A 1-m Aperture Wide-Field Telescope with a 9×9 k CMOS Detector

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Abstract. We present a concept of a wide field telescope with an aperture of 1 m that can be potentially used in future optical telescope global network (e.g. at the future node of the Russian-Cuban Observatory). Key features of the proposed concept include the large field of view (5°) optical scheme and CMOS detector with a large 9×9 k format (about 90×90 mm), fast readout (2 s) and minimal noise (5 e^- rms). We present the preliminary parameters of the proposed optical scheme, the CMOS camera with GPIXEL's new sensor and the planar and coaxial design of the filter unit.

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1 Introduction

Despite the recent rise in the global application of wide field telescopes, the daily surveying of the entire available sky with a magnitude dipper than 20^m still remains unresolved. This is attributed to the lack of medium-aperture telescopes (approx. 1 m) and the limited cooperation between existing observation facilities.

The creation of 1 m class wide field telescopes are going on in some countries. As an example, we note the outstanding project of ESA Fly-Eye telescope (Ramirez Torralba et al. 2019) with a 1 m aperture and total field of view of 44 sq. deg. The original optical scheme of the telescope is made up of a spherical main mirror and beam splitter with 16 optical lens correctors, each coupled with a 4 k format CCD camera. The first light is expected in 2020.

In Spain, the construction of the T80 telescope (Gorosabel et al. 2014) with a 0.8 m aperture, 2.3 sq. deg. field of view, and a 10×10 k CCD camera has been completed.

The ambitious SITIAN project is currently in discussion in China, with the aim of taking a snapshot of the entire sky with 3 filters (g, r, i) every 30 minutes up to 21^m. This project will use Schmidt telescopes with a field of view of 7° and a mosaic detector of 4 CCD or a 18×18 k format CMOS with a total field of view of 5° × 5°. Each telescope will include their own fixed filter.

INASAN is working to upgrading the Zeiss-1000 telescope by increasing the field of view to 0.8° using a cassegrain focus lens corrector.

The wide field survey telescope ASA AZ1000WF (Ibrahimov 2019) was developed by INASAN in 2015-2018. The telescope has an aperture of 1 m and field of view of 3° in diameter. The custom filter unit accommodates 120 mm filters and designed to operate with a 10×10 k CCD camera. The field of view of the detector is approximately 4 sq. deg. A similar 1 m wide-field telescope is thought to be constructed and installed at the future node of the Russian-Cuban Observatory in Republic of Cuba.

Here we present a new conceptual approach for the next generation INASAN 1 m wide field telescope, with a larger field of view and a modern 100 Mpixel class CMOS detector.

We plan the telescope to perform daily ∼10,000 sq. deg. survey up to 20^m-21^m with or without filters. The proposed telescope must be optimized for a field of view/sensitivity/price ratio. In the future, we suggest a longitudinally distributed network of 4-10 such telescopes to allow for daily survey of the entire available sky up to 21^m.

The proposed telescope can potentially be integrated into the international Russian-Cuban Observatory or as part of the BRICS Optical Transient Network. The main scientific goals of the network are to search for optical transients and to detect near-Earth asteroids within the 10 m class size, space debris, astrophysics.

2 Optical Scheme

We propose two options of almost identical optical systems with a 1 m aperture and F-ratio of 1:1.5 and 1:1.3 (Figure 1), as well as the third option with a 80 cm aperture and larger field of view (Table 1).

The telescope optical scheme is based on the Sonnefeld design and consists of a two-lens full aperture corrector, the internal element of which operates in a double beam path, a Mangin mirror and a two-lens corrector close to the focal plane. Unlike Schmidt cameras, the size of the primary mirror can be smaller than the diameter of the entrance pupil without resulting in vignetting. All optical element surfaces are spherical and low-cost K8 glass is selected as the material for all aperture elements. The focal plane and pre-focal corrector are placed outside of the tube for manufacturing and maintenance purposes.

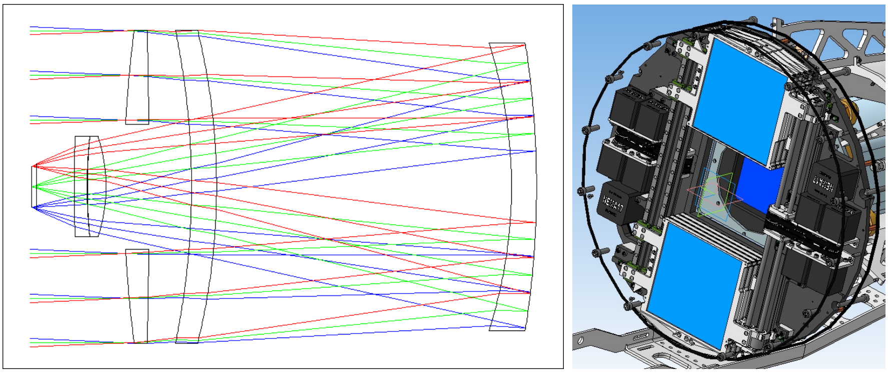

Fig. 1. Optical scheme (option 1), filter unit for 120 mm filters (ASA AZ1000WF).

Table 1. Parameters of the 1 m class telescopes

Parameter	Option 1	Option 2	Option 3
Aperture, mm	1000	1000	800
F-ratio	1:1.5	1:1.3	1:1.5
Field of view Ø, deg	5	5.7	6.2
Central obstruction	0.4	0.4	0.5
Scale, sq.deg/10 μm pixel	1.38	1.59	1.72
Field of view with 9×9 k detector, sq. deg	12.5	16.7	19.6
Detector format, pixels		8904×9178	

In general, the proposed optical scheme can be made, although the production of such large full-aperture lenses may cause some difficulties.

The closest analog of proposed optical scheme is VT-060q (Terebizh 2019), which has a larger field of view, lower F-ratio and lower image quality. Furthermore, the VT-060q corrector has an additional lens, and the aperture elements are designed with more expensive material (fused silica).

3 CMOS Detector and Focal Unit Design

CMOS detectors were previously unable to compete with large-format scientific grade CCD detectors and mosaics. However, the latest large format CMOS can achieve a performance suitable for survey telescope. The new largest CMOS sensor from the Chinese company GPIXEL with a format of 8904×9178 pixels

(89×92 mm) and a 10 μ pixel size offers a promising solution for 1 m class telescopes. The internal ADCs provide a 16 bit equivalent resolution, while the pixel full well is 90000 e^-, and the quantum efficiency at 550 nm surpasses 90%. The first samples of this new CMOS are expected in 2020 and will be employed in the mosaic of the Chinese ground based WFST telescope with an aperture of 2.5 m, field of view of 3° (9x CMOS), and CSST Space telescope.

This new CMOS can be used to develop a thermoelectrically cooled CMOS camera by "NPK Photonika", based on the existing CMOS camera "Neva6060" with 6×6 k GSENSE6060. The expected readout noise of the camera is 5 e^- rms. In order to minimize heat dissipation around the camera, thermoelectric cooling with a remote liquid heat exchanger will be used to cool the CMOS. The main advantages of the proposed CMOS camera are the fast readout and electronic shutter. The photometric quality may be compromised when the CMOS is running in HDR mode, however it is acceptable for telescope operated in survey mode to search for new objects (asteroids, comets, space debris), which generally detected in a low signal to noise ratio.

The cost of a CMOS is typically proportional to its area, not pixel size. Thus, a CMOS with a smaller pixel is characterized by a lower cost per pixel. GPIXEL is able to manufacture a single chip CMOS within the 400 Mpixel class with a 20×20 k (90×90 mm) format and 4.6 μ pixel size. This type of chip can enlarge the field of view of the 1 m telescope, or improve sampling and/or optical resolution while maintaining the field of view unchanged. In both cases, a more advanced optical scheme is required. This is the subject of further study.

The custom filter unit for 8 square 120 mm filters, a field derotator and CMOS camera are to be designed together to achieve an optimal performance. The front lens of the telescope lens corrector, the CMOS camera entrance window and the filter unit sealed housing will form a common hermetic volume, ensuring cleanliness and the absence of hoar fogging on the camera window at any ambient temperature.

We consider two options for the filter unit: the reciprocating movement parallel to the focal plane, and a coaxial design when filter move on the curved path. The design of the first option (Figure 1, right) used in the previous INASAN 1 m telescope (ASA AZ1000WF) filter unit produced by "Astrosib". The second option presents a more complicated design, but avoids additional central obstruction.

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