetric information on detected transients simultaneously. Hardware and software solutions used for the systems, as well as perspectives of its operation, are also discussed.

Key Words: telescopes — instrumentation: miscellaneous — gamma-ray burst: general — meteorites, meteors, meteoroids

1. INTRODUCTION

The systematic study of night sky variability on subsecond time scales still remains an important, but practically unsolved problem. The detection and investigation of rapid optical transients of various classes, both astrophysical and artificial, is an important task (Beskin et al. 2010b, 2013), which may be accomplished by means of continuous monitoring of the sky with wide-field optical cameras.

Zolotukhin et al. (2004) and Karpov et al. (2005) demonstrated that it is possible to achieve the subsecond temporal resolution in a reasonably wide field with small telescopes equipped with fast CCDs, to perform fully automatic searching and classification of fast optical transients. According to these ideas, we created the prototype fast wide-field camera called FAVOR (Karpov et al. 2005) and the TORTORA camera as part of the TORTOREM (Molinari et al. 2006) two-telescope complex, and operated them over several years.

The discovery of the brightest ever GRB, GRB080319B (the Naked-Eye Burst, Racusin et al. (2008)) and the subsequent discovery of its fast optical variability on time scales from several seconds down to a sub-second time scale (Beskin et al. 2010a) demonstrated that the ideas behind our efforts in wide-field monitoring with high temporal resolution are correct.

2. THE INSTRUMENT

The parameters defining the field of view size, detection limit and temporal resolution, are mutually exclusive, and are limited by the difficulties of constructing and using objectives with large relative apertures ($D/F \sim 1$ or greater). The only possible way to further improve them simultaneously is to design a multi-objective monitoring system, where detection limit is being improved by decreasing the angular pixel size (Beskin et al. 2007), and field of view – by pointing several identical channels towards different regions of the sky. To operate in a sky background dominated regime, the CCD read-out noise may be suppressed by a high amplification image intensifier, or by using low-noise EM-CCD or sCMOS

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as a detector.

Multi-objective design also gives a freedom in the choice of operation regimes, as channels fields of view may be either separated or combined, either with the same photometric (or even polarimetric) filter or with combination of different ones.

2.1. *Mini-MegaTORTORA*

As a realization of such multi-channel instrument concept we designed the prototype design – the Mini-MegaTORTORA, or MMT, which is a model of a 3x3 unit. This unit can demonstrate all the main features of such an instrument – wide-field monitoring and narrow-field follow-up regimes, and the possibility to install different filters in different channels in follow-up regime (e.g. one of B, V and R, and the polarimetric filter with one of three possible orientations, to be able to simultaneously study photometric and polarimetric properties of objects). Main design choice was to use the celostate in a gimbal suspension for a fast repointing of each channel (see Figure 1a).

We are building two variants of Mini-MegaTORTORA with different detectors and, therefore, slightly different parameters. Both variants use commercially available Canon EF85 F/1.2 lens as a main objective and celostate mirrors for a fast (faster than 0.3 s) repointing in the $\pm 20^\circ$ region of the sky.

2.2. *MMT-6*

Detector of the first variant is based on a fast Sony IX285AL CCD chip with 6.4μm pixel and 0.13 s exposure in a continuous acquisition regime, which gives 7.5 1392x1036 frames per second with 12-bit depth. Non-scaling image intensifier has a quantum efficiency of about 25%, and amplified image from its output window is transferred to the CCD by a transmission optics which downscales it 1.7 times; resulting pixel scale is 25$''$ per pixel and total field of view of a channel is about 100 square degrees.

The performance of MMT-6 is worse than we originally expected, as image intensifier significantly degrades the PSF (making it 3-4 pixels wide) and introduces significant spatially-correlated and highly non-poissonian shot-noise due to ions hitting the photocathode. Also, the image intensifier is unable to fully overcome the noise of CCD electronics, which is still greater than the sky background one (see leftmost image in Figure 2). As a result, the limiting magnitude seen on a single frame is around B$\sim$10$^{\mathrm{m}}$. Frame co-addition improves the quality of image significantly (see middle and right images in Figure 2) and allows to reach B$\sim$12$^{\mathrm{m}}$ in 100 consecutive frames (13 seconds effective exposure). Longer effective exposures are also possible.

The imaging also suffers from the non-uniform spatial sensitivity of image intensifier microchannel plates, which drives it very important to perform a proper flat-fielding. Each channel is therefore equipped with its own flat-fielding module consisting of a dull surface on the inner part of a lid and dedicated photodiodes.

Due to financial limitations, we are building only 6 channels for this variant, which is supposed to provide imaging in only two photometric (whose, of course, may be arbitrarily selected from the three available ones) and three polarimetric filters simultaneously in follow-up regime.

The mechanical scheme of a channel for this variant is shown in Figure 1.

Each two channels of MMT-6 are to be placed on a custom fork mounts based on a Skywatcher EQ-6 head (see Figure 1b). As the EQ-6 head lacks the axes position encoders, we implemented the routine for initial calibration of mount stepper motors based on blind identification of the sky image using Astrometry.net (Lang et al. 2010) software.

2.3. *MMT-9*

Second variant, MMT-9, which we started to build in early 2013 following the experience gained during the development of MMT-6, is equipped with Andor Neo sCMOS, which has 2560x2160 6.4μm pixels with 16-bit depth. Due to limitations of a PC processing power, as well as available harddrives space, we decided to operate it in a 10 frames per second regime (in contrast to 30 FPS possible), which still provides us with $\sim$3 Tb of data per night. Quantum efficiency is about 55% with read-out noise as low as 1e$^-$. Pixel scale is about 16$''$ per pixel, and the channel field of view is about 100 square degrees, like in MMT-6.

Initial tests of detector performance when observing the sky with no filters installed gives the limiting magnitude of V$\approx$11$^{\mathrm{m}}$ (S/N=5, 0.1 s exposure). We hope to reach $B \sim 12.0^{\mathrm{m}}$ in 0.1 s for monitoring with B filter installed (which will significantly lower the sky background).

Contsruction of MMT-9 will be finished in early 2014 and its commissioning and test observations at SAO RAS will be started before summer 2014.

3. STRATEGY OF MINI-MEGATORTORA OPERATION

Mini-MegaTORTORA will perform routine observations of all the available sky in wide-field

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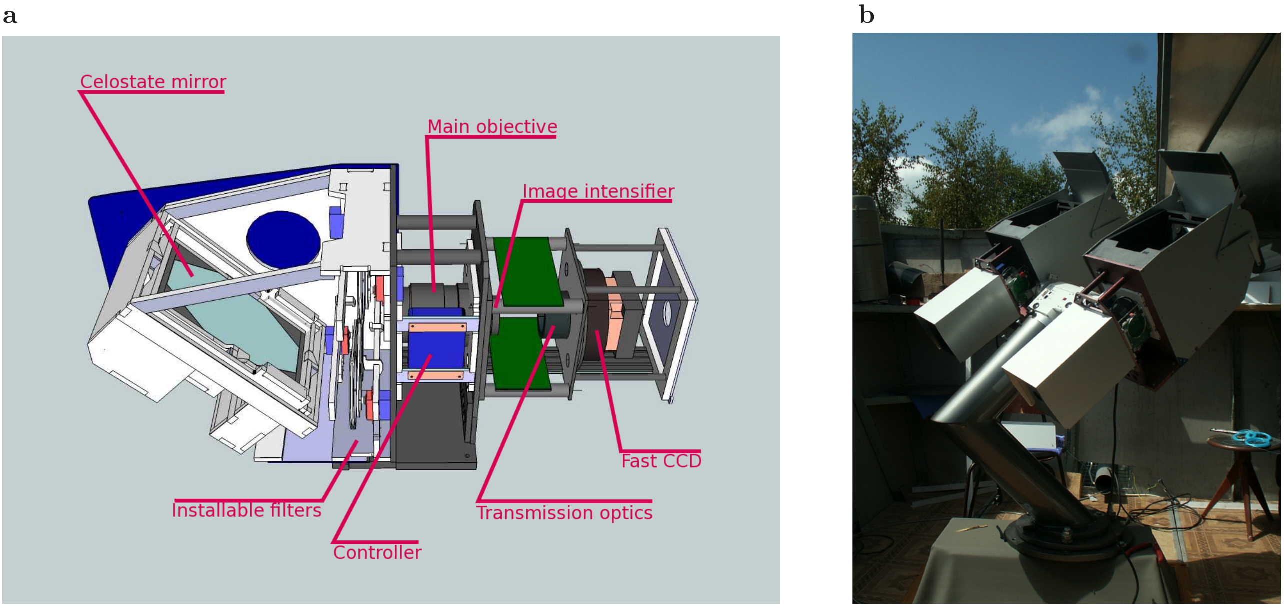

Fig. 1. (*a*) Schematic view of a single channel of MMT-6. (*b*) Photo of two of six MMT-6 channels mounted on a single mount (customized SkyWatcher EQ-6).

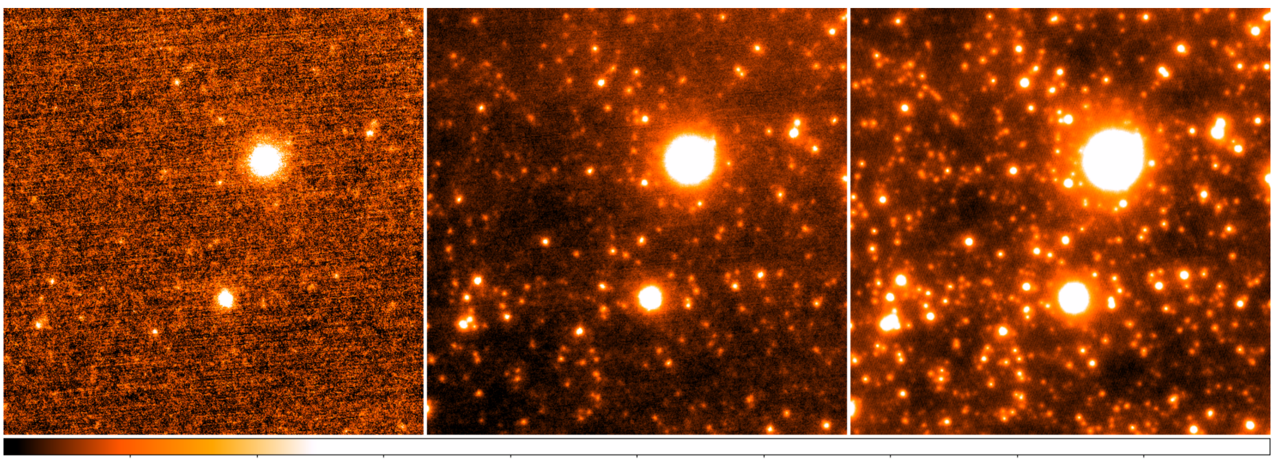

Fig. 2. Effect of a frame co-addition on image quality. Left panel – central part (approx. 3x3 degrees) of an image acquired by MMT-6 (0.13 s exposure). CCD electronics noise is clearly visible. Middle panel – result of a co-addition of 100 such consecutive images (13 s effective exposure). Right panel – result of a median co-addition of 24 such summed images.

regime, which gives a ∼900 square degrees field of view for MMT-9. It will spend up to 20 minutes on each spot, selected to follow as much as possible the fields of view of space-borne gamma-ray telescopes, while avoiding the regions close to the Moon or the horizon, and the ones recently observed by the complex itself. In 8 hours of a typical dark night, it will cover up to ∼20000 square degrees, nearly half of the whole sky, and will typically return to each spot in about one day.

On each spot, each channel will collect about 10000 frames. It will allow scientists to study its variability on different time scales with different limits by co-adding consecutive frames. We hope that this co-addition will not be subject to coordinate re-binning and varying spatial sensitivity problems, as all frames are collected consecutively on the same detector imaging the same sky region with sufficiently good telescope tracking. Co-adding of every 100 frames may improve the limit by up to 2.5^{m}, while co-adding of 10000 frames may improve the limit by up to 5^{m}, depending on the temporal stability of the detector and the sky conditions, and also on the quality of the flatfielding and dark frames. Frames co-added by 100 will be stored forever to form a time-domain atlas of the sky for further study, along with a time-domain photometric catalogue formed by measurements by means of fast aperture photometry (on a 100 frames / 10 s time scale, down to $B \sim 14.5^{\mathrm{m}}$ for MMT-9) or slower PSF-fitting photometry (on a 10000 frames / 1000 s time scale, down to $B \sim 17^{\mathrm{m}}$ for MMT-9). This catalogue will allow to study the variability of various classes of objects on time scales from 10 seconds to years, and also to detect slowly moving objects.

Compared with existing data from the ASAS-3 (Pojmanski 2002) and NSVS (Woźniak et al. 2004) surveys, which have similar detection limits, we may expect up to 15-20 millions of objects to be covered, with ~100000 being variable, and probably new classes of variable objects to be discovered due to better temporal resolution and cadence.

Real-time data processing, based on fast differential imaging and interlinking of events on several consecutive frames (Beskin et al. 2004; Karpov et al. 2010), will allow us to detect both fast flashes (with durations longer than 0.3 s) and rapidly moving satellites (with velocities up to half degree per second), as well as meteors (even meteors appearing on a single frame, as they are selected on the basis of their elongated shape), and roughly classify them on the fly. For transients, the light curve and coordinates will be stored, while for satellites, the trajectories will also be stored for further processing by more sophisticated methods in day time. If the transient is bright enough, and is not coincident with a known satellite or a bright star, the complex may be reconfigured to follow it up, pointing all the channels towards it and installing some combination of color and polarimetric filters to acquire both photometric and polarimetric information.

If all 9 channels are equipped with the same color filter, frame co-addition may yield up to 1^{m} to the complex sensitivity, while in three-color mode it may yield up to 0.6^{m}. In polarimetric mode, the limit is nearly the same as in single-channel regime due to the light losses on polarimetric filters. The expected accuracy of polarimetry is about 10% at 10^{m} and about 1% at 5^{m}.

Acknowledgements This work was supported by the Bologna University Progetti Pluriennali 2003, by grants of CRDF (No. RP1-2394-MO-02), RFBR (No. 04-02-17555, 06-02-08313, 09-02-12053 and 12-02-00743), by the Presidium of the Russian Academy of Sciences Program and by the grant of European Union (FP7 grant agreement number 283783, GLORIA project). The construction of MMT is being financed by the Kazan Federal University. S.K. has also been supported by a grant of the Dynasty foundation. G.B. thanks the Landau Network-Centro Volta and the Cariplo Foundation for a fellowship and the Brera Observatory for hospitality.

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